Studies in Systems, Decision and Control 406

Pedro M. Arezes · J. Santos Baptista · Paula Carneiro · Jacqueline Castelo Branco · Nélson Costa · J. Duarte · J. C. Guedes · Rui B. Melo · A. Sérgio Miguel · Gonçalo Perestrelo *Editors*

Occupational and Environmental Safety and Health III

Springer

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A special tribute to Béda Barkokébas Júnior and Mohammad Shariari for their remarkable technical and scientific contributions over the years. We will always miss you.

Preface

Occupational and Environmental Safety and Health III is a compilation of the most recent work of some selected authors from 13 countries within the domain of occupational health, safety and ergonomics.

This book represents the state of the art, and it is mainly based on research carried out at universities and other research institutions, as well as some on-field interventions and case studies. Due to the broad scope, relevance and originality of the contributions, it is expected that this book contains useful and up-to-date information, and it presents fundamental scientific research that is being carried out in the subject, as well as it contributes to the outreach of practical tools and approaches currently used by OSH practitioners in a global context. All the included contributions were selected based on their potential to show the newest research and approaches, giving visibility to emerging issues and presenting new solutions in the field of occupational safety, health and ergonomics.

This book is based on selected contributions presented at the 17th edition of the International Symposium on Occupational Safety and Hygiene (SHO 2021), which was held on November 17–19, 2021, in Porto, Portugal.

All the contributions included in this book were previously peer-reviewed by, at least, two of the 112 members from 16 different countries of the International Scientific Committee of the 2021 edition. The event is organised annually by the Portuguese Society of Occupational Safety and Hygiene (SPOSHO).

Editors would like to take this opportunity to thank their academic partners, namely the School of Engineering of the University of Minho, the Faculty of Engineering of the University of Porto, the Faculty of Human Kinetics of the University of Lisbon, the Polytechnic University of Catalonia and the Technical University of Delft. The editors also would like to thank the scientific sponsorship of several academic and professional institutions, the official support of the Portuguese Authority for Working Conditions (ACT), as well as the valuable support of several companies and institutions. Finally, the editors wish also to thank all the reviewers, listed below,

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Occupational and Environmental Safety

Cultural and Technical Adaptation of *SafetyCard* to the Brazilian Legislative and Organizational Context

Hernâni Veloso Neto, Pedro M. Arezes, and Béda Barkokébas Junior

Abstract Objective: This study aims at summarising the conclusions of the cultural and technical adaptation process of the *SafetyCard*—Performance Scorecard for Occupational Safety and Health Management Systems to the legislative and organisational context of Brazil. Background: Safety management systems should be imbued with a philosophy of improvement, enhanced by a capacity for performance evaluation, as prescribed by the good practices in the field and the ISO 45001 standard. Method: The methodological adaptation process consisted of two phases, the first focused on the cultural and technical adaptation of the parameters and instruments that integrate the *SafetyCard*, and the second on its application in an organizational context that could function as a basis for operational validation. Results: All the procedures carried out made it possible to successfully complete the adaptation process. The practical application in a company also demonstrated the tool's ability to maintain its configuration and how it integrates the main technical-scientific and normative-legal requirements and recommendations on occupational safety and health. Application: The adaptation increases the *SafetyCard* scope of use, as well provides Brazilian organisations and safety professionals with an approach that makes it easier for them to monitor system performance and comply with the ISO 45001 guidelines.

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Keywords *SafetyCard* · Performance Scorecard · Occupational safety and health management systems · Safety culture

1 Introduction

This article stems from a research developed with the aim of making a cultural and technical adaptation of the *SafetyCard*—Performance Scorecard for Occupational Safety and Health Management Systems to the legislative and organisational context of Brazil. The main objective is to summarise data and conclusions of this adaptation process, as well the experience of applying the *SafetyCard* in a waste collection and public hygiene company in northeastern Brazil.

The performance evaluation and review of a management system are essential pillars for the subsistence of any system, regardless of its nature (Neto 2012a). The performance evaluation of occupational safety and health (OSH) organisational systems based, solely or mainly, on accounting for the frequency and severity of work accidents, despite the importance of these procedures, is not in line with the current principles of continued improvement and development of organisations (Neto 2009, 2012a, b; Mohammadfam et al. 2016; Freitas et al. 2018). This is not least because, as Webb (2009) points out, the organisation's ability to control this type of performance indicators tends to be progressively limited. So much that ISO 45001: 2018 itself recommends that it is essential that the performance of safety management systems can be characterised by structured matrices of indicators. That matrices must reflect gains associated with this area and entrepreneurial attitudes in the search for the best working conditions.

The *SafetyCard* was developed by Neto (2012a) for application in the Portuguese context, but considers the main international technical-scientific and normative-legal OSH claims and recommendations, allowing the verification of an organisation's performance against a set of key factors of success in OSH (Neto 2009, 2012a). Its use allows to obtain a global and structured view of what is the reality of an organisation in terms of OSH, being able to be adapted to the context and legal/normative requirements in force in any country.

The fact that the original language of the tool is Portuguese facilitates its use in other Lusophone countries, particularly in a country like Brazil that already has a good legislative and normative framework on OSH. In this sense, adapting the *SafetyCard* culturally and technically to the normative and organisational context of Brazil is believed to be scientifically relevant, allowing the scope of its use to be extended, and making it available to Brazilian organisations and safety professionals. Although it is not a legal requirement, the voluntary use of the tool will facilitate the control and performance assessment of their safety management systems. Moreover, it also allows better compliance with the requirements of ISO 45001: 2018, namely in terms of requirements 9.1 and 9.3, concerning to the obligation to evaluate the performance of the OSH management system, incorporating proactive indicators and benchmarking exercises, and requirements 4.1, 4.2 and 5.4, to demonstrate the effort that is being made to understand the organization and its context, to understand the needs and expectations of workers, and to consult and promote workers' participation, respectively.

2 Materials and Methods

The SafetyCard is supported by its own analytical structure and a set of instruments and procedures that enable the collection, processing and interpretation of data for its application. In this manuscript, it will not be possible to explain all the *SafetyCard* features, but some of its main aspects can be summarized. It is organized around seven analytical domains, which integrate different analytical segments, which, in turn, integrate a set of indicators (Neto 2012a, b). These indicators are, in essence, the analytical parameters that favour data collection and a detailed assessment of the company's OSH conditions and actions.

The model considers 110 indicators that can be mobilised in their entirety or partially, in the event that some parameters do not apply to the organisational reality under study. This it is possible because the *SafetyCard* has a modular character. It also considers a system of standardisation of performance results, so that all indicators can be transformed to the same numerical basis (Neto 2009, 2012a). The entire standardisation process was created to allow a transformation to a numerical binary base, where each indicator always assumes results between zero and one, either in a discrete or continuous manner (Neto 2009, 2012a). In addition, as not all analytical elements of the matrix have the same relevance for a safety management system, it also integrates a weighting system that allows the importance of each parameter to be graded, allowing also the achievement of delimited variation ranges and the construction of a rating scale for the partial and overall performance of the safety system under evaluation (see Neto 2012a).

The 110 indicators are divided into 20 different analytical segments, which integrate the seven analytical domains that form the conceptual basis of the analytical structure (Neto 2012a, b). These domains can be briefly characterised as follows (Neto 2012a, b): (1) Organizational Design—focuses on the structural and functional arrangement of the management of OSH activities; (2) Organizational Culture—focuses on the values, norms and standards of OSH behaviour in the organisation; (3) Occupational Health Structure—focuses on the strategy and organisational approach to occupational health; (4) Operational Structure for Hygiene and Safety at Work—focuses on the organisational capacity to act in the prevention and implementation of protective measures; (5) Internal Emergency Plan—focuses on the organisational capacity to respond to emergency situations; (6) Monitoring, Measurement and/or Verification Structure—focuses on the organisational capacity to assess, monitor and intervene on the work environment conditions; and (7) Safety of Work Equipment'—focuses on the organisational capacity to safeguard OSH integration in the acquisition, maintenance and use of work equipment.

The methodological adaptation process consisted of two major phases. The first was more focused on the cultural and technical adaptation of the parameters and instruments that integrate the *SafetyCard*, with the following main procedures being carried out: (i) setting-up and specification of the general legal and normative OSH requirements applicable to organisations that carry out their activity in Brazil; (ii) verification of the adequacy of the legal and technical requirements specified in the *SafetyCard* and its data collection instruments; and (iii) verification of the adequacy of the technical terms used in the data collection instruments to the grammatical lexicon used in Brazil.

After the specification and framing of the legal and regulatory requirements, the collaboration of two Brazilian OSH specialists was sought, who are also connected to the Portuguese technical and scientific community in the field, with their presence and collaboration being frequent in research and scientific events in Portugal. This situation facilitated the verification of the characteristics of the instruments utilised in data collection, as well their alignment with the legal and normative requirements and terminology used in Brazil. As a result of this analysis, small changes were made to these instruments, but there was no need to replace any indicator in the matrix, only to adjust the application / compliance criteria of some indicators that had a legal basis.

In the second phase, the focus was on the selection and application of the *SafetyCard* in an organisational context that could serve as a basis for the study and operational validation of the tool. In this stage, the following main procedures were carried out: (I) selection and establishment of a partnership with a company to have a practical context for the application of the *SafetyCard*; (ii) meeting with the OSH managers of the company to understand their operating logic and specificities, as well to finalize the work plan and data collection; (iii) visiting the organisation's facilities, participation in meetings with OSH technicians and analysing the documents made available by the company to understand the characteristics of the safety management system under study; (iv) application of the *SafetyCard* notation form to the organisation's OSH services, for carrying out the structural diagnosis of its management system; (v) applying a questionnaire to a sample of workers to record a pattern of shared attitudes, values and behaviours regarding OSH in the organisation. It was used the QTCCS—Questionnaire to Workers about Occupational Safety Culture and Climate, developed by Neto (2013) and adapted to Brazil by Neto et al. (2021).

As a case study, it was used a waste collection and sanitation company in the Northeastern of Brazil, which was willing to participate as part of its frequent collaborations with members of the research team. It is a large company with national implantation, but the study focused on the unit located in a city in the northeast of the country. The data were collected and processed in 2019 and 2020. The *SafetyCard* notation form was filled out by the company's OSH services. The notes collected during visits and meetings with technicians were used to understand and characterize the company's operation and management approach. The questionnaire responses were collected randomly over five working days at the company's facilities, seeking to cover both work shifts (morning and night) and different types of workers. The data from the questionnaires helped to determine the company's safety climate, being one of the segments that enters into the assessment of the organizational culture domain.

In total, 200 questionnaires were validated. In sociodemographic terms, the majority of respondents were male (85%), and were married or of a similar status (54.5%). The youngest worker surveyed was 19 years old and the oldest 63, with an average of 38.8 years. Most had completed formal schooling (higher incidence of cases in middle school—2nd grade), and covered workers in both administrative or technical areas (e.g. personnel management, safety technicians, technical assistants) and operational areas (e.g. waste collection, street sweeping/washing, weeding and mowing, drivers, supervisors), with the majority of participants being integrated in the last work area mentioned. The length of service with the company ranged from a few months to 18 years. The average seniority was 5.2 years of service.

3 Results

The application of the *SafetyCard* in the company under study made it possible to obtain a scoring grid with the results for the 110 indicators. Given the size of that grid, it was decided to present a summary table in this article. Table 1 has these elements and allows an overall reading of the management system performance under evaluation. The global score determined was 0.745, which in the light of the classification grid of the *SafetyCard* global result (Neto 2012a), indicates good performance (applicable when the score is between 0.700 and 0.850). This reveals a performance effectiveness of 74.5%, with the remaining 25.5% being the performance improvement differential to be improved in the future. In a more disaggregated reading, it is possible to perceive which segments or domains in which the performance was better or worse. The occupational health domain reveals a perfect performance (100% effectiveness), with all the indicators being globally achieved. The Operational Structure for Hygiene and Safety at Work also reveals a positive result (88% efficiency), namely in terms of organisation and technical operability of the OSH services and focuses on prevention and protection. However, the work accidents component has an unfavourable performance, partly due to the increase in the number of accidents and the working days lost due to them, as well the maintenance of a high volume of hours not worked due to illness.

The domains where the company showed the lowest performance were related to safeguarding the safety of work equipment' (58% of effectiveness) and internal emergency management (59.3%). In the first case, the main problem was the lack of integrating OSH aspects in the specifications for the selection and acquisition of work equipment' and the provision of instructions and other safety guidelines. As for emergency planning, the main problem was the reduced assignment of roles and responsibilities in emergency response situations.

The two domains mentioned were the ones that showed the lowest performance effectiveness, and should be a priority for intervention. In any case, attention should also be drawn to the Monitoring, Measurement and/or Verification Structure, which

Table 1 Summary of results obtained with *SafetyCard*

Analytical domain	Analytical segment		Segment weighting		Domains weighting		
		PB	M	RD	M	RD	%
1. Organisational Design	Technical coverage	1.000	0.700	0.700	0.050	0.035	70.0
	Systemic approach	0.000	0.300	0.000			
2. Organisational Culture	Values	0.950	0.250	0.238	0.200	0.147	73.5
	Norms and basic standards of evaluation	0.800	0.300	0.240			
	Workers' basic assumptions	0.570	0.450	0.256			
3. Occupational Health Structure	Vigilance	1.000	0.750	0.750	0.100	0.100	100.0
	Promotion	1.000	0.250	0.250			
4. Operational Structure for Hygiene and Safety at Work	Organisation and operability	1.000	0.050	0.050	0.250	0.220	88.0
	Accidents loss ratio	0.424	0.150	0.064			
	Training	0.904	0.250	0.226			
	Prevention	0.975	0.400	0.390			
	Protection	1.000	0.150	0.150			
5. Internal Emergency Plan (PEI)	Planning	0.750	0.400	0.300	0.150	0.089	59.3
	Attributes and responsibilities	0.250	0.250	0.063			
	Devices	0.650	0.350	0.228			
6. Monitoring, Measurement and/or Verification Structure	Control of Environmental Conditions	0.500	0.550	0.275	0.200	0.126	63.0
	Monitoring, measuring and/or verification mechanisms	0.688	0.300	0.206			
	Corrective action	1.000	0.150	0.150			
7. Safety of Work Equipment's	Maintenance	1.000	0.500	0.500	0.050	0.029	58.0
	Safety prescriptions	0.160	0.500	0.080			
Total					1.0	0.745	74.5

Table 2 *SafetyCard* results with original weightings and company weightings

Analytical domain	*SafetyCard* results with original weightings			*SafetyCard* results with company weightings		
	Weightings (%)	Results	%	Weightings (%)	Results	%
1. Organisational design	5	0.035	70.0	15	0.105	70.0
2. Organisational culture	20	0.147	73.5	15	0.110	73.3
3. Occupational health structure	10	0.100	100.0	15	0.150	100.0
4. Operational structure for hygiene and safety at work	25	0.220	88.0	15	0.132	88.0
5. Internal emergency plan	15	0.089	59.3	10	0.059	59.0
6. Monitoring, measurement and/or verification structure	20	0.126	63.0	15	0.095	63.3
7. Safety of work equipment's	5	0.029	58.0	15	0.087	58.0
Total	100	0.745	74.5	100	0,738	73.8

only achieved 63% of performance effectiveness. To a large extent, this lower percentage was due to insufficient control of environmental working conditions. The assessment of the risk of exposure to various physical, chemical and biological agents was already somewhat old (more than 2 years), and there are still some parameters that have not been assessed (e.g. exposure to vibrations). Another opportunity that could be considered has to do with the implementation of safety management systems in accordance with ISO 45001. It could improve the systemic approach, as the company currently does not have certifications by any ISO standard.

Table 2 compares the results of the *SafetyCard* with the original weightings and the weights assigned by the company. The tool allows the company under study to assign its own weighting importance to each analytical domain under evaluation, in order to understand if there would be relevant differences in performance compared to what the original structure of the *SafetyCard* shows, and also to identify which areas the company values most in its safety management system.

Although the company weights the domains differently, the overall value of performance and effectiveness does not change significantly (74.5–73.8%). The classification remains at the same level (good performance). The company's OSH managers chose not to differentiate the relevance of the domains too much. The original *SafetyCard* structure established that difference, since safety system components are not all of the same importance. They don't contribute in the same way to achieve the success in the accident prevention and healthy workplace promotion (Neto 2012a, b, 2013).

4 Discussion and Conclusions

In the last two decades there has been a gradual increase in the interest of organisations in the implementation of management systems (Neto 2009, 2012a, 2013), including in the area of OSH itself. However, these systems presuppose continuous monitoring, favouring indicators that provide constant information and enable preventive action on hazards and risks in the occupational environment (Neto 2012a, 2013; Freitas et al. 2018; ISO 45001:2018), as well the assessment of workers' attitudes, values and safety behaviours (Neto 2012a, 2013).

Safety indicators play an important role in providing information to an organisation on its safety management system performance (Reiman and Pietikäinen 2012; Mohammadfam et al. 2016). The recognition and use thereof can be a motivating factor for the stakeholders (Reiman and Pietikäinen 2012), namely for the workers, and contribute to the enhancing organisation's OSH potential.

The *SafetyCard* meets all of these requirements, having already demonstrated its relevance in previous studies. Now with the successful completion of the cultural and technical adaptation to the legislative and organisational reality of Brazil, the tool's scope of use can be increased. The practical application in a Brazilian company demonstrated the tool's ability to maintain its configuration and be applied in different organizational contexts, regardless of the country, since it incorporates scientific, technical, legal and normative requirements essential to the OSH area.

The results of this case study are evidence in themselves of the success of the adaptation, but also indicate the type of analyses and conclusions that can be drawn therefrom. Although the data has been explored briefly, some of its potential is clear. The company under study showed a performance effectiveness of 74.5%, revealing a good OSH performance. These data are comparable with other studies published using the *SafetyCard* (e.g. Neto 2012a, 2013; Pereira and Neto 2020). Even if they are from different industries, some trends can be signalled. All of these organizations have a good or very good performance, largely because that they have a consolidated OSH system and structure. The safety climate proved to be positive, with workers showing a favourable level of safety internalisation and risk awareness, as well a strong recognition of the company's safety strategy and its ability to implement safety rules. However, in the case of this waste collection company, this positive pattern portrayed is also accompanied by the workers' negative assessment of the quality of safety communications in the organization. The same scenario was obtained by Moreira and Neto (2019), demonstrating that the communication component is one of the most challenging for the success of a safety management system (Moreira and Neto 2019; Pereira and Neto 2020).

With this adaptation process completed, new challenges arise. It is true that this article has some inherent limitations, in that it was not possible to fully develop the research results, and also only data from a practical application case were presented. However, the potential was portrayed and the main objective was duly achieved. The investigation can now progress to another phase, aiming to further disseminate the integration of the *SafetyCard* in the Brazilian organisational reality.

The use of the *SafetyCard* in more organisations will help to consolidate the adaptation/integration process. In addition, this increase in case studies will also open up the opportunity to work on other aspects, such as, for example, the possibility of creating a specific module with some exclusive indicators for the Brazilian context, increasing the tool's adjustment and the range of evaluation possibilities for OSH professionals in Brazil. This version can reinforce the ability to monitor performance and enhance the possibility of carrying out performance benchmarking exercises between organisations or between production units of the same economic group. The *SafetyCard* has great potential to favour performance benchmarking, another aspect that can be explored in that second phase of the research.

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References

Freitas, M., Vieira, A., Nogueira, I.: Indicadores de Avaliação do Desempenho na Gestão da SST em Sistemas Multimunicipais de Água e Saneamento em Portugal - Estudo de Caso. CESQUA - Cadernos de Engenharia de Segurança, Qualidade e Ambiente. N.o **1**, 141–153 (2018)

ISO-International Standard Organization: ISO 45001:2018—Requirements for An Occupational Health and Safety management system. ISO, Geneva (2018)

Moreira, C., Neto, H.V.: Cultura organizacional de segurança e saúde no trabalho numa empresa de construção e manutenção de instalações elétricas. Int. J. Work. Cond. No. 17, 20–42 (2019). https://doi.org/10.25762/fjh4-7h90

Mohammadfam, I., Kamalinia, M., Momeni, M., Golmohammadi, R., Hamidi, Y., Soltanian, A.: Evaluation of the quality of occupational health and safety management systems based on key performance indicators in certified organizations. Saf. Health Work **8**(2) (2016). https://doi.org/10.1016/j.shaw.2016.09.001

Neto, H.V.: Novos Indicadores de Desempenho de Segurança e Saúde no Trabalho. In: Guedes Soares, C., Jacinto, C., Teixeira, A.P., Antão, P. (eds.), Riscos Industriais e Emergentes, pp. 931–945. Edições Salamandra, Lisboa (2009)

Neto, H.V.: Avaliação de Desempenho de Sistemas de Gestão de Segurança e Saúde no Trabalho. Civeri Publishing, Vila do Conde (2012)

Neto, H.V.: Performance scorecard for occupational safety and health management systems. Int. J. Work. Cond. No. 3, 42–53 (2012b). https://doi.org/10.25762/kpmr-xg93

Neto, H.V.: Construção social do risco e da segurança no trabalho em contexto organizacional. Civeri Publishing, Porto (2013)

Neto, H.V., Arezes, P., Barkokébas Junior, B.: Adaptation and psychometric validation of a questionnaire about organizational safety culture and climate for the Brazilian reality. Int. J. Occup. Saf. Ergon. (2021). https://doi.org/10.1080/10803548.2021.1911915

Pereira, R., Neto, H.V.: Avaliação do clima de segurança numa indústria de espumas a partir das atitudes e comportamentos dos trabalhadores. CESQUA - Cadernos de Engenharia de Segurança, Qualidade e Ambiente. N.o **3**, 18–38 (2020)

Reiman, T., Pietikäinen, E.: Leading indicators of system safety-monitoring and driving the organizational safety potential. Saf. Sci. **50**(10), 1993–2000 (2012). https://doi.org/10.1016/j.ssci.2011.07.015

Webb, P.: Process safety performance indicators: a contribution to the debate. Saf. Sci. **47**, 502–507 (2009)

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SWS—A Decision-Making Tool to Support Occupational Safety

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Abstract Disorders caused by poor lighting, inappropriate thermal environments, noise and manual handling constitute a daily challenge for workers, since these factors influence worker productivity and can trigger long-term health problems. It is essential to ensure that workers carry out their tasks in suitable conditions, without compromising technicians' physical and psychological wellbeing, as well as their hygiene and safety. In order to address these issues, the support provided by equations such as NIOSH, noise assessment through spectral analysis or exposure time, as well as assessment of lighting and the thermal environment, enable an evaluation of workers' conditions and the application of measures to guarantee worker safety. The software tool Safe Work Space (SWS) was tested at a furniture manufacturing company, and was developed to facilitate the daily work undertaken by hygiene

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and safety technicians, reducing the time spent on data treatment. Based on the parameters of load movement, the results of the NIOSH equation [recommended weight limit] and the lifting index are obtainable in fractions of a second. The SWS tool also assesses lighting and thermal environment values which, according to the references of the workplace location, provide results regarding lighting and room temperature. Finally, a third feature evaluates noise by assessing the need for the use of PPE (personal protection equipment) and, if necessary, it provides information as to which equipment is available on the market. This tool is extremely useful for professionals as it was specifically developed for the analysis of noise, lighting, thermal environment and lifting loads, all in one.

Keywords Health safety work · Assessment tool · Noise · Lighting · Hazard evaluation

1 Introduction

Conditions at work, or the lack of these, cause many physical and/or psychological illnesses to workers. According to Karin et al. Karin et al. (2008), musculoskeletal disorders (MSDs) are the most common work-related health problems in Europe, affecting millions of workers. Furthermore, when workers are exposed to excessive noise levels, their safety and health are also at risk, due to the fact that high noise levels cause irreversible hearing loss. Indeed, stress resulting from time spent in a high noise level environment has been associated to increased workplace accident rates Roşca et al. (2020). Having appropriate lighting is not only a worker's right; it is also advantageous in enabling workers to be more productive and more accurate (able to perform visual tasks even under complex circumstances, and during longer periods of time). Moreover, absenteeism decreases when appropriate lighting in the workplace is guaranteed Dianat et al. (2016); Begemann et al. (1997). On the other hand, incorrect lighting can lead to several problems such as: lack of alertness, poor performance and sleep, discomfort, fatigue, pain and burning eyes Knave (1984). This can, in turn, also affect interpersonal relationships Juslén et al. (2007). Enabling workers to control light sources can generate a very positive impact on their productivity (which can increase by 4.5%) Lee et al. (2011). In addition, room temperature has led to many occupational disorders, which disrupt worker performance and the quality of work: in extreme cases, this can even lead to death. In the industrial context, thermal discomfort is cited as being one of the major causes of dissatisfaction in workplaces where people are exposed to extremely hot or cold thermal environments Mariana et al. (2017).

The Safe Work Space (SWS) tool was developed to support Health and Safety Technicians in identifying and analyzing the hazard related to the lifting of loads, as well as issues such as noise, lighting and room temperature. This practical and intuitive tool allows users to obtain quick results after entering the collected data. The tool verifies whether the working conditions are favorable and recommends alterations when necessary. For example, it recommends personal protection equipment (PPE) models for cases in which the noise values are not within an acceptable range, and also indicates improvement measures for load lifting tasks. The authors do not know of any other tool which is as sophisticated as the SWS. For example, Serdyuk et al. Serdyuk et al. (2020) developed a tool which uses the NIOSH equation (an equation directly associated to load lifting); it is able to calculate the RWL (the recommended weight limit), as well as the LI (lifting index). However, its format is neither user-friendly nor intuitive. It is important to note that, unlike Safe Work Space, it does not draw any conclusions regarding the LI values; nor does it suggest measures which could be implemented to improve the lifting process and tasks analyzed. Regarding noise assessment, the application developed by Piňosová et al. Piňosová et al. (2018) only assigned a color scale, without indicating any conclusions and/or recommendations. This tool is innovative in the sense that it joins the analysis of the 4 strands (noise, lighting, load handling and thermal environment) all in one. It also makes recommendations for the improvement of the load handling tasks, and selects the most appropriate PPE if the noise levels are higher than recommended. Brito et al. Brito et al. (2020) developed a tool called ErgoSafeCI, using lean manufacturing methods and guidelines, together in conjunction with safety and ergonomics features, which were assessed with the ultimate objective of finding a way to improve the workplace by considering workers' efficiency and well-being. However, this tool does not calculate the RWL, LI values or make recommendations regarding the use of PPE. SWS will also serve as support for implementing the ISO 45001:2018 which will establish and monitor the measurable annual Occupational Health and Safety (OHS targets, by implementing a risk prevention program and carrying out internal audits to evaluate OHS concerns Morgado et al. (2019).

2 Methodology

In the context of this study, and since a platform to facilitate the process in question was identified, one considered it appropriate to develop an MS Excel®tool, using Visual Basic code, to support decision-making in the process of hazard analysis. The justification for the selection of this type of program (MS Excel®) ensues from the fact that it is an extremely intuitive platform, to which any company on the market has easy access. In order to reinforce the explored theme, one decided to use a company which had previously been chosen, due to its track record of musculoskeletal injuries and hearing damage, for the practical application of the tool. During this test, one was also able to present suggestions to the organization, in accordance with the characteristics of the workstation studied. The initial phase consisted of a survey of existing software programs which would be suited to the theme, of which the following should be highlighted: software for the implementation of the NIOSH equation; and a software program to obtain and register noise data. In fact, it was through this process that one expected to gain an understanding of the similarities and differences between the programs already in use and the SWS tool. In terms of implementation, it was decided that the SWS tool would enable evaluating noise, as well as the manual handling of loads and lighting. Indeed, the study of these factors involves specific training, which includes a process of interpretation and some indirect calculations in order to reach a final consideration. Thus, the tool will allow for a presentation of desired information in a much more direct and intuitive manner. One should also refer that no other hazards were selected for analysis, since the examination of other factors is quite straightforward and merely visual. With regard to the preparation of the tool on MS Excel®, one set up the necessary codes and buttons to be used in future interaction with the user, which will make it possible to operate the entire tool. As was previously mentioned, once the tool was completed, it was tested by using real data from a company in order to assess the risks workers were exposed to. This practical application generated data, which was extracted from the software in question. This information was duly analyzed and commented on, which then led to suggestions for improvements to be implemented in the respective company.

3 Results

Taking into account the need to improve and facilitate the calculations carried out by occupational hygiene and safety professionals, a tool was then created using Visual Basic, where algorithms are available for the three abovementioned topics, namely: lighting, noise, work environmental and the manual handling of loads. Accordingly, the initial menu is presented in Fig. 1, where there are four respective buttons.

Fig. 1 Initial menu for the implementation of safety at work

3.1 Noise

With regard to the assessment of noise, this application provides the user with two options for the insertion of data: spectral analysis (Fig. 2) and an analysis related to exposure time. This versatility constitutes a relevant point since it allows the person in charge of the occupational safety area to be able to evaluate noise by using a process which is considered to be the most suitable, or by means of available measurement equipment.

Thus, regardless of the process chosen, the application calculates the continuous noise level weight equivalent A and, depending on this value, assesses the need (or not) for personal protective equipment (PPE). If a possible need is detected, the tool itself presents several options, providing images, suppliers and prices, in order to facilitate the selection process for the user. It should also be noted that the options presented consider the NP EN 458 (1998) standard; namely, they ensure that there is neither excessive nor insufficient insulation. Manual Handling of Loads.

Regarding RWL (Recommended Weight Lifting) estimates, Occupational Health and Safety professionals currently carry out several types of intermediate calculations (multipliers related to horizontal and vertical locations, asymmetry and distance, as well as coupling and frequency). By using the support provided by the Safe Work Space tool (Fig. 3), and the collection of the required data, an answer can be obtained in a few seconds. Using the NIOSH equation for RWL, if one aims to increase this value, approximating the various multipliers to 1, the software will provide suitable suggestions to address the context. The tool also enables calculating the LI, as well as reaching a respective conclusion, namely, whether the situation is suitable or

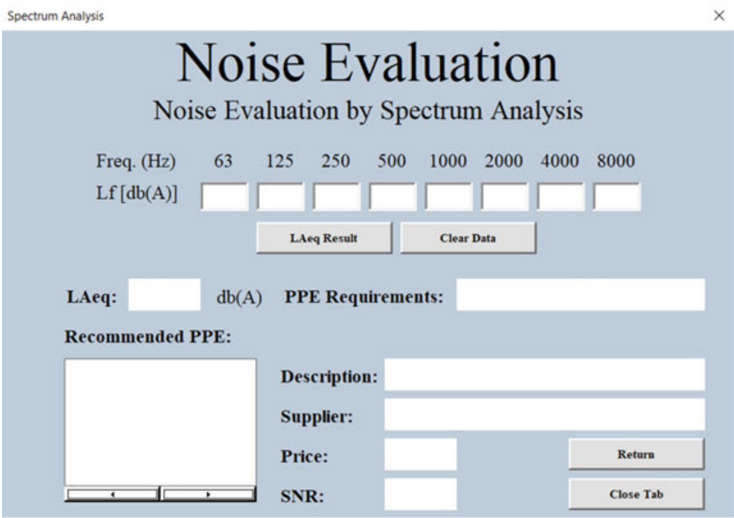

Fig. 2 Noise evaluation by spectrum analysis

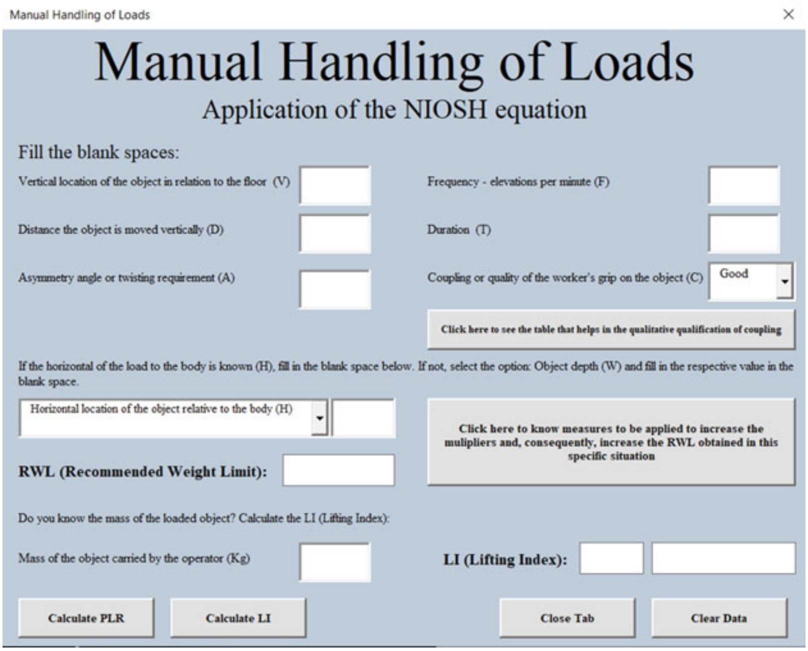

Fig. 3 Manual handling evaluation using the NIOSH lifting equation

requires correction. In this manner, professionals will not have to invest as much time in resolving calculations and will be able to draw conclusions more simply and quickly.

3.2 *Lighting*

After the presentation of the manual handling of loads, the lighting component follows (Fig. 4). In this context, it should be noted that this risk can be assessed for various types of jobs, the selection of which is also possible. Accordingly, a study can be carried out for places where activities classified as Class I, II, III or IV occur. In the evaluation process, a framework is set up, which takes into account the type of work and the amount of light required. This functionality thus clearly adds value to workstation operations since, even if only indirectly, it allows one to adjust the amount of light required for the conditions in question. The Safe Work Space (SWS) tool is a preliminary tool for analyzing the occupational environment, so we consider only the illuminance parameter for lighting as it is the most representative. Finally, one should add that unlimited tests can be carried out and, additionally, that the program can be closed when it is no longer useful.

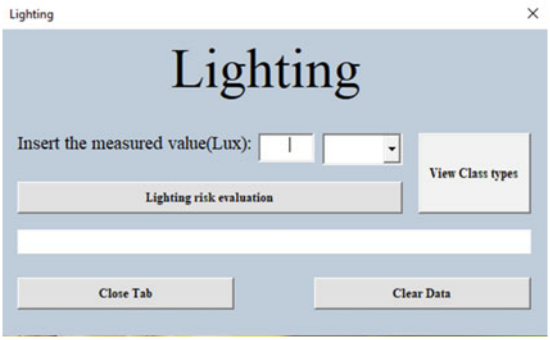

Fig. 4 Lighting evaluation

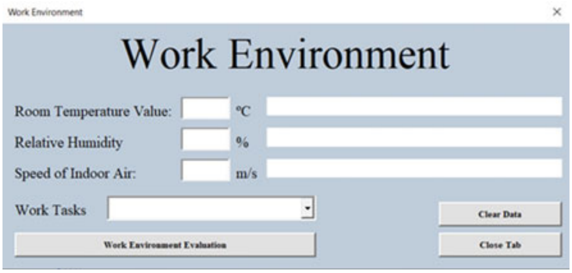

Fig. 5 Work environment evaluation

3.3 Thermal Environment

Finally, there is also the possibility of evaluating the thermal environment (Fig. 5); namely, whether factors such as temperature, relative humidity and air speed are suited to the type of task performed. Consequently, it is important to understand that one can simultaneously perceive which values are appropriate, and which are outside the limits. These minimum and maximum values must be presented in order to inform the user of what would be expected for the workstation concerned.

3.4 Practical Validation

In order to test the viability of the tool, one decided to carry out a practical implementation at a furniture manufacturer, due to its track record of musculoskeletal and hearing disorders. To this end, one selected a workstation where the operation of the wooden board sawing takes place. For the evaluation of noise, by spectral analysis, the Lf values measured on the shop floor were entered, which then allowed to obtain an LAeq. In view of this value, the mandatory use of PPE was notified. This information was supported by the presentation of 3 suggestions for equipment, one of which is presented in Fig. 6.

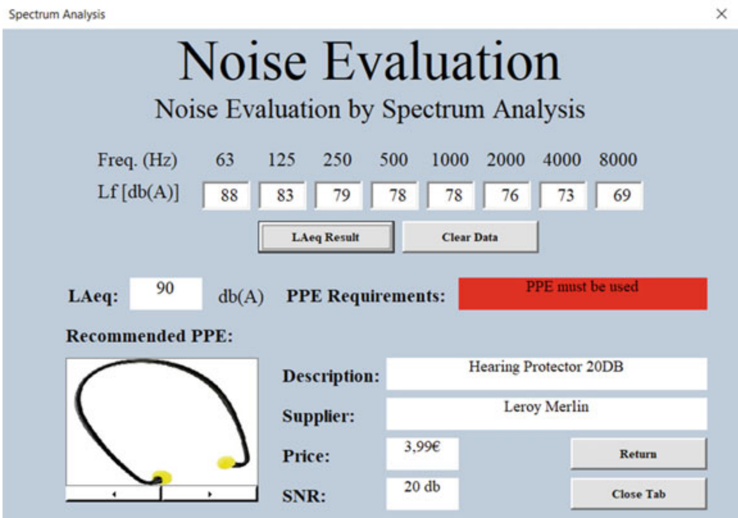

Fig. 6 Noise evaluation at the furniture manufacturer company

The next step consisted of an analysis of the operator's movements when lifting a wooden board weighing 15 kg. One should mention that this required the operator to carry out a complete torso rotation (180°), and that this movement was repeated every 100 s. The grip action was considered to be reasonable as the object in question presented structural rigidity. Once all the data had been introduced, one obtained a RWL value of 4.48 kg. When the data was considered, it was concluded that the situation required correction, since the LI exceeded 3, as can be observed in Fig. 7. In order to rectify this situation, several suggestions were presented to increase the multipliers, with the ultimate purpose of improving the RWL value, as it is presented in Fig. 8.

With regard to lighting, the location of analysis was determined as being Class I (a simple visual task that does not require much effort), with a measured value of 280 lux, which is within the recommended interval (250–500 lux). As such, this led to a positive evaluation, as can be observed in Fig. 9.

In the case of the thermal environment, the work was classified as being Heavy Work Tasks; the values measured for temperature, humidity and air velocity were within the recommended interval, as is observed in Fig. 10. As expected, the company needs to implement measures regarding noise, as well as the manual handling of loads and, to this end, the suggestions provided by the tool are crucial.

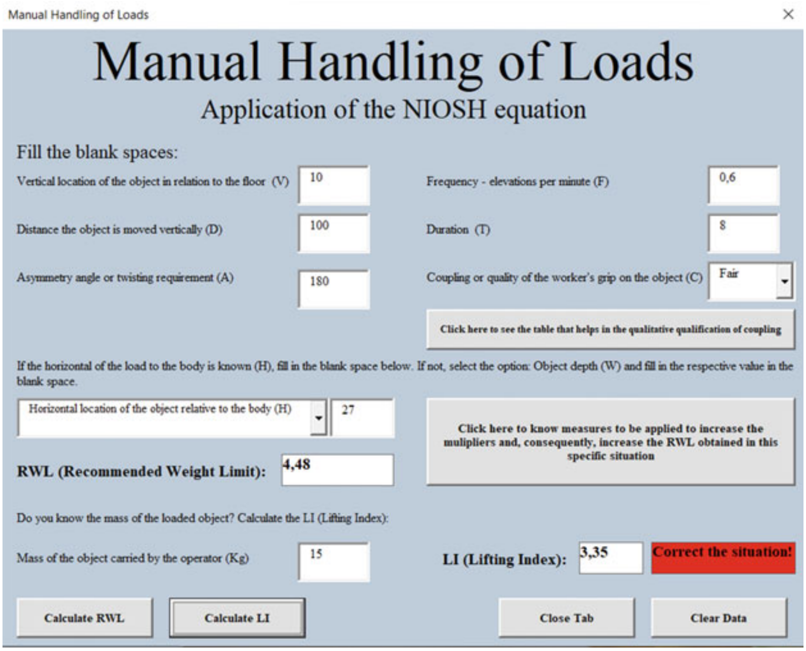

Fig. 7 Manual handling evaluation at the furniture manufacturer company

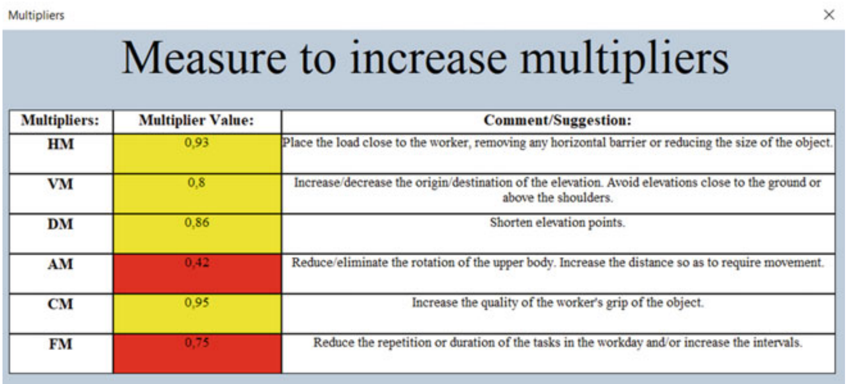

Fig. 8 Manual handling evaluation at the furniture manufacturer company

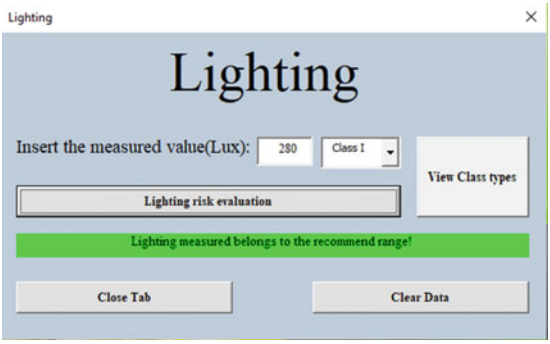

Fig. 9 Lighting evaluation at the furniture manufacturer company

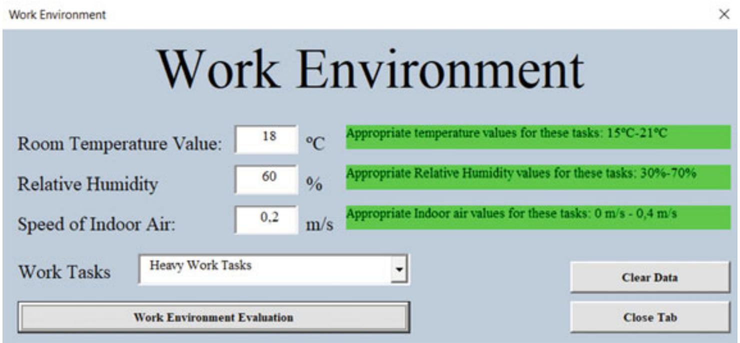

Fig. 10 Work environment evaluation at the furniture manufacturer company

4 Conclusions

The tool developed provides assistance in the four desired areas of analysis in this study: noise, manual handling of loads, lighting and thermal environment. Indeed, the technical staff involved in these tasks had already expressed the need for a platform to facilitate the calculation process, and one which would automatically draw conclusions from the results obtained. Regarding the authors' analysis of existing tools, SWS seems to be more intuitive and pleasant, when compared to the one which focuses on the application of the NIOSH equation. It also proposes improvements that would enhance the conditions of the workers' health and well-being. Other factors are still being considered with regard to the LI. Furthermore, if one is to establish a parallel with the alternative found for noise assessment, although the SWS requires an auxiliary device for data collection, it does all the work of processing this information. It additionally draws conclusions and proposes recommendations for PPE. Accordingly, it presents several options of protective equipment, which is complemented by the characteristics required (supplier price and noise mitigation), thus assisting in the decision-making process, and differentiating it from other tools.

In general terms, none of the applications found is multifunctional; namely, they are capable of assessing only one type of risk, whereas the SWS tool provides an assessment of three types. In order to validate the viability of the application/tool, a practical implementation was carried out at a furniture factory, which confirmed what one intended to test: the tool detected the existence of problems due to noise and the manual handling of loads. Subsequently, it suggested suitable PPE for the first case; for the second, it proposed measures which would impact on RWL, thus reducing values to minimize the existence of muskoskeletal disorders. With a view to future improvements, it is considered appropriate to improve the risk assessment process by means of the implementation of methodology of the simplified method. With regard to the analysis of lighting, it would be suitable to present possible improvement proposals for cases where the values measured are not within the recommended parameters. The insertion of data also presents a potential for future development. Indeed, this process would constitute an asset if the tool is automatic; namely, it would be able to collect data autonomously, without the need for auxiliary equipment.

References

Begemann, S.H.A., Beld, G.J., Tenner, A.: Daylight, artificial light and people in an office environment, overview of visual and biological responses. Int. J. Ind. Ergon. **20**(3), 231–239 (1997)

Brito, M., Vale, M., Leão, J., Ferreira, L.P., Silva, F.J.G., Gonçalves, M.A.: Lean and Ergonomics decision support tool assessment in a plastic packaging company. Procedia Manuf. **51**, 613–619 (2020)

Dianat, I., Vahedi, A., Dehnavi, S.: Association between objective and subjective assessments of environmental ergonomic factors in manufacturing plants. Int. J. Ind. Ergon. **54**, 26–31 (2016)

Juslén, H., Wouters, M., Tenner, A.: The influence of controllable task-lighting on productivity: a field study in factory in a factory. Appl. Ergon. **38**(1), 39–44 (2007)

Karin, R., Piia, T., Viiu, T., Silver, S.: Innovations at workplace: improvement of ergonomics. Eng. Econ. **5**(60), 85–94 (2008)

Knave, B.: Ergonomics and lighting. Appl. Ergon. **15**(1), 15–20 (1984)

Lee, E.C., Lee, J.W., Park, K.R.: Experimental investigations of pupil accommodation factors. Investig. Ophthalmol. Vis. Sci. **52**(9), 6478–6485 (2011)

Mariana, M., Mário, T., Leonor, T.: A new simplified model for evaluating thermal environment and thermal sensation: an approach to avoid occupational disorders. Int. J. Ind. Ergon. **60**, 3–13 (2017)

Morgado, L., Silva, F.J.G., Fonseca, L.M.: Mapping occupational health and safety management systems in mapping occupational health and safety management systems in Portugal: outlook for ISO 45001:2018 adoption. Procedia Manuf. **38**, 755–764 (2019)

Piňosová, M., Andrejiová, M., Badida, M., Moravec, M.: Analysis and evaluation of risks from exposure to noise in a working environment. Acta Mech. Slovaca **22**(3), 44–52 (2018)

Roşca, C., Dascălu, L.C., Solomon, G.: Assessment of occupational noise exposure in tyre manufacturing. In: IOP Conference Series: Materials Science and Engineering, vol. 916, No. 1, p. 012094. IOP Publishing (2020)

Serdyuk, V.S., Vladiomova, O.V., Aleshkov, D.S., Bedrina, E.A.: Research and increase of efficiency of noise load monitoring and minimization of occupational risks in conditions of industrial noise exposure. In: IOP Conference Series: Earth and Environmental Science, vol. 408, No. 1, p. 012032. IOP Publishing (2020)

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Analysis of Occupational Accidents in Greek Construction Sector—the Use of Deviation in Accident Reports

Panagiota Katsakiori, Eva A. Sgourou, and Ioanna Konsta

Abstract Objective: This paper presents the Greek Labour Inspectorate statistics relevant to occupational accidents in the construction industry for the years 2000–2017 and aims to explore patterns of all occupational accidents and fatalities among the construction workers, especially in relation with deviations. Background: The construction sector, due to its nature, is one of the most risky industries, occupying the first place in terms of fatal accidents. Method: In this study, from the analysis of the data derived from all published annual reports of Greek Labour Inspectorate, a statistical analysis of incidence rates (IRs) and mortality rates (MRs) was conducted to reveal the trend of occupational construction accidents. A further assessment of deviation as defined by the European Statistics on Accidents at Work (ESAW) methodology was performed. Results: From the statistical analysis, falls to a lower level, slips and falls to the same level were related to the higher number of occupational fatalities for the years 2009–2017. The deviation type has proved to be statistically significant to the causation of all occupational construction accidents and of fatalities. Conclusion: Findings could help towards comparing data from other countries in Europe to formulate a European effective prevention strategy, taken into consideration the probable underreporting of non-fatal occupational accidents in construction, and the quality of statistical data. Application: Analysing national accident data can help to assess a country's performance in construction safety and design effective prevention policies.

Keywords Accident statistics · Construction accident · Incidence rate · Mortality rate

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1 Introduction

The construction industry has a disproportionately high rate of recorded accidents. According to the International Labour Organization estimates, at least 60,000 people are fatally injured in construction sites every year, while many hundreds of thousands more suffer serious injuries and ill health (International Labour Organization 2003). In Europe, according to data provided by Eurostat, the construction sector showed in 2018 the highest number of fatalities and the third place in non-fatalities, as shown in Fig. 1 (Eurostat 2018). The construction sector in Greece follows a similar pattern. During the period 2000-2017 almost a half of the fatal occupational accidents occurred in construction (www.sepenet.gr/liferayportal/15).

Statistical analysis of accidents in the construction industry have been performed in various countries and have revealed the extent of the construction safety problem all over the world (Kartam and Bouz 1998; Colak et al. 2004; Camino López et al. 2008; López Arquillos et al. 2012; Dumrak et al. 2013; Yilmaz 2014; Ahmad et al. 2016; Jo 2017; Ayob et al. 2018). Moreover, various studies have examined risk factors related to construction accident causation. Shafique and Rafiq (2019) analysed the factors related to month, day of week, time interval of day, province, accident type and severity. Shafique and Rafiq (2019) and Choi et al. (2019) examined accident type of occupational construction accidents. Szóstak (2019) analysed accidents in

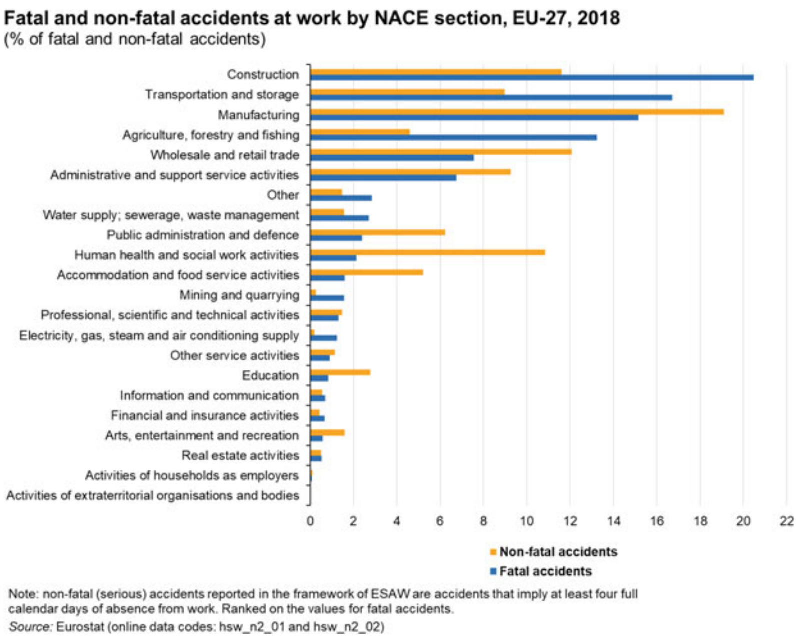

Fig. 1 Fatal and non-fatal occupational accidents per National Classification of Economic Activities (Eurostat 2018)

the construction industry in relation to selected time parameters. Reis (2018) defined, in terms of importance in the occurrence of accident risk in construction, variables referring to the worker, work and means and equipment used. Ayob et al. (2018) conducted research in the causes and accidental agents of fatal occupational accidents in the Malaysian construction sector and Yilmaz (2014) investigated causes and results of occupational accidents in the construction sector in Turkey.

In Greece, data related to occupational construction accidents are available from 2000 until 2017 because of changes in the structure of the Greek Labour Inspectorate. Before 2000, there was no provision for statistical data collection in the central offices of the Ministry of Labour and Social Affairs. Since 2000, statistical data have been collected by the Directorate of Programming and Coordinating, which is the governmental agency in charge of accident statistics under the Greek Ministry of Labour and Social Affairs.

In 2009 a new statistical coding, based on European Statistics on Accidents at Work (ESAW) methodology (Eurostat 2001), was introduced. Greek Labour Inspectors investigate the accidents reported by the Employers and write a formal investigation report, which serves as the basis for subsequent legal action. Based on the investigation report, they also fill in certain statistical variables according to ESAW methodology, which refer to working environment, working process, main type of work or task being performed by the victim at the time of the accident, specific physical activity, deviation, contact and mode of injury, material agent. Each year, an Annual Report of the Greek Labour Inspectorate is compiled and published at a later date. These reports present, among other activities of the Labour Inspectorate, a part of the accident statistical analysis for that year. For the accidents occurring in the construction sector, the only statistical variable made publicly available is the deviation leading to an accident.

Deviation is described, according to ESAW methodology, as the last link in a chain of abnormal events. It is the last event differing from the norm and leading to the accident, and it describes the way in which the circumstances of the accident differed from normal practice. Defining the deviation with specific codifiers helps Labour Inspectorate to have a homogeneity in data gathering and in practice deviation can represent the best possible input for cause-oriented prevention since it describes the immediate cause of an accident (Jacinto and Guedes Soares 2008). It is foreseen that there will not be an accident due to the lack of deviation because the deviation is immediately before the accident (Çalış and Küçükali 2019), so it can constitute one of the immediate determinants on which to develop specific prevention programs (Molinero-Ruiz et al. 2015) and it is therefore fundamental for decision making towards well designed prevention strategies (Jacinto et al. 2016).

This paper analyses the Greek Labour Inspectorate's official statistical data relevant to occupational accidents in the construction industry for the years 2000–2017, with an aim to identify patterns and future trends, especially in terms of the main deviations, which cause occupational accidents and fatalities among the construction workers. The research subject is of particular importance since it aims to give an overview of the situation in Greece in terms of the accident statistical analysis in the construction sector and examines the statistical variable of deviation from the ESAW methodology applied throughout Europe at practice level.

2 Materials and Methods

Data for occupational accidents in construction were extracted from the official website of the Greek Ministry of Labour and Social Affairs, in which the Annual Reports of Greek Labour Inspectorate are published (www.sepenet.gr/liferayportal/15). All published reports, for the years 2000–2017, were selected for this study. Data on employees in the construction industry were collected from annual workforce research, published by the Hellenic Statistical Authority (www.statistics.gr).

Accident incidence rates and mortality rates were measured using the following equations (Eurostat 2020; International Labour Organization 2020). The total number of occupational accidents presented in this study includes the fatal and non-fatal occupational accidents, reported to the Greek Labour Inspectorate.

$$Incident\ Rate(IRs) = \frac{Total\ number\ of\ occupational\ accidents}{Total\ number\ of\ workers \times 10^5}$$

$$Mortality\ Rate(MRs) = \frac{Total\ number\ of\ occupational\ accidents}{Total\ number\ of\ workers \times 10^5}$$

Data analysis was conducted using Statistical Package for Social Sciences (SPSS) v.19. To analyse data on each accident deviation and their relationship, ANOVA tests were performed. The pairwise comparisons between individual categories were performed through the post hoc tests. P-values below 0.001 were acknowledged as statistically significant.

3 Results

Occupational accidents (OA) and fatal occupational accidents (FOA) in all activity sectors and in construction in Greece for the years 2000–2017 are presented in Table 1.

Occupational accidents, fatal occupational accidents and their percentage to total accidents, incidence rates (IR), and mortality rates (MR) in the construction sector for the years 2000–2017 are presented in Table 2. For the period under study, it is observed that the incidence rates of accidents in the construction sector range from 170.24 occupational accidents per 100,000 employees in 2012 (lower) to 324.45 occupational accidents per 100,000 employees in 2002 (maximum). In terms of mortality rates, they range from 6.47 fatalities per 100,000 employees in 2012 to 27.28 fatalities per 100,000 employees in 2001. The proportion of fatal occupational

Table 1 Number of OA and FOA in all activity sectors and in construction in Greece for the years 2000–2017

Year	OA all sectors	OA construction	FOA all sectors	FOA construction
2000	4,032	765	127	66
2001	5,155	916	188	86
2002	6,021	1,058	153	80
2003	6,235	1,076	145	79
2004	6,333	925	127	81
2005	6,044	683	111	66
2006	6,255	797	128	61
2007	6,561	828	115	64
2008	6,657	872	142	61
2009	6,381	912	113	53
2010	5,721	581	94	36
2011	5,203	448	70	22
2012	4,858	342	64	13
2013	5,126	332	67	21
2014	5,497	398	63	18
2015	5,930	442	67	19
2016	6,515	436	73	13
2017	7,357	456	76	16
Mean	5,882	682	107	48

accidents in the total number of occupational accidents in construction ranges from 2.98% in 2016 to 9.66% in 2005. That year almost one in ten construction accidents reported to the Greek Labour Inspectorate was a fatality.

Figures 1 and 2 present graphically the evolution of incidence rate and mortality rate respectively, in the construction sector for the years 2000–2017. In Fig. 1, small fluctuations in the value of incidence rate around the mean IR are depicted, while in Fig. 2, an almost continuous downward trend in the value of mortality rate from 2001 to 2012 followed by a small increase and stabilization period are observed.

In terms of construction activity numbers and since there is no consolidated data published for the whole construction activity for the period under study, the data retrieved from the Hellenic Statistical Authority refer to construction permits for private new-built properties, their volume and surface during 2000–2017. Table 3 shows that private construction sector was booming before 2010 with a peak in 2005.

Table 4 presents the general deviation codes which were linked with construction accidents for the years 2009–2017. Each code has a number of subcategories of deviations leading to an accident, as it can be understood by their description. Furthermore, the deviation code 00 (no information) is attributed to accidents for which not enough information is available to relate them to a certain deviation, and the deviation code 99

Table 2 Incidence and mortality rates in Greek construction sector for the years 2000–2017

Year	Workforce	OA	FOA	% FOA	IR	MR
2000	300,096	765	66	8.63	254.92	21.99
2001	315,192	916	86	9.39	290.62	27.28
2002	326,086	1,058	80	7.56	324.45	24.53
2003	352,321	1,076	79	7.34	305.40	22.42
2004	357,069	925	81	8.76	259.05	22.68
2005	367,611	683	66	9.66	185.79	17.95
2006	367,308	797	61	7.65	216.98	16.61
2007	397,890	828	64	7.73	208.10	16.08
2008	397,255	872	61	7.00	219.51	15.36
2009	370,701	912	53	5.81	246.02	14.30
2010	319,623	581	36	6.20	181.78	11.26
2011	245,803	448	22	4.91	182.26	8.95
2012	200,898	342	13	3.80	170.24	6.47
2013	162,334	332	21	6.33	204.52	12.94
2014	151,624	398	18	4.52	262.49	11.87
2015	145,175	442	19	4.30	304.46	13.09
2016	147,090	436	13	2.98	296.42	8.84
2017	149,268	456	16	3.51	305.49	10.72
Mean	281,852	682	48	6.45	245.47	15.74

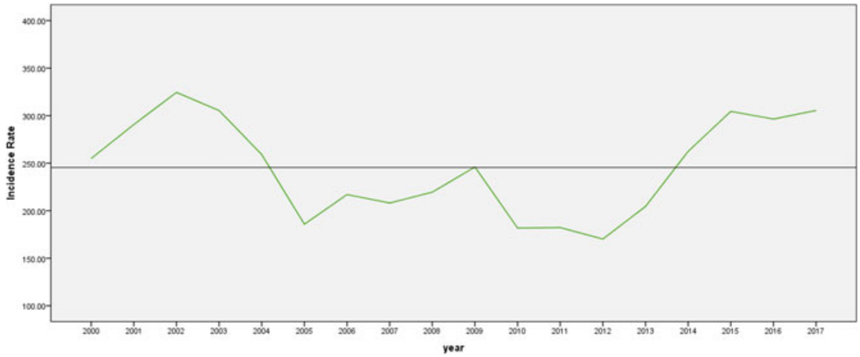

Fig. 2 Evolution of incidence rate in Greek construction sector for the years 2000–2017

Table 3 Construction permits for private new-built properties, their volume and surface from 2000 to 2017

Year	Number of permits for new built properties	Volume (m3)	Surface (m2)
2000	35200	50389208	13976780
2001	40448	57981269	16269724
2002	45195	64995536	18969174
2003	45253	65694798	18361774
2004	43447	61979467	17294032
2005	56342	88775762	25876755
2006	45406	67153393	18494123
2007	41790	62825628	16910545
2008	34021	51859356	13664965
2009	27447	35823008	9833690
2010	23380	27823083	7987904
2011	15114	16411950	4464072
2012	9066	9577553	2641200
2013	5675	6494208	1688735
2014	4620	6004603	1435481
2015	4618	5372321	1301613
2016	4305	5254169	1286560
2017	4930	7084135	1685326

(other deviations not listed) is attributed to accidents which are related to deviations not included in the given list (Fig. 3). It is observed that most construction accidents during the period under study (1,398 accidents) were attributed to the deviation type with general code 50 (Slipping, stumbling and falling—Fall of persons). Codes 00 and 99, which in the published data are presented as a total, were attributed to 985 accidents. The previous deviation codes are followed by code 30 (breakage, bursting, splitting, slipping, fall, collapse of material agent) with 728 accidents and code 40 (loss of control of machine, means of transport or handling equipment, hand-held tool, object, animal) with 618 accidents. In terms of fatal occupational accidents, as shown in Table 5, the deviation code 50 shows the highest frequency (67 accidents), followed by codes 00, 99 (56 accidents), and code 30 (42 accidents).

One-way analysis of variance (ANOVA test) was applied in order to compare accident deviation types and assess their effects on incidence and mortality rates, as shown in Tables 6 and 7 respectively. The results in Table 6 indicate that there is significant difference between the means of incidence rates across the deviation types ($F = 59.737$, p-value <0.001). The mean incidence rate of deviation type with code 50 (slipping, stumbling and falling—fall of persons) differs significantly compared with all other deviation types, while the mean incidence rates of deviation types with codes 30, 40 and 00, 99 also differ significantly in comparison with 6 other types of

Table 4 Deviation types of occupational accidents in Greek construction sector

Deviation type		Occupational accidents									Total
ESAW code	Description	2009	2010	2011	2012	2013	2014	2015	2016	2017	
10	Electrical problems, explosion, fire	24	20	9	8	7	5	10	11	9	103
20	Overflow, overturn, leak, flow, vaporization, emission	25	14	11	5	6	18	6	10	6	101
30	Breakage, bursting, splitting, slipping, fall, collapse of material agent	135	116	80	59	67	67	63	67	74	728
40	Loss of control of machine, means of transport or handling equipment, hand-held tool, object, animal	86	63	62	56	60	65	65	77	84	618
50	Slipping, Stumbling and falling—Fall of persons	286	176	150	128	104	141	128	139	146	1398
60	Body movement without any physical stress	102	24	18	14	19	22	21	28	30	278
70	Body movement under or with physical stress	17	15	12	11	7	7	10	16	9	104
80	Shock, fright, violence, aggression, threat, presence	6	2	4	1	6	7	1	3	2	32
00, 99	No information—Other deviations not listed	231	151	102	60	56	66	138	85	96	985
	Total	912	581	448	342	332	398	442	436	456	4347

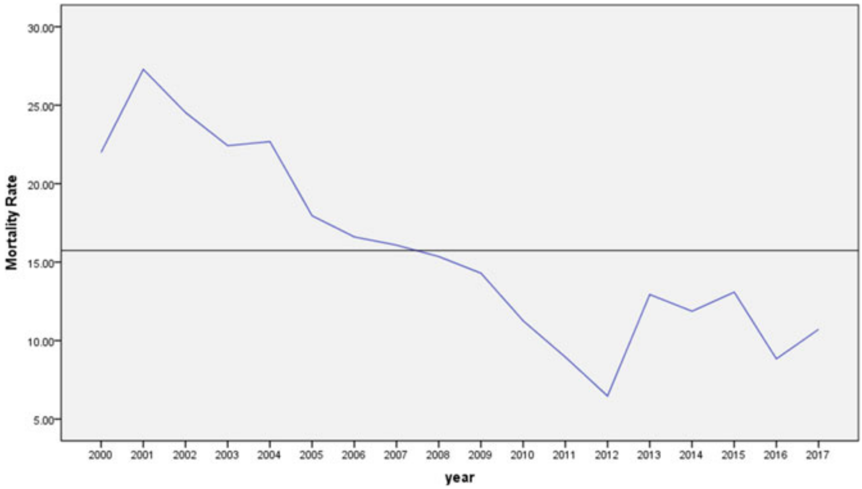

Fig. 3 Evolution of mortality rate in Greek construction sector for the years 2000–2017

Table 5 Mortality rate per deviation type of occupational accidents in Greek construction sector

Deviation		Mortality rate									Mean
ESAW code	Description	2009	2010	2011	2012	2013	2014	2015	2016	2017	
10	Electrical problems, explosion, fire	1.62	0.31	1.22	1.49	1.85	1.32	0.69	1.36	0.67	1.17
20	Overflow, overturn, leak, flow, vaporization, emission	0.27	0.00	0.00	0.50	0.00	0.66	0.00	0.00	0.00	0.16
30	Breakage, bursting, splitting, slipping, fall, collapse of material agent	2.97	2.19	2.03	1.00	3.08	0.66	4.13	1.36	2.01	2.16
40	Loss of control of machine, means of transport or handling equipment, hand-held tool, object, animal	0.27	0.94	2.03	0.50	1.23	0.00	0.69	0.68	0.67	0.78
50	Slipping—Stumbling and falling—Fall of persons	3.51	4.07	1.63	1.99	3.08	5.94	6.20	3.40	3.35	3.68
60	Body movement without any physical stress	0.27	0.31	0.00	0.00	0.00	0.00	0.69	1.36	0.00	0.29
70	Body movement under or with physical stress	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	Shock, fright, violence, aggression, threat, presence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.07
00, 99	No information—Other deviations not listed	5.40	3.44	2.03	1.00	3.70	3.30	0.69	0.68	3.35	2.62

Table 6 Post-Hoc tests performed after one-way ANOVA, based on incidence rates

		Deviation type								
Deviation type	Mean IR (S.D.)	10	20	30	40	50	60	70	80	0–99
10	5.38 (1.56)			***	***	***				***
20	5.40 (2.79)			***	***	***				***
30	39.85 (6.60)	***	***			***	***	***	***	
40	36.58 (13.28)	***	***			***	***	***	***	
50	77.17 (16.58)	***	***	***	***		***	***	***	***
60	14.35 (6.95)			***	***	***				***
70	5.82 (2.07)			***	***	***				***
80	1.86 (1.42)			***	***	***				***
00, 99	52.90 (19.81)	***	***			***	***	***	***	

*** indicates significant difference result at 0.001 level

deviation. The mean incidence rates of the rest of deviation types differ significantly in only four out of eight comparisons among deviation types.

Similarly, in Table 7 it is observed that there is significant difference between the means of mortality rates of all deviation types ($F = 19.616$, p-value <0.001). The

Table 7 Post-Hoc tests performed after one-way ANOVA, based on mortality rates

		Deviation type								
Deviation type	Mean MR (S.D.)	10	20	30	40	50	60	70	80	0–99
10	1.170 (0.505)					***				
20	0.159 (0.257)			***		***				***
30	2.159 (1.100)		***					***	***	
40	0.779 (0.590)					***				
50	3.684 (1.550)	***	***		***		***	***	***	
60	0.292 (0.464)					***				***
70	0 (0)			***		***				***
80	0.074 (0.223)			***		***				***
00, 99	2.620 (1.620)		***				***	***	***	

mean mortality rate of deviation type with code 50 differs significantly compared with six other deviation types, deviation type with codes 00, 99 differs significantly with four deviation types, while the rest of the deviation types differ significantly with three or less deviation types.

4 Discussion

This paper presents the analysis of a large set of occupational accident data from the Greek construction sector. These data were derived from the Greek Labour Inspectorate's Annual Reports for the years 2000 to 2017, which are made publicly available by the Greek Ministry of Labour and Social Affairs.

The evolution of incidence and mortality rates in the construction sector during the period under study was initially examined. In general, the high accident rates in the construction industry represent a major concern all over the world and are a subject of analysis in numerous studies and statistics (Gürcanli and Müngen 2013; Jo 2017; Japan Industrial Safety and Health Association 2018; Reis 2018; Health and Safety Executive 2019; Eurostat 2020; Shafique and Rafiq 2019). Our analysis revealed a relatively low incidence rate, when compared to Europe's countries (Eurostat 2020), ranging from 170.24 occupational accidents per 100,000 construction employees in 2012 (lower) to 324.45 occupational accidents per 100,000 construction employees in 2002 (maximum). These findings can be related with the economic conditions in Greece, at that time.

The major construction activity undertaken in Greece prior to the Athens Olympic Games of 2004, has resulted in a significant increase in reported occupational accidents (both fatal and non-fatal) (Tatsaki et al. 2019). The global financial crisis and the resulting recession in Greek economy, since 2010, affected all types of business activities, including construction (Anyfantis et al. 2018). However, this finding may also be attributed to a high degree of under-reporting, especially of non-fatal occupational accidents. This assumption coincides with the findings of Ivascu and Cioca (2019) who supported that the current reporting systems in Europe do not encourage victims in reporting occupational accidents.

When examining the pattern of mortality rate of occupational accidents in the Greek construction sector, high rates are again observed in the years 2000–2004, followed by a sharp downward trend until 2012. Moreover, it was observed that during the period under study, a high percentage of reported accidents are fatalities (mean 6.45%, max 9.66% in year 2005), a finding, which further supports the previous assumption of under-reporting of non-fatal construction accidents.

Following the alterations in the statistical coding in 2009 based on ESAW methodology, and the introduction of the deviation codes in the official accident statistics published by the Greek Ministry of Labour and Social Affairs, this study focused on the deviations, which were linked with construction accidents for the years 2009–2017.

A high incidence and mortality rate (second in place) was related with deviation code 00 (accidents with no information) and code 99 (deviations not listed). A further investigation regarding the training of Labour Inspectors in the implementation of the ESAW methodology is required in order to ensure that the use of the above codes is correct. This is an issue related to the quality of data analysis, which depends on its inputs, as it was also indicated by Wilke et al. (2014). Another interesting subject for further analysis could be the comparison with other countries implementing the same methodology, because significant differences in statistics' data collection is often observed between countries, as it is also highlighted in the research of Choi et al. (2019).

From the descriptive analysis of the sample, the majority of occupational accidents and of fatalities in the construction sector during the period 2009–2017 were attributed to falls to a lower level, slips and falls to the same level (general deviation code 50). This finding is in agreement with other studies that identified falls as a major cause of fatalities in the construction sector (Janicak 1998; Wong et al. 2009; Yung 2009; Wong et al. 2016; Shao et al. 2019). The majority of the studies support the need of wide use of fall protection, of suitable and well-maintained equipment and of organizational preventive measures against falls and collapses in construction.

From the ANOVA tests performed, two more general deviation codes were identified as statistically significant in terms of incidence rates, the code 30 (breakage, bursting, splitting, slipping, fall, collapse of material agent) and the code 40 (loss of control of machine, means of transport or handling equipment, hand-held tool, object, animal). Both codes cover a wide range of sub-categories, which due to lack of available data were not able to be further assessed. However, a direct linkage of construction accidents with the use machinery and other equipment can be concluded from the above deviation codes, which is also in accordance with other studies (Chinniah 2015; Marsh and Fosbroke 2015; Kazan and Usmen 2018).

4.1 Limitations

The basic restriction of this study relates to the limited information available through the Annual Reports of Greek Labour Inspectorate published in the official website of the Greek Ministry of Labour and Social Affairs. Data on other variables related to occupational accidents per sector, which are already coded in the accident investigation reports by the Labour Inspectors, would enable a more enhanced statistical analysis in the future.

5 Conclusions

This study sought to investigate the trends of occupational accidents and fatalities in the Greek construction sector, during the years 2000–2017. Moreover, a statistical analysis of accident deviations since 2009 (the year that ESAW methodology was introduced in Greece) was performed in order to examine the immediate causes related to construction accidents, as identified during the accident investigation performed by the Labour Inspectors.

The results show that construction incidence rate was relatively low during the period under study, while the respective mortality rate was increased during the period prior to Athens Olympic Games, and decreased sharply immediately after, possibly as a result of a shrinkage in construction activities following Greek economic recession. Another finding of this study is a significant percentage of fatalities in the reported construction accidents, which can be related to a high degree of under-reporting of non-fatal accidents in construction, which coincides with the results of previous research.

Regarding the results of the analysis of deviations attributed to occupational accidents in construction, the major immediate causes identified are slips, trips (falls at the same level) and falls to a lower level, a finding in total accordance with several other studies. An additional finding is the frequent use of two deviation codes describing accidents with no information and accidents attributed to deviations not listed in the ESAW methodology. A further investigation regarding the implementation of the methodology by the Labour Inspectors is recommended.

In conclusion, accident statistical analysis can provide a valuable reference for policy makers and other stakeholders in order to design and coordinate safety improvements in the construction industry. The results found in this study could be used for the development of strategic actions both internally in Labour Inspectorates to enhance quality of statistical data and externally to encourage Employers to establish effective accident reporting systems and thorough investigation of deviations related to falls. A further assessment of other statistical variables would add to this purpose.

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References

Anyfantis, I., Boustras, G., Karageorgiou, A.: Maintaining occupational safety and health levels during the financial crisis—a conceptual model. Saf. Sci. **106**, 246–254 (2018)

Ahmad, S., Iraj, M., Abbas, M., Mahdi, A.: Analysis of occupational accidents induced human injuries: A case study in construction industries and sites. J. Civil Eng. Constr. Technol. **7**(1) (2016). https://doi.org/10.5897/JCECT2015.0379

Ayob, A., Shaari, A.A., Zaki, M.F.M., & Munaaim, M.A.C. (2018). Fatal occupational injuries in the Malaysian construction sector—causes and accidental agents. IOP Conf. Ser.: Earth Environ. Sci. **140**, 012095 (2018). https://doi.org/10.1088/1755-1315/140/1/012095

Çalış, Ç., Küçükali, U.F.: How reliable variables that entered on SGK accident e-notice? Procedia Comput. Sci. **158**, 1067–1076 (2019)

Camino López, M.A., Ritzel, D.O., Fontaneda, I., González Alcantara, O.J.: Construction industry accidents in Spain. J. Saf. Res. **39**, 495–505 (2008)

Chinniah, Y.: Analysis and prevention of serious and fatal accidents related to moving parts of machinery. Saf. Sci. **75**, 163–173 (2015)

Choi, S.D., Guo, L., Kim, J., Xiong, S.: Comparison of fatal occupational injuries in construction industry in the United States, South Korea, and China. Int. J. Ind. Ergon. **71**, 64–74 (2019)

Colak, B., Etiler, N., Bicer, U.: Fatal occupational injuries in the construction sector in Kocaeli, Turkey, 1990–2001. Ind. Health **42**, 424–430 (2004). https://doi.org/10.2486/indhealth.42.424

Dumrak, J., Mostafa, S., Kamardeen, I., Rameezdeem, R.: Factors associated with the Severity of Construction Accidents: the case of South Australia. Australasian J. Const. Econ. Build. (2013). https://doi.org/10.5130/ajceb.v13i4.3620

Eurostat: Accidents at Work-Statistics by Economic Activity (2020)
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_-_statistics_by_economic_activity

Eurostat: Fatal and non-fatal accidents at work by NACE Section (2018). https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Fatal_and_non-fatal_accidents_at_work_by_NACE_Section,_EU-27,_2018_(%25_of_fatal_and_non-fatal_accidents)_AAW2020.png

Eurostat: European Statistics on Accidents at Work (ESAW)—Methodology (2001). https://ec.europa.eu/eurostat/ramon/statmanuals/files/ESAW_2001_EN.pdf

Gürcanli, G.E., Müngen, U.: Analysis of construction accidents in Turkey and responsible parties. Ind. Health **52**, 581–595 (2013)

Health and Safety Executive: Construction Statistics in Great Britain (2019)
http://www.hse.gov.uk/statistics/industry/construction.pdf

International Labour Organization: Quick guide on sources and uses of statistics on occupational safety and health (2020). https://ilo.org/wcmsp5/groups/public/---dgreports/---stat/documents/publication/wcms_759401.pdf

International Labour Organization: Safety in numbers—Pointers for a global safety culture at work (2003)
https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_142840.pdf
Ivascu, L., Cioca, L.-I.: Occupational accidents assessment by field of activity and investigation model for prevention and control. Safety **5** (2019). https://doi.org/10.3390/safety5010012
Jacinto, C., Santos, F.P., Guedes Soares, C., Silva, S.A.: Assessing the coding reliability of work accidents statistical data: how coders make a difference. J. Saf. Res. **59**, 9–21 (2016)
Jacinto, C., Guedes Soares, C.: The added value of the new ESAW/Eurostat variables in accident analysis in the mining and quarrying industry. J. Saf. Res. **39**, 631–644 (2008)
Janicak, C.A.: Fall-Related deaths in the construction industry. J. Saf. Res. **29**(1), 35–42 (1998)
Japan Industrial Safety and Health Association: OSH Statistics in Japan (2018). https://www.jisha.or.jp/english/statistics/accidents_in_detail_2018.html
Jo, B.W., Lee, Y.S., Kim, J.H., Khan, R.M.A.: Trend Analysis of Construction (2017)
Industrial Accidents in Korea from: to 2015. Sustainability **9**(8), 1297 (2011)
Kartam, N.A., Bouz, R.G.: Fatalities and injuries in the Kuwaiti construction industry. Accid. Anal. Prev. **30**, 805–814 (1998)
Kazan, E., Usmen, M.: Worker safety and injury severity analysis of earth moving equipment accidents. J. Saf. Res. **65**, 73–81 (2018)
López Arquillos, A., Rubio Romerro, J.C., Gibb, A.: Analysis of construction accidents in Spain, 2003–2008. J. Saf. Res. **43**, 381–388 (2012)
Marsh, S.M., Fosbroke, D.E.: Trends of occupational fatalities involving machines, United States, 1992–2010. Am. J. Ind. Med. **58**(11), 1160–1173 (2015)
Molinero-Ruiz, E., Pitarque, S., Fondevila-McDonald, Y., Martin-Bustamante, M.: How reliable and valid is the coding of the variables of the European Statistics on Accidents at Work (ESAW)? A need to improve preventive public policies. Saf. Sci. **79**, 72–79 (2015)
Reis, C., Gomes, V., Braga, P., Silva, J.F., Correis, J.A.F.O., Oliveira, C.: Case study of risk assessment in single family housing. In: Arezes et al. (eds.), Occupational Safety and Hygiene VI. Taylor & Francis Group, London (2018). ISBN 978-1-138-54203-7. https://doi.org/10.1201/9781351008884-97
Shafique, M., Rafiq, M.: An overview of construction occupational accidents in Hong Kong: a recent trend and future perspectives. Appl. Sci. **9**, 2069 (2019). https://doi.org/10.3390/app9102069
Shao, B., Hu, Z., Liu, Q., Chen, S., He, W.: Fatal accident patterns of building construction activities in China. Saf. Sci. **111**, 253–263 (2019)
Szóstak, M.: Analysis of occupational accidents in the construction industry with regards to selected time parameters. Open Eng. **9** (1) (2019). https://doi.org/10.1515/eng-2019-0027
Tatsaki, E., Sgourou, E., Katsakiori, P., Konsta, I., Gerasimou, S.: The impact of occupational accidents and gross domestic product on the sanctions imposed by the Greek OSH Inspectorate. Saf. Sci. **115**, 349–352 (2019)
Yilmaz, F.: Analysis of occupational accidents in construction sector in Turkey. J. Multidiscip. Eng. Sci. Technol. **1**(5) (2014)
Yung, P.: Institutional arrangements and construction safety in China: an empirical examination. Constr. Manag. Econ. **27**, 439–450 (2009)
Wilke, S., Majumdar, A., Ochieng, W.Y.: A framework for assessing the quality of aviation safety databases. Saf. Sci. **63**, 133–145 (2014)
Wong, F.K.W., Chan, A.P.C., Yam, M.C.H., Wong, E.Y.S., Tse, K.T.C., Yip, K.K.C., Cheung, E.: Findings from a research study of construction safety in Hong Kong: accidents related to fall of person from height. J. Eng. Des. Technol. **7**(2), 130–142 (2009)
Wong, L., Wang, Y., Toran Law, P.E., Lo, C.T.: Association of root causes in fatal fall-from-height construction accidents in Hong Kong. J. Constr. Eng. Manag. **142**(7) (2016)

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Towards the Application of a Simplified Approach for OSH Risk Assessment Through a User-Friendly and Expedite Computational Tool

Pedro D. Gaspar, Joel Alves, and Tânia M. Lima

Abstract Objective: This study describes a simplified computational tool to provide a simple initial diagnostic of occupational hazards and risks and help companies to implement innovative management practices in terms of Occupational Safety and Health (OSH) to prevent work accidents. Background: The enterprises of the non-financial business sector in the EU-28 are mostly micro, small and medium-sized enterprises (MSMEs). Portugal follows this trend, where the largest industry sector is the agri-food. Generally, the companies of this sector have reduced financial, technical and human resources, thus jeopardizing the quality and accuracy of risks evaluation and the implementation of protective measures. Method: This study explains a simplified approach for occupational safety and health risk assessment through a user-friendly and expedite computational tool and its in-field application. Data from sixty OSH audits executed in dairy, meat processing, bakery and horticultural food processing companies in Portugal was analysed. Results: The spreadsheet software, Excel, usually used by the managers of this sector was used to implement the computational tool. It is divided into three "Sheets": Risk assessment, Results summary and Report with solutions. Conclusion: Thus, it is important to develop OSH simplified risk assessment tools that helps Agri-food MSME to improve their OSH management and ultimately contribute to the productivity and competitiveness of this sector.

Keywords Agri-food industry · Occupational health and safety · MSMEs · Computational tool

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1 Introduction

Small and medium-sized enterprises (SMEs) account 99.8% of enterprises in the EU-28 (EU-OSHA 2018), In Portugal, this figure is even higher, where 96% are micro, small and medium enterprises (MSME) (Pordata 2021). The European MSMEs employ 66.4% of the labor market. In Portugal, this figure increases to 77.4% (Pordata 2021). Specifically, the agri-food industry accounts for 20% of the national industry, ensuring employment for more than 110 thousand workers (FIPA 2017). Moreover, the Portuguese exportation market depends in more than 11% in the agri-food industry (AICEP 2019). Thus, the implementation of effective Occupational Safety and Health (OSH) management systems in MSMEs is relevant. Due to financial, technical and human constrains, MSME usually assign the minimum resources only to comply with the legal obligations. This management practice was a direct influence on the quality and accuracy of risks evaluation. The approach was a direct influenced on the preventive measures that can and are implemented. Although the relevance and extent of the agri-food industry to the Portuguese economy, no specific OSH risk assessment tools are developed or proposed. Several computational tools have been developed to assess OSH risk in different sectors. A critical review of the state-of-the-art in OSH risk assessment studies using multi-criteria decision-making-based approaches was performed by Gul (2018). The OSH risk assessment in manufacturing, construction, energy, transportation, and maritime industry is essential. Fuzzy analytic hierarchy process-based approaches prevail among all other. Most of risk assessment studies are related to manufacturing sector. Some computational tools to perform risk assessments in different sectors are listed taking into account the citations number in the scientific databases: professional drivers (Useche et al. 2019), textile industry (Amador-Rodezno 2005; Mutlu and Altuntas 2019), steel industry (Mehrifar et al. 2019), construction (Bojar et al. 2019), paints industry (Paun et al. 2019), nanoparticles industry (van Duuren-Stuurman et al. 2016), power generation plants (Saedi et al. 2014), health care (Franchi et al. 2000), hazardous substances (Koppisch and Gabriel 2012) automotive industry (Karlheinz et al. 2012), chemical industry (Tjoe-Nij et al. 2018). Despite its worldwide importance, there is no risk assessment tools developed for the agri-food sector.

This chapter presents online free computational tools for simple OSH risks assessment in agri-food MSMEs. These tools are directed to dairy, meat, bread/pastry and horticultural product industries. A simple and expedite diagnostic of occupational hazards and risks is provided by the tools, identifying successful practices and easy-to-implement solutions for the prevention of occupational risks that can be carried out.

2 Materials and Methods

OSH audits were conducted in sixty agri-food MSMEs to support the development of the risk assessment tools (Gaspar et al. 2018, 2019; Lourenço et al. 2019). The main risks were identified through a survey of the OSH conditions in the workplace. The main improvement actions were defined based on the inquiry results. Noise, illumination and thermal environment measurements were conducted to strengthen the analysis. The development of the online risk assessment computational tool was conducted in close cooperation with the Portuguese Authority for Work Conditions (ACT), as national Focal Point of the European Agency for Safety and Health at Work (EU-OSHA), with the social partners Portuguese Enterprises Confederation (CIP), Federation of Portuguese Agro-Food Industries (FIPA), Food Industry Workers Union and the General Union of Workers (UGT). The computational tool was prepared in the web platform OiRA (Online interactive Risk Assessment) developed and supported by the EU-OSHA (https://oiraproject.eu). OiRA intends to simplify and promote conducting risk assessments in MSMEs due to their potential resources unavailability or technical know-how to in last instance decrease the number of occupational accidents and diseases. Thus, working conditions may be improved as well as competitiveness due to less monetary burden with occupational accidents and illness. This objective is European driven although these specific OiRA tools were developed to support the Portuguese meat, dairy, horticultural and bread/pastry products sectors (Gaspar and Lima 2020).

3 Results

Simplified Workplace Safety Assessment Tool, FaST, is a simplified risk assessment tool, easy to use, that aims improving working conditions through the assisting in conducting an occupational risk assessment and presenting risk control solutions. FaST is structured in the three sections (see Fig. 1). It starts with the Risk assessment section composed by checklist. Filling out this checklist leads to the Results section composed by a graphical overview of the risk control level. User is able to identify visually the control level of the main risks. The third section is composed by a report that contains corrective and preventive OSH measures for each one of the identified risk.

The tool was developed for meat, horticultural, bread/pastry and dairy products sectors. In addition, the horticultural products are split in 3 segments: canned, doughs and sauces, and, sweets and jams. All of these main groups of agro-industry are classified and structured by the analysis dimensions making part of the checklist shown in the first section (see Table 1).

As described in Table 1, Meat Agro-industry present 18 dimensions of analysis, as well the Bread/Pastry industry. All of the product segments of horticultural industry have 17 dimensions of study. Finally, the industry of Dairy products current 15 dimensions for analyze.

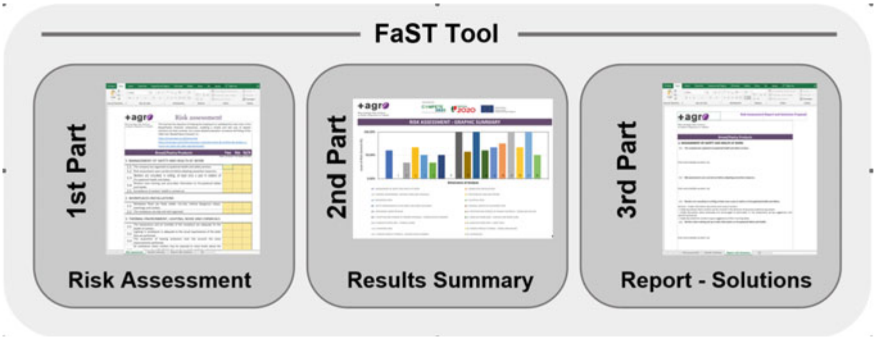

Fig. 1 Structure of the risk assessment tool

FaST does not requires internet connection or any software installation. It is also important to highlight that the FaST Tool should be used as a "screening" tool and then the complete "diagnosis" using the OiRA Tool designed specifically for Dairy companies. This tool can also be used for workers' training, since it is increasingly important to integrate and involve workers in work systems in order to improve their health, well-being and safety.

3.1 Tool Application

The tool is implemented in the spreadsheet software, Excel, usually used by the managers of this sector. As already described above, it is divided into three "Sheets": Risk assessment, Results summary and Report with solutions.

In the "Risk Assessment" Sheet, the FaST Tool objectives and the questions related to hazard identification are firstly defined. As shown in Fig. 2a, each question from the different dimensions of analysis should be answer with "Yes", "No" or "N/A" (Not Applicable). However, in order to obtain correct results and to promote the easy use of the available risk assessment tool, exists important alerts that must be taken in account. In the first place, before starting to fill the checklist, all the options are "salmon" or "roasted yellow", depending on the monitor, and only change to another color when the desired option is set. Thus, this function allows to check that have not left any statements to evaluate. When placing a cross (X) in the pretended option, all the options in this line change color, passing to a white background, as shown in the Fig. 2b. Sometimes may can appear an error that happens when two or three options for the same question were putted. In this case, the cells will change color, as will the crosses, passing the background to pink and the crosses to the red color, as shown in Fig. 2c, so that the user can easily perceive that he should analyze the question again and leave only one option.

Table 1 Dimensions of analysis from FaST checklist

Dimensions	Meat	Horticultural			Bread/ pastry	Dairy
		Canned	Doughs and Sauces	Sweets and Jams		
Management of OSH at Work	X	X	X	X	X	X
Workplaces Installations	X	X	X	X	X	X
Thermal Environment, Lighting, Noise and Chemicals	X	X	X	X	X	X
Psycho-social Risks and Stress	X	X	X	X	X	X
Ergonomic Risks	X	X	X	X	X	X
Electrical Risks	X	X	X	X	X	X
Safety Machinery and Work Equipment	X	X	X	X	X	X
Personal Protective Equipment (PPE)	X	X	X	X	X	X
Containers Under Pressure	X	X	X	X	X	X
Reception/Storage of Primary Materials						X
Reception/Storage of Primary Materials - Stands and Shelves	X	X	X	X	X	
Reception/Storage of Primary Materials - Conservation Chambers	X	X	X	X	X	
Reception/Storage of Primary Materials - Silos					X	
Preparation of Ingredients		X	X	X		
Canned Confection		X				
Preparation of Doughs and Sauces			X			
Cooking of Sweets and Jams				X		
Preparation					X	
Use of Gas and Ventilation					X	
Oven					X	
Manufacturing Area						X
Manufacturing Area - Surfaces and Work Plans	X					
Manufacturing Area - Thermal Burns	X					
Manufacturing Area - Hand Tools	X					
Packaging Area	X					X
Primary Packaging		X	X	X		
Secondary Packaging		X	X	X		

(continued)

Table 1 (continued)

Dimensions	Meat	Horticultural			Bread/pastry	Dairy
		Canned	Doughs and Sauces	Sweets and Jams		
Final Product Storage		X	X	X		
Final Product Storage Stands/Shelves	X					
Final Product Storage-Cold Chambers	X					
Finishing and Packaging					X	
Storage and Shipping					X	
Conservation Chambers						X
Expedition						X
Emergencies	X	X	X	X	X	X

At the end of the checklist, there is also, beyond the date, a space for the signature of the person responsible for the evaluation (Fig. 2d), but this document can only be signed after it has been printed. Another important detail is when by filling in the checklist, the user can save the work done so that he can interrupt and resume this activity whenever necessary. At the end of the checklist, there is a cell that updates the fill date whenever a recording is performed, so the user can always know when the file was last updated.

The synthesis of the results comes after completing the checklist and is presented by means of a 2D bar graph that allows us to quickly verify the companies' situation related to the dimensions of analysis proposed. This represent the FaST tool second section and it is exemplified in Fig. 3.

In order to know the percentage obtained in each dimension of analysis, the user must place the cursor on the respective column and, thus, obtain the indication of the exact value. Reading this graph should allow the user to make several observations: in what dimensions of analysis the enterprise is at an adequate risk control level and, in what dimensions of analysis will the enterprise have to make interventions because the risk control is deficient or does not exist. In the case of the dimensions of analysis that fall under an adequate risk control situation, the enterprise should be vigilant to ensure that there are no changes that could interfere with current levels of risk control and to continue adopting an attitude of continued improvement. For dimensions with values below 100%, it is considered that risk control is not being adequate or efficient, and there is, therefore, a need to promote initiatives to change. After completing the checklist and careful reading of the graphical summary of the results, the user should consult the "Report with Solutions" Sheet. In this section, a set of options, proposals and alternatives are proposed that may allow to control the risk inherent in each statement whose answer fell to the option "No" (See Fig. 4).

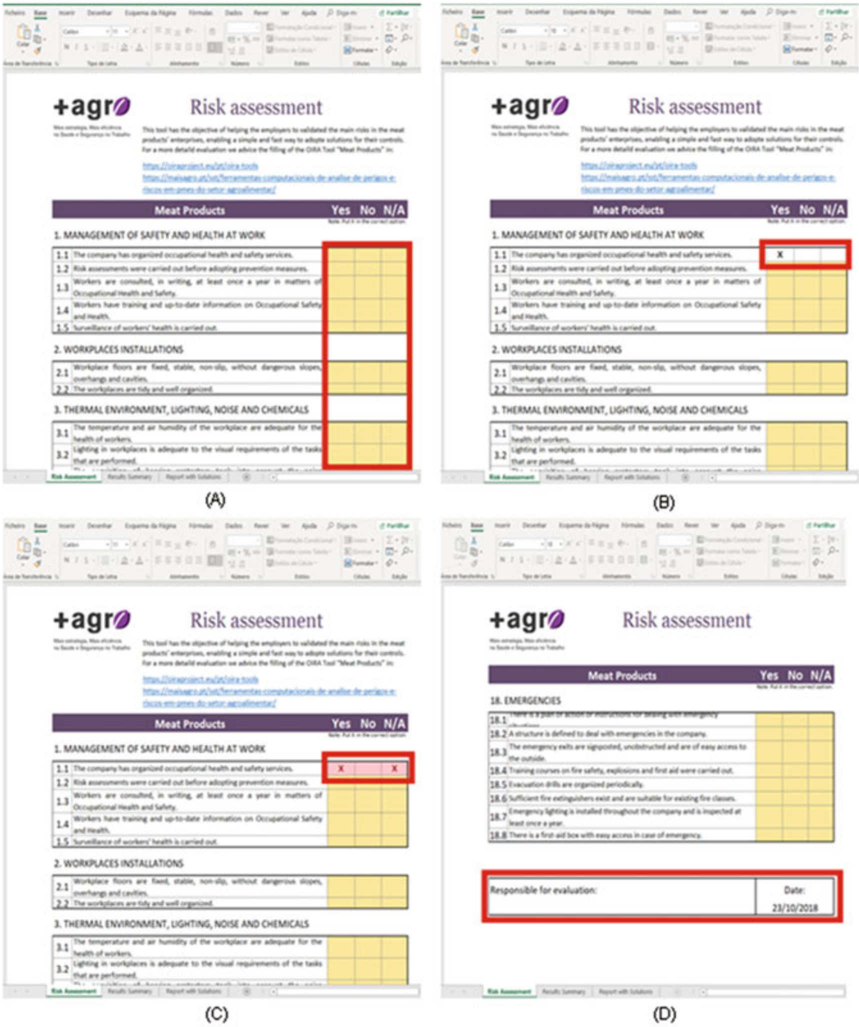

Fig. 2 Structure and Alerts of the "Risk assessment" Sheet: **a** Checklist; **b** Desired option set; **c** Error Alert; **d** Signature of responsible and Date of analysis

Thus, the report made available is not an end in itself but a window of opportunities for improving working conditions in the company, by implementing measures that translate into adequate control of risks.

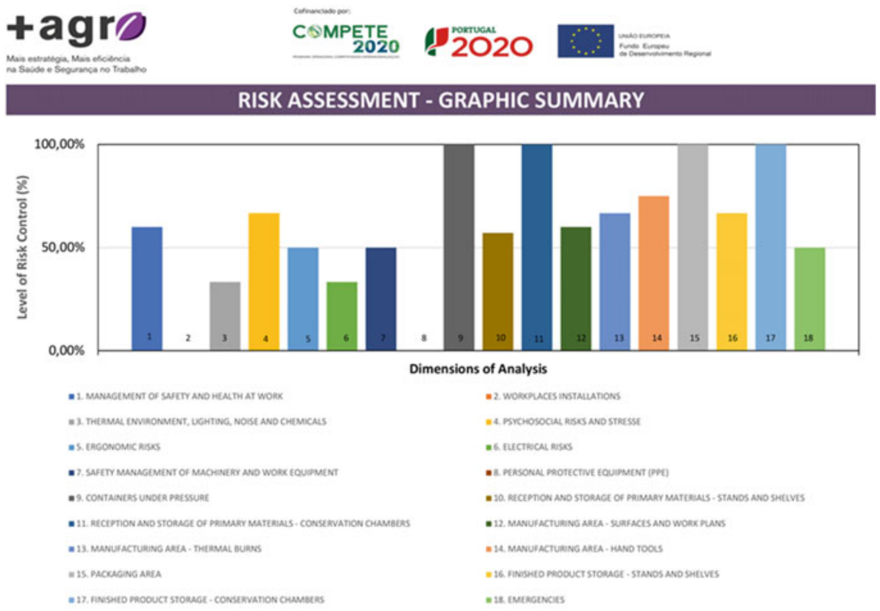

Fig. 3 Graphical summary of the results - Levels of Risk Control (%)

4 Conclusions

An online simple and expedite risk assessment tool was developed to help MSMEs to managed OSH risks. It aims in the long run to allow MSMEs agri-food industries to structure a well-implemented OSH service, with the main objective of reducing accidents, occupational diseases and absenteeism. This result improves the quality of work, and promotes productivity and competitiveness. Nevertheless, it is important to highlight that the willingness, participation and commitment of employers and workers is fundamental to turn these computational tools efficient and effective.

These tools can be further improved. A large sample of companies in each subsector will provide more detailed risk assessment. The measurements on noise, illumination and thermal environment in all workplaces will strength the results. Conducting ergonomics and psychosocial risk evaluations will increase the spectrum of the tool applicability.

The improvements concerning the management and prevention of work accidents will be increasingly required due to the increasing importance of OSH related topics, to the increasingly importance of the agri-food industry based on MSMEs.

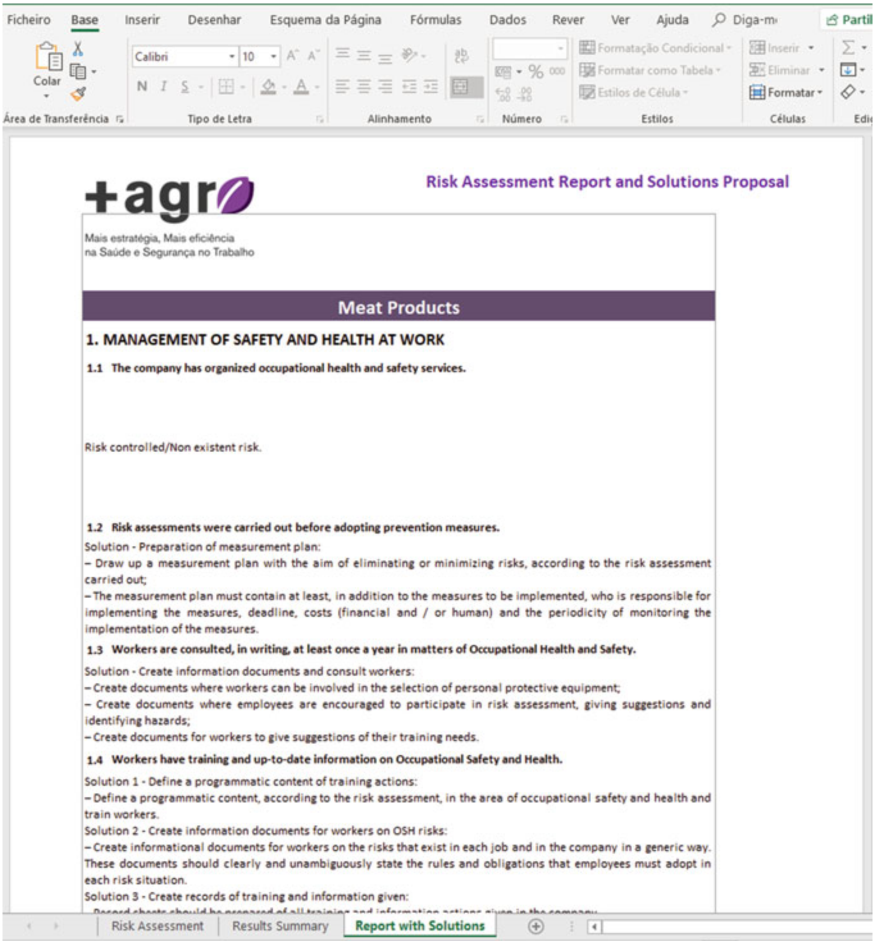

Fig. 4 Graphical summary of the results - Levels of Risk Control (%)

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References

AICEP: Fileira agroalimentar portuguesa um sucesso fora de portas. AICEP Portugal Global, n.o 119 (2019)

Amador-Rodezno, R.: An overview to CERSSO's self evaluation of the cost-benefit on the investment in occupational safety and health in the textile factories: "A step by step methodology". J. Saf. Res. **36**(3), 215–229 (2005)

Bojar, H., Silveira, F., Rebelo, M., Czarnocka, E., Czarnocki, K.: Health behaviours in scaffold use risk assessment model - SURAM. Annu. Agric. Environ. Med. **26**(1), 138–142 (2019)

EU-OSHA: Occupational safety and health in micro and small enterprises [Online]. European Agency for Safety and Health at Work, Belgium (2018). https://osha.europa.eu/en/themes/safety-and-health-micro-and-small-enterprises

FIPA: Dados Macroeconómicos [Online]. Federação da Indústrias Portuguesas Agro-alimentares. Lisboa, Portugal (2017). https://www.fipa.pt/estatisticas/dados-macroeconomicos-industria-alimentar

Franchi, A., Amicosante, M., Rovatti, E., Benini, R., Marchegiano, P., Girardi, E., Guaraldi, G., Franco, G., Saltini, C.: Evaluation of a western blot test as a potential screening tool for occupational exposure to Mycobacterium tuberculosis in health care workers. J. Occup. Environ. Med. **42**(1), 64–68 (2000)

Gaspar, P.D., Elias, M., Pereira, C.D., Andrade, L.P., Pinheiro, R., Paiva, T., Soares, C., Gândara, J., Henriques, M., Laranjo, M., Potes, M.E., Santos, A.C.A., Santos, F.C., Silva, P.D., Nunes, J., Coutinho, P., Carneiro, J., Várzea, J.P., Vaz-Velho, M., Araújo, M.A., Ribeiro, M., Santos, J., Matias, J.: Caracterização e Análise das Condições de Segurança e Saúde no Trabalho em empresas Agroalimentares. +AGRO-Qualificação Organizacional, Energética e de Segurança e Saúde no Trabalho da Indústria Agroalimentar. Gaspar, P.D., Elias, M. Universidade da Beira Interior, Covilhã, Portugal (2018)

Gaspar, P.D., Lima, T.M., Lourenço, M.: Relevant occupational health and safety risks in the portuguese food processing industry. Int. J. Occup. Environ. Saf. **3** (2019)

Gaspar, P.D., Lima, T.M.: OSH Empowerment of Portuguese Agri-food MSMEs through the application of computational tools of risks assessment. In: Arezes P. et al. (eds.) Occupational and environmental safety and health II. Studies in systems, decision and control. Springer, Cham. **277**, 755–763 (2020)

Gul, M.: A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. Hum. Ecol. Risk Assess. Int. J. **24**(7), 1723–1760 (2018)

Karlheinz, S., Ulf, S., Max, B., Michaela, K., Ralph, B.: MultipLa - a tool for the combined overall estimation of various types of manual handling tasks. Work-A J. Prev. Assess. Rehabil. **41**(1), 4433–4435 (2012)

Koppisch, D., Gabriel, S.: The GESTIS Stoffmanager - a tool of the IFA for risk assessment for activities involving hazardous substances. Gefahrstoffe Reinhaltung Der Luft **72**(6), 267–273 (2012)

Lourenço, M., Lima, T.M., Gaspar, P.D., Charrua Santos, F.: Assessment and improvement opportunities for occupational health and safety in the portuguese food processing industry. In: Occupational and Environmental Safety and Health. Studies in Systems, Decision and Control, vol. 202, Springer (2019). https://doi.org/10.1007/978-3-030-14730-3_76

Mehrifar, Y., Zeverdegani, S.K., Faraji, M., Rismanchian, M.: Risk assessment of welders exposure to the released contaminated gases in different types of welding processes in a steel industry. Health Scope **8**(1) (2019)

Mendes, L., Santos, H.B., Ichikawa, E.Y.: Health and safety at work: analysis from the Brazilian documentary film flesh and bone. Saf. Health Work **8**(4), 347–355 (2017)

Mutlu, N.G., Altuntas, S.: Risk analysis for occupational safety and health in the textile industry: integration of FMEA, FTA, and BIFPET methods. Int. J. Ind. Ergon. **72**, 222–240 (2019)

Paun, A.P., Monea, M., Dura, C.: Some practical tools to mitigate occupational safety and health risks within the industrial environment. Qual.-Access Success **20**(1), 429–434 (2019)

Pordata: homepage: https://www.pordata.pt/, last accessed 2019/10/25

Saedi, A.M., Thambirajah, J.J., Pariatamby, A.: A HIRARC model for safety and risk evaluation at a hydroelectric power generation plant. Saf. Sci. **70**, 308–315 (2014)

Tjoe-Nij, E., Rochin, C., Berne, N., Sassi, A., Leplay, A.: Chemical risk assessment screening tool of a global chemical company. Saf. Health Work **9**(1), 84–94 (2018)

Useche, S.A., Montoro, L., Alonso, F., Pastor, J.C.: Psychosocial work factors, job stress and strain at the wheel: validation of the copenhagen psychosocial questionnaire (COPSOQ) in professional drivers. Front. Psychol. **10** (2019)

van Duuren-Stuurman, B., Pelzer, J., Moehlmann, C., Berges, M., Bard, D., Wake, D., Mark, D., Jankowska, E., Brouwer, D.: A structured observational method to assess dermal exposure to manufactured nanoparticles DREAM as an Initial Assessment Tool. Int. J. Occup. Environ. Health **16**(4), 399–405 (2016)

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Analysis of Safety Culture Maturity in Two Finnish Companies

Julius Pirhonen, Sari Tappura, and Aki Jääskeläinen

Abstract Objective: The aim of this study was to analyze perceptions of safety culture in two Finnish industrial companies. Background: The link between safety culture and safety performance has been investigated in many studies. However, understanding of the status of safety culture and the specific needs for development is still limited. Method: A recently developed safety culture maturity model was used to analyze the level of safety culture through a survey of two Finnish companies. A questionnaire was sent to 1109 respondents, 289 of whom completed it (26% response rate). Results: The state of safety culture was rather advanced in both case companies, and the personnel in both companies were overall satisfied with it. However, the analysis indicated considerable differences in safety culture perceptions within the companies. Particularly, top management and safety experts perceived the state of safety culture as more advanced than employees did. Conclusion: There are differences in perceptions of safety culture, especially between top management and employees, which might hinder the development of safety culture in organizations. By understanding such differences within an organization, it is possible to identify appropriate managerial actions for different levels.

Keywords Safety culture · Safety performance · Maturity model · Maturity analysis · Self-evaluation survey

The original version of this chapter was revised. The author's name has been corrected as "Julius Pirhonen", and the corresponding chapter author changed to "Sari Tappura" and the email id corrected to sari.tappura@tuni.fi. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-89617-1_59.

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1 Introduction

Many studies have shown that safety culture (or safety climate) is linked to safety performance (e.g., Carde and Ragan 2003; Lee 1998; Stemn et al. 2019; Vinodkumar and Bhasi 2009). Safety climate scores have been suggested as the most important safety performance indicators (e.g., Hoffmeister et al. 2014). However, safety culture can be difficult to measure, as it concerns individual and group attitudes, beliefs, values, and behaviors related to health and safety in an organization (Hale 2000), which are difficult to quantify. To measure the level of safety culture in an organization, maturity models are often used (Goncalves Filho and Waterson 2018).

Maturity models represent an anticipated, desired, or typical evolution path shaped in discrete stages (Becker et al. 2009). They are valuable measurement instruments because they allow the assessment of the current situation of a company, as well as the identification of obvious development needs (Becker et al. 2009). Maturity of safety can be defined as a certain level of effectiveness and performance in the management of safety and occupational health and safety (Kaassis and Badri 2018). Recently, Jääskeläinen et al. (2020) analyzed the maturity and performance implications of safety performance measurement practices in industrial companies.

Several maturity models have been developed for safety culture evaluation. Goncalves Filho and Waterson (2018) identified 41 different models. Typically, maturity models provide one overall maturity score for an entire organization and do not assess differences between organizational levels (e.g., Goncalves Filho et al. 2010; Jespersen et al. 2016; Tappin et al. 2015). This is probably the result of earlier safety literature, which suggested that a company should have a uniform safety culture across all levels (Hale 2000). However, it is highly questionable whether attitudes are the same at all levels (Guldenmund 2000). Several studies have identified differences in safety culture between organizational levels (e.g., Clarke 1999; Findley et al. 2007; Prussia et al. 2003; Tear et al. 2020). Accordingly, some maturity models attempt to measure the state of safety culture between groups within an organization (e.g., Parker et al. 2006). However, relevant studies are still limited.

To contribute to this research, this study aimed to analyze the state of safety culture in two Finnish industrial companies and to identify differences between organizational levels. To that end, the study employed a recently designed maturity model for safety culture and related survey tool (Tappura et al. in press), which is a synthesis of previous maturity models with verified validity and/or reliability. The model encompasses five main themes:

(1) communication;
(2) training;
(3) organizational learning;
(4) management and supervisor commitment;
(5) employee commitment and involvement.

Unlike previous maturity models, this model evaluates maturity by combining written descriptions of best practices and the perceived satisfaction of employees in the evaluated aspects.

Table 1 Example of the maturity levels of a questionnaire item

Level	Item: "working under pressure"
Level 1	It is common for employees to take shortcuts at the expense of safety when under pressure
Level 2	Employees rarely take shortcuts at the expense of safety when under pressure
Level 3	Employees do not take shortcuts at the expense of safety when under pressure but rarely intervene when someone else does
Level 4	Employees do not tolerate any unsafe behavior even when under pressure

2 Materials and Methods

A self-evaluation survey was conducted in two participating Finnish companies. Company 1 is an infrastructure builder (approximately 1400 staff). Company 2 operates in the chemical industry (approximately 200 staff). The survey tool was assessed by fellow safety researchers and safety experts at the participating companies. Based on their feedback, minor changes were made to the questionnaire to improve clarity and ease of responding. The survey tool was based on a recently designed maturity model for safety culture (Tappura et al. in press).

Invitations to complete an online questionnaire were sent to 1109 respondents, and 289 completed responses were received (26% response rate). Of those, 252 (87) were from Company 1, and 37 (13%) were from Company 2. The respondents were from all organizational levels of the participating companies, from the operative employee level to top management. The responses by respondent group were as follows: top management: 10 (3%); middle management: 41 (14%); supervisors: 60 (21%); safety experts: 9 (3%); administrative employees: 28 (10%); and other employees: 141 (49%).

The questionnaire consisted of 29 items organized in five main themes: (1) communication, (2) training, (3) organizational learning, (4) management and supervisor commitment, and (5) employee commitment and involvement. Each item was measured on a four-level maturity scale with written evaluation criteria of company practices in the questionnaire. The answers were scaled from 1 to 4, where 1 represented the lowest and 4 represented the highest level of maturity (see example in Table 1). Also, in each theme, satisfaction was rated on a 5-point Likert scale, where 1 represented very dissatisfied and 5 represented very satisfied (satisfaction scores).

Based on the safety culture levels and satisfaction scores, the final responses were visualized in a maturity matrix (Jääskeläinen and Roitto 2015). In this matrix, the closer an organization is to the top right corner, the higher its safety culture level is, and the more satisfied with it the organization's members are. The results were discussed with the company representatives, but the further development actions were out of the scope of this study.

Fig. 1 Overall safety culture maturity levels and satisfaction scores of the two case companies (maturity matrix adapted from Jääskeläinen and Roitto 2015)

3 Results

The positions of the two companies in the maturity matrix according to the survey results are shown in Fig. 1. The averages of the two companies were very similar. Both companies had fairly advanced safety practices and were overall satisfied with their respective safety cultures. However, the results showed that there was still room for development regarding the overall safety culture maturity in both organizations. The observed overall safety culture level was slightly below Level 3–that is, below the levels that typically represented a more proactive attitude toward safety (i.e., Levels 3 and 4). The overall satisfaction scores were between 3 and 4, which represented neither satisfied nor dissatisfied and satisfied, respectively. Taken together, the results indicated not only that there was room for improvement but also that the staff perceived a need for development, as suggested by the moderate level of satisfaction.

When the safety culture levels were calculated separately for each theme, the results showed that most themes were at a similar level (Fig. 2). The training theme scored the lowest. Within this theme, the items "training of supervisors" and "training systematization" had the lowest scores. However, satisfaction with training was not lower than the levels of satisfaction in other themes. The employee commitment and involvement theme had the second lowest safety culture level and the lowest satisfaction score. The lowest-scoring items were "employees' actions for safety" and "working under pressure." These results indicated that employees participated in safety development mostly through incident reporting and rarely intervened when others took shortcuts at the expense of safety.

Fig. 2 Average safety culture levels and satisfaction scores for each theme. The error bars represent standard errors

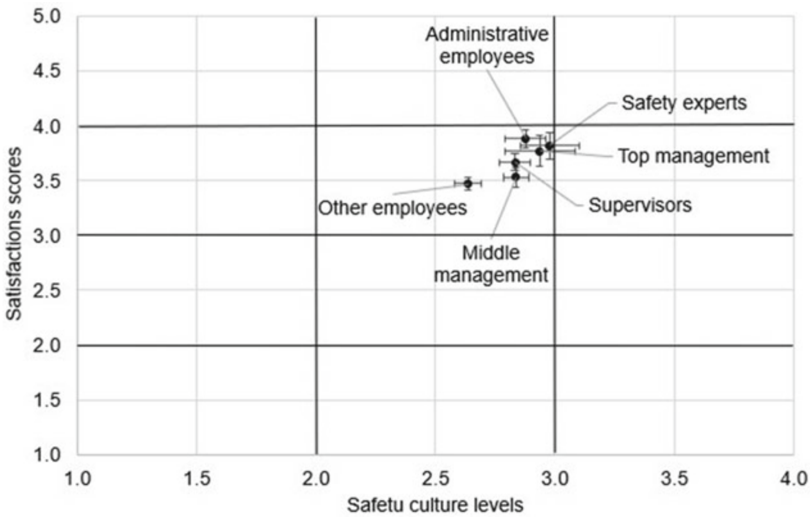

Fig. 3 Overall safety culture maturity levels and satisfaction scores by respondent group. The error bars represent standard errors

When the maturity levels were analyzed according to the respondent groups (Fig. 3), a clear trend emerged. Safety experts and top management were closest to the top right corner of the matrix, supervisors and middle management were in the middle, and employees were separated from the rest and located more on the left. Safety experts and top management clearly had more positive perceptions of safety culture than the other respondent groups did, whereas employees perceived safety culture as less advanced than the other groups did and were less satisfied with it. Thus, perceptions of safety culture seemed to follow the organizational hierarchy.

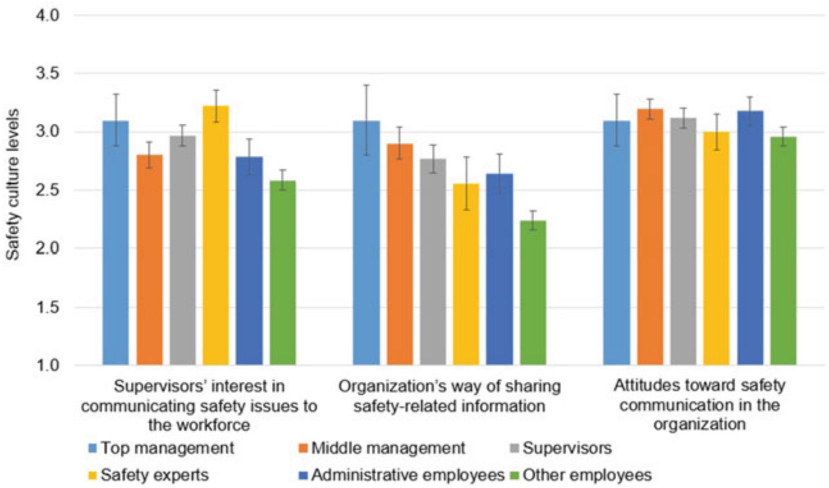

Fig. 4 Average safety culture maturity levels by respondent group in the communication theme. The error bars represent standard errors

These differences were also visible in the responses to the individual items. For example, in the communication theme (Fig. 4), the trend was seen especially in the 'supervisors' interest in communicating safety issues to the workforce" and "organization's way of sharing safety-related information" items. Top management and safety experts perceived a greater interest on the part of supervisors in communicating safety issues than the other groups did. Likewise, top management perceived the way in which safety-related information was shared to be more advanced than the other groups did. These results suggest that the approach to information sharing might be quite advanced at higher organizational levels, but the information does not reach the lower levels. The same trend was observed in most other themes, except for the employee commitment and involvement theme, where the differences between respondent groups were not as large.

The results of each company were also analyzed separately. As seen in Fig. 1, the overall results and the results of each theme were similar. In both companies, top management clearly had a more positive perception of safety culture than the other respondent groups did, and the overall score corresponded to the respondents' position in the hierarchy.

4 Discussion

This study investigated the level of safety culture in two Finnish industrial companies. A recently developed safety culture maturity model (Tappura et al. in press) was used for the analysis. The results showed that the level of safety culture was relatively high, and the participating companies were overall satisfied with it. Nevertheless, the findings suggest that both companies could further develop their respective safety cultures. Particularly safety training practices were not very advanced, even though respondents were quite satisfied with them. Employee commitment and involvement, which is often considered the most safety-critical theme (e.g., Hamid et al. 2008), had the lowest satisfaction score and the second lowest safety culture level.

The results also shed light on the differences in safety culture between organizational levels. The analysis by respondent group revealed significant differences in the perception of safety culture aspects, especially between top management and safety experts on the one hand and employees on the other. The perception of and satisfaction with safety culture seemed to reflect the respondents' hierarchical level. Top management tended to overestimate the state of current practices, especially practices for which top management is responsible (e.g., communication and employee training), whereas employees were the most critical and least satisfied with the safety culture. These results are in line with Clarke (1999), Findley et al. (2007), and Tear et al. (2020), who also reported significant differences in safety culture between organizations' hierarchical levels. A maturity analysis of safety performance measurement practices by Jääskeläinen et al. (2020) indicated the same phenomenon.

Our findings suggest that all organizational levels should be included in safety culture evaluations, and the results should be analyzed separately. When it is not possible to cover an entire organization, the results of one organizational level should not be generalized to the overall state of safety culture in the organization. By understanding the differences within an organization, it is possible to identify more specific ways of improving the safety culture for different organizational levels. For example, by identifying differences in safety communication perceptions between top management and employees, this issue could be addressed with a specific plan to improve the flow of information between levels. Treating safety cultures as uniform across organizational levels may conceal important issues. Although Taras et al. (2009) highlighted this aspect when describing the best practices for culture measurements, this issue remains underexplored in the safety culture literature.

The similar results of the two case companies suggest that the state of safety culture is not industry-dependent. Previous research (e.g., Hale et al. 2010; Killimett 2006; Veltri et al. 2013; Yorio and Wachter 2013) has also indicated that contextual factors (such as the industry or the competitive environment) do not predict safety culture. Other factors, such as leadership, seem to influence safety culture and distinguish successful from unsuccessful organizations.

This study has certain limitations. First, although the results are based on two companies, most responses (87%) were from Company 1. Therefore, the findings may be more representative of that company than of Company 2. Second, both companies were from Finland, which may limit the generalizability of the results. Further qualitative studies using the same maturity model in different regions and with more case companies could enhance the reliability of the results. Finally, the results were concurred with the company representatives, but no further interpretations were made. In further studies, the results could be statistically analyzed to better understand the division of the scores in the different groups, as well as the relationships between different dimensions and overall satisfaction related to safety culture in an organization.

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References

Becker, J., Knackstedt, R., Pöppelbuß, J.: Developing maturity models for IT management. Bus. Inf. Syst. Eng. **1**(3), 213–222 (2009)

Carder, B., Ragan, P.: A survey-based system for safety measurement and improvement. J. Saf. Res. **34**(2), 157–165 (2003)

Clarke, S.: Perceptions of organizational safety: implications for the development of safety culture. J. Organ. Behav. Int. J. Ind. Occup. Organ. Psychol. Behav. **20**(2), 185–198 (1999)

Findley, M., Smith, S., Gorski, J., O'neil, M.: Safety climate differences among job positions in a nuclear decommissioning and demolition industry: Employees' self-reported safety attitudes and perceptions. Saf. Sci. **45**(8), 875–889 (2007)

Goncalves Filho, A., Waterson, P.: Maturity models and safety culture: a critical re-view. Saf. Sci. **105**, 192–211 (2018)

Goncalves Filho, A., Andrade, J., de Oliveira Marinho, M.: A safety culture maturity model for petrochemical companies in Brazil. Saf. Sci. **48**(5), 615–624 (2010)

Guldenmund, F.W.: The nature of safety culture: a review of theory and research. Saf. Sci. **34**(1–3), 215–257 (2000)

Hale, A.R.: Culture's confusions. Saf. Sci. **34**(1–3), 1–14 (2000)

Hale, A.R., Guldenmund, F.W., van Loenhout, P.L.C.H., Oh, J.I.H.: Evaluating safety management and culture interventions to improve safety: effective intervention strategies. Saf. Sci. **48**(8), 1026–1035 (2010)

Hamid, A.R.A., Majid, M.Z.A., Singh, B.: Causes of accidents at construction sites. Malays. J. Civ. Eng. **20**(2), 242–259 (2008)

Hoffmeister, K., Gibbons, A., Johnson, S., Cigularov, K., Chen, P., Rosecrance, J.: The differential effects of transformational leadership facets on employee safety. Saf. Sci. **62**, 68–78 (2014)

Jespersen, L., Griffiths, M., Maclaurin, T., Chapman, B., Wallace, C.: Measurement of food safety culture using survey and maturity profiling tools. Food Control **66**, 174–182 (2016)

Jääskeläinen, A., Roitto, J.: Designing a model for profiling organizational perfor-mance management. Int. J. Product. Perform. Manag. **64**(1), 5–27 (2015)

Jääskeläinen, A., Tappura, S., Pirhonen, J.: Safety performance measurement maturity in finish industrial companies. In: Arezes, P., Babtista, J.S., Barroso, M., Carneiro, P., Cordeiro, P., Costa, N., Melo, R., Miguel, A.S., Perestrelo, G. (eds.) Occupational and Environmental Safety and Health II. Studies in Systems, Decision and Control, vol. 277, pp. 41–49. Springer Nature (2020)

Kaassis, B., Badri, A. (2018). Development of a preliminary model for evaluating occupational health and safety risk management maturity in small and medium-sized enterprises. Safety **4**(5)

Killimett, P.: Organisational factors that influence safety. Process Saf. Prog. **25**(2), 94–97 (2006)

Lee, T.: Assessment of safety culture at a nuclear reprocessing plant. Work Stress **12**(3), 217–237 (1998)

Prussia, G.E., Brown, K.A., Willis, P.G.: Mental models of safety: do managers and employees see eye to eye? J. Saf. Res. **34**(2), 143–156 (2003)

Stemn, E., Bofinger, C., Cliff, D., Hassall, M.: Examining the relationship between safety culture maturity and safety performance of the mining industry. Saf. Sci. **113**, 345–355 (2019)
Tappin, D., Bentley, T., Ashby, L.: An implementation evaluation of a qualitative culture assessment tool. Appl. Ergon. **47**, 84–92 (2015)
Tappura, S., Jääskeläinen, A., Pirhonen, J.: Designing a Maturity Model for Analyzing Safety Culture. Manuscript submitted for publication (in press)
Tear, M., Reader, T., Shorrock, S., Kirwan, B.: Safety culture and power: interactions between perceptions of safety culture, organisational hierarchy, and national culture. Saf. Sci. **121**, 550–561 (2020)
Veltri, A., Pagell, M., Johnston, D., Tompa, E., Robson, L., Amick, B.C., III., Hogg-Johnson, S., Macdonald, S.: Understanding safety in the context of business operations: an exploratory study using case studies. Saf. Sci. **55**, 119–134 (2013)
Vinodkumar, M., Bhasi, M.: Safety climate factors and its relationship with accidents and personal attributes in the chemical industry. Saf. Sci. **47**(5), 659–667 (2009)
Yorio, P.L., Wachter, J.K.: The impact of human performance focused safety and health management practices on injury and illness rates: do size and industry matter? Saf. Sci. **62**, 157–167 (2013)

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Sari Tappura Tampere University, D.Sc. (Tech.) (2018) Tampere University.

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Prevention of Occupational Risks in a Construction Site Using BIM

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Abstract Changing the document commonly used to manage occupational risks in construction in Portugal, the Safety and Health Plan, to the Building Information Modelling (BIM) format will be inevitable, as is already happening with other specialty projects. The management of the construction site is a part of that plan and it is important to obtain good logistic and financial results. However, it is also important due to the risks it creates for workers and third parties. This paper shares the first approach, in Portugal, to using 3D, 4D and 5D BIM to the construction health and safety site management, using a case study, and validates the approach with a comprehensive survey. The conclusions are that this approach allows for a better perception of risks and preventive measures; the improvement of the training level implemented; a better logistic and financial management of the construction site; and, finally, a better integration of prevention in the work planning.

Keywords Site management · Health and safety · BIM

1 Introduction

1.1 Overview

The new Information and Communication Technologies (ICT) have brought about several technical and scientific advancements to the Architecture, Engineering and Construction (AEC) field. Using this new technology, namely Building Information

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Modelling (BIM), for the Occupational Health and Safety (OHS) theme is justified by four key-factors as follows described:

1. Despite several positive evolutions in the construction processes, a large number of accidents at work and occupational diseases continue to occur;
2. Prevention is not always a priority, increasing the risk of accidents at work and occupational diseases. As safety should always be of prime importance, regardless of deadlines and economic interests, a change of mind-set is needed (Tender et al. 2015);
3. The AEC sector is experiencing changes influenced by the need to improve the methods employed in undertaking ever more complex projects with increasingly strict budgets, faster pace of construction and higher quality. BIM tools have become increasingly important as an integrated management tool in the development of Architecture, Structures, and Mechanical, Electrical, Plumbing (MEP) project designs, given their proven advantages (Tender et al. 2018b). The authors of this paper developed and validated BIMSafety concept and shared results through a real case study, one of the first in Portugal (Tender et al. 2018a). In this paper, it is claimed that "in the future, studies should be conducted to verify the applicability of "BIMSafety" to other components of the Health and Safety Plan and the Technical File". This will be one of the objectives of this chapter;
4. For legal and regulatory reasons: Considering the general principles of prevention set forth in the current legislation, attention must be given to the state of the art, namely at the level of ICT.

From all the above reasons, it is clear to see that mechanisms and tools must be created to overcome the identified gaps. To solve the mentioned gaps, this research has as main purposes analysing the implementation of BIM 3D, 4D and 5D for construction site planning and management using in a real case with a verification by survey. Research question were so established: in terms of planning OHS in a construction site, is it BIM 3D, 4D and 5D better than the traditional method?

This section has provided an outline of the context of the study and the technical-scientific gaps. The following sections provide an overview of the relevant literature (Sect. 1.2), the presentation of methodology which includes the details of case study, mainly in terms creation of the BIM model and the survey procedure that was implemented for validating the approach (Sect. 2), the results and its discussion (including its limitations), demonstrating its feasibility and effectiveness (Sect. 3) and the conclusions of the research and future trends (Sect. 4).

1.2 BIM and OHS Risks Prevention

Nowadays, from the analysis of the studies already conducted, it can be concluded that BIM appears to be a valid instrument for the planning of OHS risks prevention (Tender et al. 2017). Below you can find a brief historical review of the main studies already carried out in this field.

Akinci studied the applicability of BIM 4D to safety on site by studying the spaces and accessibility to different workplaces (Akinci et al. 2002a, b, c). Winch used BIM to analyse the concept of "critical areas" trying to optimize the spaces intended for workers (Winch and North 2006). Kim used BIM for temporary equipment planning (Kim and Ahn 2011). Azhar and Behringer performed walk through workplace simulations and risk rendering at the design phase (Azhar and Behringer 2013). Ganah focused on safety planning in a BIM environment (Ganah and Goudfard 2015). Kumar has focused on construction sites with limited available space and on the management of materials therein, and developed a software to optimize material distribution, thus optimizing construction site space management (Kumar and Cheng 2015). Kim added the automation of cost estimates for materials, safety equipment, and scaffolding (Kim et al. 2016). Trani implemented BIM 4D to study the different levels of detail for the various construction site elements (Trani et al. 2015). Biagini applied BIM in a church restoration work, analysing the impact of the tower crane on the neighbourhood as well as the scaffolding used (Biagini et al. 2016). Ji focused on automating the assessment of tower crane collision risk (Ji and Leite 2018).

It should be noted that Publicly Available Specifications (PAS) 1192-6 stresses the improvement of the skills of the designers, a direct opportunity to improve risk mitigation, as well as the need to equate the use of 3D and 4D to support the development of safe methods, including implications for work at height, temporary work (The British Standards Institution 2018).

Construction site management, an element to be included in the HSP, is very important for the correct logistics management of the work, due to its financial impact and dynamic nature, and to the risks it creates for workers and third parties. However, the management of time and space in the construction site is not always very systematic (Choe and Leite 2017), often because of the limitations that two dimensional drawings present.

2 Materials and Methods

2.1 Research Framework

The goal of this research is to analyse the feasibility of using BIM (in its dimensions 3D, 4D and 5D) for planning the construction site using a real case study. A comprehensive research methodology, although simple but criteriously chosen in order to assure an adequate and fruitful research, was established (based in literature review) and consists in four major phases: applying 3D modelling for tridimensional visualization, applying 4D for simulating evolution of construction site planning, testing 5D for cost estimation and implementing a survey (to construction experts) for validating the approach. The use of a combined and user friendly methodology with analysis of real case and an expert's survey should ensure that this approach is based on correct assumptions.

2.2 Case Study

The case study chosen concerns a construction project of a multifamily building in the urban centre of Porto, in an area with a high density of construction and movement of people. OHS analysis will be applied to this case study utilizing BIM tools, with the objective to highlight the advantages of a new method of managing safety in the Portuguese construction industry. Subsequentially, the advantages of this new application will be validated by a survey, with a panel of 31 experts. It was fairly hard to find a work to serve as a case study, because BIM is not yet commonly used in Portugal in this type of works. This research was developed during the design and construction phases and BIM approach was only applied to OHS issues.

2.3 Collaborative Environment and 3D Approach

The collaborative environment used during this study was the "VIEWPOINT FOR PROJECTS" platform. The software chosen for building modelling was Autodesk Revit. The model was loaded and superimposed on a point cloud survey (a tool increasingly used as a facilitator of the planning of the work (Azhar and Behringer 2013)), obtained from photogrammetry using an UAV (unmanned aerial vehicle), so that the survey would provide not only information on the terrain topography but also on the buildings that make up the block, for a correct analysis of the building's impact on its immediate surroundings (New York County Buildings 2013). The final result of the general modelling of the construction site is shown in Fig. 1.

For planning simulation (4D), Autodesk Navisworks. For this purpose, a video was made with a simulation of the evolution of the construction site assembly: as the dates would advance, the tasks being carried out were mentioned and the percentage of the work done could be seen every day. This type of visualization complements the 3D model.

Quantification (5D) and cost allocation for each task/equipment was also performed with Autodesk Navisworks. Figure 2 shows the Map of Works and Quantities (MWQ) obtained for the construction site in question.

2.4 Validation Survey

In order to assess the relevance of this approach in the practical case, a survey was conducted on a panel of construction industry experts previously chosen from

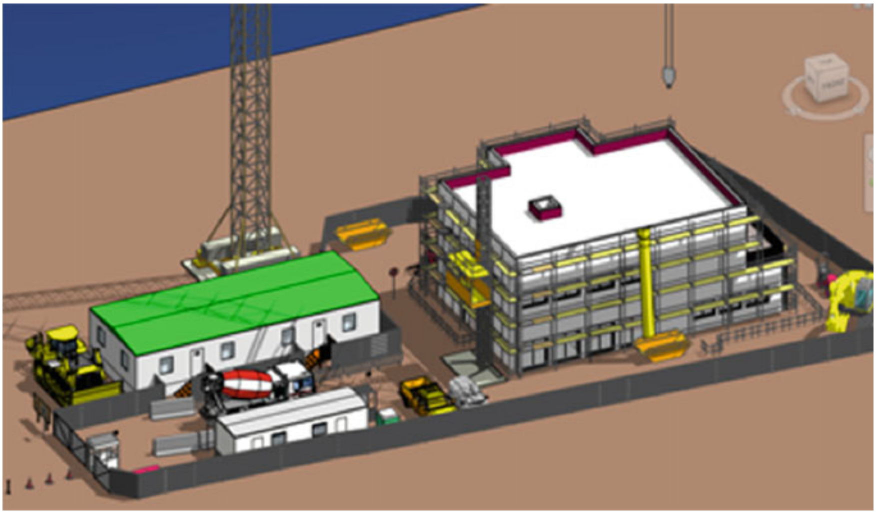

Fig. 1 Final result of site modelling

Cap.	Descrição de trabalhos	UN	Quantidades	Val.unit.	Valores totais
1	**PREPARAÇÃO DO ESTALEIRO**				
1.1	Demolições e remoção de elementos existentes	Vg	1,0	500,00	500,00 €
1.2	Desmatação e Limpezas	m2	2 100,00	5,00	10 500,00 €
1.3	Fornecimento e instalação de Betão para lajes de fundação de Grua e	m3	12,34	100,00	1 234,00 €
2	**VEDAÇÕES, GUARDAS E ANDAIMES**				0,00 €
2.1	Montagem modulos de vedação metálica 2x2,1 mt incluindo postes	Un	168,00	15,00	2 520,00 €
2.2	Montagem de modulos 2,5x2,1 para portão incluindo postes	Un	3,00	200,00	600,00 €
2.3	Montagem de guarda corpos incluindo prumos e tábuas	Un	55,00	10,00	550,00 €
2.4	Montagem de barreiras divisórias de 1mt de altura	ml	13,25	10,00	132,50 €
2.5	Montagem de andaimes				0,00 €
2.5.1	no piso 0	Un	56,00	25,00	1 400,00 €
2.5.2	no piso 1	Un	42,00	25,00	1 050,00 €
3	**SINALIZAÇÃO**				0,00 €
3.1	Instalação de barreira de trafego à entrada do estaleiro	Vg	1,00	100,00	100,00 €
3.2	Fornecimento de cones de trafego	Un	9,00	50,00	450,00 €
3.3	Fornecimento de New Jerseys para organização de trafego	Un	6,00	120,00	720,00 €
3.4	Fornecimento e instalação de sinalização vertical	Un	5,00	75,00	375,00 €
4	**INSTALAÇÕES DE APOIO**				0,00 €
4.1	Montagem de contentores para escritorio	m2	133,80	40,00	5 352,00 €
4.2	Montagem de contentores para armazém de apoio à obra	m2	30,00	40,00	1 200,00 €
4.3	Instalação de Passadiço Coberto no acesso ao contentor de apoio	ml	12,00	30,00	360,00 €
5	**EQUIPAMENTOS (mobilização)**				0,00 €
5.1.1	Bulldozer	Un	1,00	3 000,00	3 000,00 €
5.1.2	Cilindro	Un	1,00	2 500,00	2 500,00 €
5.1.3	Contentor de Residuos	Un	1,00	1 500,00	1 500,00 €
5.1.4	Escavadora	Un	1,00	2 400,00	2 400,00 €
5.1.5	Geradores	Un	1,00	2 000,00	2 000,00 €
5.1.6	Giratória	Un	1,00	2 400,00	2 400,00 €
5.1.7	Grua	Un	1,00	4 500,00	4 500,00 €
5.1.8	Monta Cargas	Un	1,00	1 900,00	1 900,00 €
5.1.9	Equipamento de iluminação	Un	1,00	1 250,00	1 250,00 €
5.1.10	Manga de Residuos	Un	1,00	1 100,00	1 100,00 €
	TOTAL (Euros)				**49 593,50 €**

Fig. 2 Map of works and quantities obtained

Table 1 Survey questions

The way this construction site plan is presented (compared to the traditional way and regarding risk prevention), with regard to...	Equal	Better	Much better
Q1 - the (3D) visualization of construction site facilities, is...			
Q2 - planning (4D), is...			
Q3 - quantities/cost control (5D), is...			
Q4 - commonly used in the traditional method, is...			

the author's network. The sampling technique used had the objective of creating a random sample, with the inclusion of the only restriction that all selected members of the panel had a minimum previously defined experience in order to ensure the collection of a sufficiently sustained and credible vision and at the same time being representative of the general population. The panel was selected after a first approach with a broader set in order to assess the availability to respond and above all the affinity and interest in the subject under study. From the 31 positive answers in first approach, the survey was sent to all these 31 specialists. There was a concern to choose a sample of professionals to answer the survey and a case study regarding the multifamily construction building that were as representative as possible, not forgetting that this is the first phase of a study that will be followed up. The survey aimed to assess the usefulness of using the 3D, 4D and 5D dimensions of BIM in construction site management. The survey and description of case study was sent via email to a panel of experts with at least 5 years of experience in the field of construction (in the fields of prevention, production, design and academy). All the elements and clarifications requested by the specialists were provided in order to have the best possible knowledge about the project. It was obtained 31 valid answers. 35.5% of the respondents in the panel work in prevention, 25.8% in work management (production), 29.0% in design, and 9.7% in academic field, with an average of 16.5 years of professional experience (far exceeding the minimum stipulated experience). The following data were presented and explained to the respondents: various 3D print-screens, the 4D /simulation video of the construction site assembly, and the MWQ. The survey consisted of four questions (Table 1): one about each of the BIM dimensions studied (3D, 4D and 5D), and a final question of overall appreciation. Possible answers to each question were "Equal", "Better" and "Much better".

In a scenario of a very low implementation phase of BIM in this area, this type of approach also intended, beyond obtaining the general perception of respondents about use of BIM for Health and Safety, to show and raise awareness among stakeholders about this theme. Thus, it was understood that the approach that was adopted for this phase would be appropriate, and the treatment of data and analysis of results would adequately respond to the established assumptions and objectives.

3 Results and Discussion

The results were analysed in an aggregate way not differentiating the work fields of respondents. The results obtained in the case study and survey are analysed and discussed below.

Regarding each of the dimensions analysed, the advantages found by the authors in the implementation of the case study are mentioned first; then, the survey results are presented in addition:

- **3D Dimension** - The results obtained in the case study show that this approach allows a visualization of both the facilities (and their areas) and the tasks which is wider and closer to reality, done sooner, in a more understandable way (namely regarding temporary works), and is less ambiguous than by using two dimensional drawings. It is also possible to identify the areas with the highest level of risk. It is also found that this type of visualization, simple to read, provides a better perception and identification of the various elements of the construction site. This approach also improves planning capacity (notably in tasks related to the movement of equipment in the site and tower crane movements) and facilitates the geometric changes to be made, and any change made for reasons related to the production area of the work implies a change in preventive terms, which is quite simple to make automatically. It takes less time to identify hazards and risks, and preventive measures to be implemented, in each working place. The approach also enables a better identification of areas or times when there is a higher level of risk, namely of runovers (especially in the pathways to the construction site), fall of objects from a higher level (within the crane's radius of influence), and fall of people to a lower level. Another of the advantages identified in the case study was the fact that it also becomes easier to identify potential constraints, both in the workspace and in the surroundings. In terms of communication on the construction site, this instrument is validated as being useful both for training and awareness raising activities for workers, and for communicating with those responsible for the installation and operation of the construction site, minimizing or eliminating the typical "communication conflicts". In terms of site inspection, it made it easier to compare was expected to what was done.
  Regarding the survey results, the vast majority of respondents (88%) considered this approach to be "Much better" than the traditional one, validating the opinion of researchers.
- **4D Dimension** - This approach allows for a better planning, stemming from an earlier, more structured, and less abstract approach to tasks, making the process closer to the reality, objectifying the steps of each task in a virtual environment, improving and optimizing the movements of machinery as well as the use of spaces and volumes (and their execution times), and clearly showing the assembly sequence from a safety point of view, reducing the need for improvisation or last-minute solutions. The simulation of the task sequence allowed to identify several scenarios in advance, especially in situations stemming from changes in the construction site organization, or at critical times when, due to overlapping activities, there is a

highlight or increase of the level of risks, for example of runovers, or where there is a spatial mismatch of tasks, allowing for a fast reassessment of the situation. It also allows to assess the movements in the surroundings of the construction site, and which interfere with the surroundings.
With regard to the survey results, the 4D dimension is less valued than the 3D visualization dimension. Still, most respondents (60%) consider it to be "Much better" than the traditional approach, thus also validating the researchers' perception of this dimension.
- **5D Dimension** - The automated quantity extraction (which is impossible to do with the traditional process) gives a fast listing at any given time (especially when faced with changes to the construction site structure or site planning) of the installed preventive elements such as guardrails, barriers, signs. With this automation in linking the protection equipment to its respective costs, it becomes possible to separate, in the tender dossier, the different protection equipment to be used, instead of applying the usual "price per global value", thus solving the "old" problem of the lack of quantification of prevention items, and creating an instrument with great potential to minimize unfair competition in Portugal. It was also shown in the case study that it is possible to simulate several cost solutions, thus allowing to optimize the most favourable financial scenario. During the survey, a less favourable point was made, something that will improve in the future: the phases of maintenance and disassembly were not addressed.
With regard to the survey results, it is found that this dimension was considered "Much better" by 44% of the respondents. This, combined with the 31% of respondents who considered it "Better" is still quite acceptable as a figure (75%), thus also validating the researchers' perception of this dimension.
- **Global Opinion** - This question summarizes the whole research, as well as the whole purpose of the survey. In the survey responses, it is possible to see that the totality of the respondents (100%) consider that this approach is "Better", or "Much better", than the traditional one, based on two dimensional drawings, thus showing the suitability of the proposal.

Figure 3 shows the results obtained through the survey of the aforementioned panel of experts.

4 Conclusions

There has been a broad increase in understanding and interest in applying BIM to the area of prevention of occupational risks. However, using BIM in this area is not yet a reality harnessed by companies (despite some legislative and normative initiatives in some countries), namely in Portugal. The results obtained show that the methodology was implemented appropriately based on the established objectives. Observing the results obtained, it can be seen that they have been well received by the technical

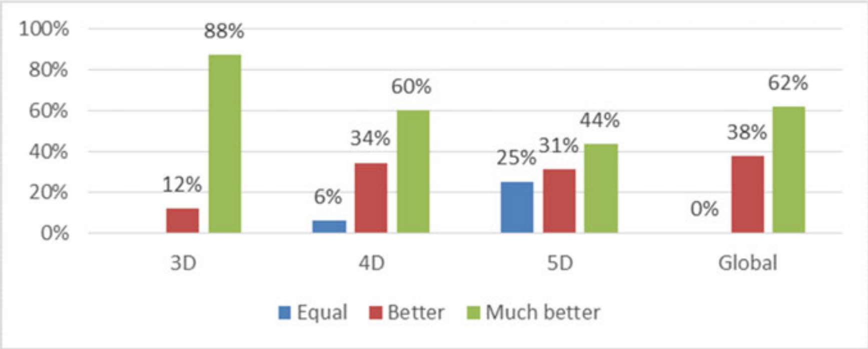

Fig. 3 Results obtained

community, which reinforces and validates the results of previous studies. It can then be concluded that:

- In terms of planning and managing OHS in a construction site, BIM 3D, 4D and 5D appear to be more appreciated than the traditional method;
- The survey shows that, regarding the four questions, an absolute majority of the panel of respondents consider that the approaches adopted are actually better than the traditional methodologies, with the 3D dimension of BIM proving to be the most appealing for the respondents;
- The results obtained in this case study show that this approach can revolutionize the creation of construction site plans (an essential part of the Safety and Health Plans), leading to a paradigm shift with great potential to prevent occupational accidents (due to its influence on risk identification and preventive measures implementation, with regard to communicative, training, implementation, and inspection aspects). It is also noted that this approach has the potential to bring OHS and production closer together and to streamline the analysis procedure, the technical validation by the Safety and Health Coordinator at the construction stage, and the approval by the Work Owner, in accordance with current legislation;
- Tests should be carried out to determine the best mode of parameterization, of a preventive nature, clarifying the various perspectives still existing internationally, namely in PAS1192:6;
- Institutions should join efforts to create an international normative document for the transmission and use of preventive information using BIM.

Limitations were found during this research, such as following described:

- Lack of experience in the modelling skills as this is a recent way of designing and building;
- Lack of total ability of two or more systems to exchange information and interpret them, then use the information (interoperability);
- Lack of information sharing or knowledge on how to share information effectively;

- Sample size of the survey and the impossibility of addressing other complementary aspects;
- Multifamily construction project: a construction project with more significant safety issues would have been better to show the effectiveness of BIM tools; future research can pursue this objective.

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References

Akinci, B., Fischen, M., Levitt, R., Carlson, R.: Formalization and automation of time-space conflict analysis. J. Comput. Civ. Eng. **16**(2), 124–134 (2002a)

Akinci, B., Fischer, M., Kunz, J.: Automated generation of work spaces required by construction activities. J. Constr. Eng. Manag. **128**(4), 306–315 (2002b)

Akinci, B., Fischer, M., Kunz, J., Levitt, R.: Representing work spaces generically in construction method models. J. Constr. Eng. Manag. **128**(4), 296–305 (2002c)

Azhar, S., Behringer, A.: A BIM-based approach for communicating and implementing a construction site safety plan. In: Paper presented at the 49th ASC Annual International Conference Proceedings, Califórnia, EUA (2013)

Biagini, C., Capone, P., Donato, V., Facchini, N.: Towards the BIM implementation for historical building restoration sites. Autom. Constr. **71**(1), 74–86 (2016)

Choe, S., Leite, F.: Construction safety planning: site-specific temporal and spatial information integration. Autom. Constr. **84**, 335–344 (2017). https://doi.org/10.1016/j.autcon.2017.09.007

Ganah, A., Goudfard, J.: Integrating building information modeling and health and safety for onsite construction. Saf. Health Work **6**(1), 39–45 (2015). https://doi.org/10.1016/j.shaw.2014.10.002

Ji, Y., Leite, F.: Automated tower crane planning: leveraging 4-dimensional BIM and rule-based checking. Autom. Constr. **93**, 78–90 (2018). https://doi.org/10.1016/j.autcon.2018.05.003

Kim, H., Ahn, H.: Temporary facility planning of a construction project using BIM (Building Information Modeling) Computing in Civil Engineering, pp. 627–634 (2011)

Kim, K., Cho, Y., Zhang, S.: Integrating work sequences and temporary structures into safety planning: automated scaffolding-related safety hazard identification and prevention in BIM. Autom. Constr. **70**, 128–142 (2016). https://doi.org/10.1016/j.autcon.2016.06.012

Kumar, S., Cheng, J.: A BIM-based automated site layout planning framework for congested construction sites. Autom. Constr. **59**, 24–37 (2015). https://doi.org/10.1016/j.autcon.2015.07.008

New York County Buildings.: Building Information Modeling Site Safety Submission Guidelines and Standards. New York City Department of Buildings, New York (2013)

Tender, M., Couto, J., Ferreira, T.: Prevention in underground construction with sequential excavation method. In: Arezes et al. (Ed.), Occupation Safety and Hygiene III, pp. 421–424. Taylor & Francis, London, United Kingdom (2015)

Tender, M., Couto, J., Fernandes, J.: Using BIM for risk management on a construction site. In Arezes et al. (Ed.), Occupational Safety and Hygiene V, pp. 269–272. CRC Press/Balkema, London, United Kingdom (2017)

Tender, M., Couto, J. P., Lopes, C., Cunha, T., Reis, R.: BIM (Building Information Modelling) as a prevention tool in the design and construction phases. In: A. et al. (Ed.), Occupational Safety and Hygiene VI. Taylor & Francis, Londres (2018a)

Tender, M., Couto, J.P., Reis, R., Monteiro, P., Rocha, T., Delgado, T., Vicente, G.: BIM as a 3D, 4D and 5D management tool in a construction site. Paper presented at the 2nd Portuguese BIM Congress, Lisbon, Portugal (2018b)

The British Standards Institution.: Publicly available specification PAS 1192-6 - Specification for collaborative sharing and use of structured Health and Safety information using BIM (2018)

Trani, M., Bossi, B., Cassano, M., Todaro, D.: BIM oriented equipment choice on construction site. In: Proceedings of International Structural Engineering and Construction(2) (2015). https://doi.org/10.14455/ISEC.res.2015.209

Winch, G., North, S.: Critical space analysis. J. Constr. Eng. Manag. **132**(5), 473–481 (2006)

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Improving Occupational Health and Safety Data Integration Using Building Information Modelling

An Initial Literature Review

Manuel Tender, João Pedro Couto, and Paul Fuller

Abstract The main objective of this paper is to address the technical-scientific gap identified in the literature by presenting an overview of the existing coverage of the use of BIM (Building Information Modelling) for Occupational Health and Safety (OHS) management. The Scopus and Web of Science research literature databases were selected as the most suitable for the literature review. Appropriate keywords were identified and a search in each of the databases was performed, resulting in a satisfactory number of papers. Priority was given to papers from sources with peer review and a high impact factor. The main findings reveal the areas where BIM related digital technologies are being applied to improve H&S management outcomes. This work fills a gap in the existing literature and provides a platform for the development of improved safety management systems resulting in more efficient H&S processes and increased productivity which will provide a stronger link between production and safety. The number of research studies will increase as people realize the importance of OHS in the digital data environment and recognize the advantages of using BIM and related technologies. Future research should explore in more detail some of the areas identified and establish the benefits of using digital technologies to improve OHS outcomes. New emerging technologies such as Virtual Reality, Augmented Reality, Internet of Things, Big Data, Artificial Intelligence and their integration with BIM will certainly become essential areas of research in the future.

Keywords BIM · Health · Safety · Risks · Review

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1 Introduction

BIM has now evolved into and mature methodology, and is the most visible face of the 4th Industrial Revolution in AECO (Architecture, Engineering, Construction and Operations). In fact, BIM is a collaborative methodology encompassing the whole life cycle of the project covering design and construction through to operation and maintenance (O&M) It enables the digital representation of physical and functional features of a building which can then be accessed remotely and collaboratively. BIM is currently considered to be a shared model made up of a set of 3D objects and parameterized information that is updated throughout the project's life cycle and is accessible directly by the project owner, the designer, the contractors, the suppliers, the consultants, etc. Using BIM all the stakeholders can communicate and exchange information in real-time through a virtual environment. This means that information can be shared without the need to use written documents as all of the actors have direct access to a centralized model which ensures that all stakeholders have immediate access to the latest version of any document. The use of BIM in construction is now widespread mostly in architecture, structures, or mechanical/electrical/plumbing (MEP). It is not, however, very widely used for OHS purposes. Existing literature shows that the lack of OHS information in digital form is one of the many factors contributing to the poor performance of OHS management in the construction industry.

Due to the rapid development and adoption of BIM the use of digital technologies for risk management has become a growing research trend. This has led to demands for a complete review of the state of the art of these technological developments focused on BIM in general and also on usages of BIM for OHS. Some authors have already explored and reviewed the potential areas where BIM can be applied in OHS settings (Table 1).

The main objective of this paper is to address the technical-scientific gap identified in the literature by presenting an overview of the existing literature covering the use of BIM for OHS management. The review will identify the main areas where BIM can be applied to improve OHS outcomes. The following section outlines the methods that were used for literature review. The next section covers the results and the final section outlines the conclusions, explores limitations, and identifies future trends.

1.1 Review Methodology

A number of research databases were examined and the Scopus and Web of Science databases were selected as the most suitable. Appropriate keywords were identified and a search in each of the databases was performed, resulting in a satisfactory number of papers After identifying the keywords, a simple search was performed in each of the databases, obtaining adequate results. In order to ensure that the articles

Table 1 Published literature reviews

Year	Author	Paper title
2020	Fargnoli and Lombardi	Building Information Modelling (BIM) to enhance occupational safety in construction activities: research trends emerging from one decade of studies
2019	Mihić et al.	Review of previous applications of innovative information technologies in construction health and safety
2019	Akram et al.	Exploring the role of building information modeling in construction safety through science mapping
2019	Jin et al.	A science mapping approach based review of construction safety research
2018	Martínez-Aires et al.	Building information modeling and safety management: A systematic review
2017	Aguilera	Review of the state of knowledge of the BIM methodology applied to health and safety in construction
2017	Zou et al.	A review of risk management through BIM and BIM-related technologies
2016	Hallowell et al.	Information technology and safety: Integrating empirical safety risk data with building information modeling, sensing, and visualization technologies
2015	Ganah and Goudfard	Integrating Building Information Modeling and Health and Safety for Onsite Construction
2012	Zhou et al.	Construction safety and digital design: A review
2011	Azhar	Building Information Modeling (BIM): Trends, benefits, risks and challenges for the AEC Industry

studied were credible priority was given to primary sources, particularly those with peer review.

The key words used were: "BIM" or "Building Information Modelling"; "Safety" and "Risks". The following types of sources were used in the search:
(1) articles published in international publications (preference given to reputed magazines such as Automation in Construction, Safety Science, Journal of Safety Research, International Journal of Project Management, Journal of Computing in Civil Engineering, Construction; Construction Management and Economics; Engineering, Construction and Architectural Management; Information Technology in Construction; Journal of Architectural Engineering; Journal of Construction Engineering and Management; Reliability Engineering & System Safety);
(2) books by renowned publishers;
(3) proceedings of conferences on the theme;
(4) legal and normative documents;
(5) academic theses and dissertations;
(6) Institutional reports.

To optimize the bibliographic review the following document screening criteria were established: written in Portuguese or English; works published after 2007 (within these, priority was given work published less than 5 years ago); evaluated by peers; and of recognized prestige. It should be noted, however, that some older publications were also included due to their high relevance to the topic. Papers with a focus on structural safety and fire safety were excluded.

The abstracts of all those documents identified were reviewed to assess whether the content of the paper fell within the scope of the research being undertaken. Papers that were in scope were then reviewed and analysed. The bibliographies and references in the articles initially read were also reviewed and additional relevant articles were identified. Finally, all the documents used were added into Endnote and any duplications were eliminated. After all these stages a total of 78 papers were identified as being suitable for further analysis.

In this chapter, the authors chose to categorize areas where BIM can be applied to OHS into the following ones using as a starting point the main areas described in Council Directive 92/57/EEC (on the implementation of minimum safety and health requirements in temporary construction sites). To cover all the requirements of the Directive, six groups were used (1) risk identification and assessment; (2) training; (3) site planning; (4) tasks planning; (5) emergency planning and accident investigation; 6) rule checking.

2 Results and Discussion

2.1 Risk Identification and Assessment

A number of authors have carried out research on this theme. Kamardeen focused on the design phase and on understanding the safety risks and consequences using automated risk detection (Kamardeen 2010). Zhang developed an automated risk identification process covering the design and construction planning stages (Zhang et al. 2012). Malekitabar studied the analysis of accident drivers linked with safety rules based on BIM (Malekitabar et al. 2016). Mihic studied the requirements for using risk and hazard databases based on BIM (Mihić et al. 2018). Deng explored the use of risk assessment databases and safety management modules based on the development of the Revit platform for identifying relevant risk sources (Deng et al. 2019). Perez focused on the integration of the OHS risk assessment in building projects using BIM by considering a specific OHS subdiscipline in the model (Pérez et al. 2017).

2.2 Training

Godfaurd proposed a framework for integrating BIM technology and planning software for OHS site inductions (Godfaurd and Abdulkadir 2011). Ganah focused on BIM usage for project communication purposes (Ganah and Goudfard 2015). Kiviniemi addressed the use of multi -wall virtual reality room (CAVE) for analysing interactively the 3D and 4D models from a site safety viewpoint (Kiviniemi et al. 2011).

2.3 Site Planning

Several Authors Have Studied the Use of BIM for Site OHS Planning:
Chau created a 4D model for planning daily activities more efficiently (Chau et al. 2004). Sulankivi worked on 3D and 4D models in order to manage site layout risk zones during crane operations (Sulankivi et al. 2009). Sulankivi investigated how to implement site planning and fall protection using BIM (Tekla Structures) by linking construction schedules to building components, temporary structures, and site production equipment (Sulankivi et al. 2010). Kiviniemi used 4D BIM models for managing and communicating construction safety plans, namely site layout and anti-crane collapse plans, visualization of wall demolition, modelling of safety railing, formwork planning with integrated fall protection, and a design for checking safety model (Kiviniemi et al. 2011). The New York City Department of Building (NYC-DOB) process for submission of site plans can still be considered the best example for managing site planning permissions (New York County Buildings 2013). Vimonsatit showed how BIM tools can be used for construction site layout planning and simulation using 3D models (Vimonsatit and Lim 2014). Yi proposed including site safety planning in project schedule based on temporal and spatial inputs, maximizing analysis of periods and zones in terms of safety (Yi et al. 2015). Cassano developed criteria for a level of development (LOD) scale for construction site temporary elements (Cassano and Trani 2017). Trani developed a database for integration of construction site design during the design stage with several detail levels for BIM site objects (Trani et al. 2015). Choe proposed a proactive site safety planning framework based on temporal and spatial inputs, integrating activity safety data with a project schedule and a 3D model (Choe and Leite 2017).

2.4 Task Planning

Several authors have been carrying out research covering the integration of OHS works planning using BIM: Akinci created various types of space occupation in 4D BIM for automated workspace conflict identification (Akinci et al. 2002). Chantawit used 4D to perform risk identification (Chantawit et al. 2005). Winch used BIM to explore and optimize critical zones in construction sites (Winch and North 2006). Kiviniemi developed a detailed framework for fall protection modelling and 4D visualisation, including the modelling of the temporary and permanent safety structures and equipment needed to carry out safe construction and O&M works (Sulankivi et al. 2009). Sulankivi focused on the implementation of safety measures such as guardrails in the model (Sulankivi et al. 2010). Kiviniemi studied specific activities i.e. site layout, crane collapse risk, wall demolition, activities with fall form heights risk (Kiviniemi et al. 2011). Eastman showed two practical examples of safety planning through BIM related to safety perimeters (Eastman et al. 2011). Chi developed specific BIM objects for temporary construction activities covering modularised scaffolding and formwork objects (Chi et al. 2012). Azhar studied the use of BIM technology to perform safety planning and management in a case study that focused on crane management, excavation risk management, fall protection for leading edges, fall protection for roofers and emergency response plans (Azhar et al. 2012). Zhang focused on automatically detecting falling hazards and setting up preventive measures (Zhang et al. 2012). Zhang focused on detecting workspace conflicts by analysing the geometric conditions of different phases of the workspace to identify workspace congestion and safety hazards (Zhang et al. 2015). Bargstad focused on identifying challenges to site planning (Bargstädt 2015). Choe formalized a case study 4D construction safety planning process using a case study that focused on temporal and spatial safety information integration (Choe and Leite 2017). Feng carried out research into risks in scaffold management using Dynamo to automate risk identification (Feng and Lu 2017). Wang implemented scaffold safety (guard-rails and toe-boards) checking using 3D point cloud data (Wang 2019).

2.5 Emergency Planning and Accident Investigation

Emergency planning, one of the least studied areas on BIM for OHS, using BIM has been studied by some authors. Marzouk studied a framework for planning evacuation of workers using BIM to estimate evacuation times (Marzouk and Daour 2018). Some authors have carried out research on accident investigation. Marks studied collection of near misses using a specific BIM report database (Marks and Shen 2016).

2.6 Rule Checking

Several authors have already conducted research on using rule-checkers for OHS purposes: Based on a 4D model case study, Benjaoran used a rule-based system to identify hazardous situations in working at height, establish preventive measures and included them in 4D planning (Benjaoran and Bhokha 2010). Qi designed a prototype for safety checking that automatically identify fall hazards in a BIM model and provide design alternatives (Qi et al. 2011). Shih explored a BIM-enabled rule-checking system to help identify and mitigate OHS risks (Shih et al. 2012). Sulanikivi researched risk identification during early planning phases and developed a rule checker which was tested on a residential building project in Finland (Sulankivi et al. 2013). Wang created a rule checking tool for identifying fall and cave-in hazards in excavation activities (Wang et al. 2015). Hongling performed the integration of design safety codes and OSHA regulations with BIM in order to automatically identify safety issues (Gyorgy and Fogarasi 2015; Hongling et al. 2016). Getuli proposed a validation workflow using a parametric ruleset, to establish minimum requirements for construction site layout submissions (Getuli et al. 2017). Schwabe studied rules for verifying site planning (Schwabe et al. 2019). Hossain implemented an automated fall safety checking system in the planning phase (Hossain and Ahmed 2019).

3 Conclusions

This paper reveals the areas where BIM related digital technologies are being applied to improve OHS management. It fills a gap in the existing literature and provides a platform for the development of improved safety management systems. These will lead to quicker and better prevention planning resulting in more efficient OHS processes and increased productivity which will provide a stronger link between production and safety. Future studies will include references to some of the outputs described in the papers that were reviewed. The number of research studies will increase as people realize the importance of OHS in the digital data environment and recognize the advantages of using BIM and related technologies. The main limitation of this study is the vast number of topic areas covered, each of which would justify a whole chapter. In terms of future research, further work should be considered which explores in more detail some of the areas identified and establishes the benefits of using digital technologies to improve OHS outcomes. New emerging technologies such as Virtual Reality, Augmented Reality, Internet of Things, Big Data and Artificial Intelligence and their integration with BIM will certainly become essential areas of research in the future.

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References

Aguilera, A.: Review of the state of knowledge of the BIM methodology applied to health. In: Arezes et al. (eds.) Occupational Safety and Hygiene V, pp. 447–452. CRC Press/Balkema, Londres, Inglaterra (2017)

Akinci, B., Fischen, M., Levitt, R., Carlson, R.: Formalization and automation of time-space conflict analysis. J. Comput. Civ. Eng. **16**(2), 124–134 (2002)

Akram, R., Thaheem, M., Nasir, A., Ali, T., Khan, S.: Exploring the role of building information modeling in construction safety through science mapping. Saf. Sci. **120**, 456–470 (2019). https://doi.org/10.1016/j.ssci.2019.07.036

Azhar, S.: Building information modeling (BIM): trends, benefits, risks and challenges for the AEC Industry. J. Leadersh. Manag. Eng. Sci. **11**(3) (2011). https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Azhar, S., Behringer, A., Sattineni, A., Maqsood, T.: BIM for facilitating construction safety planning and management at jobsites. In: Paper presented at the CIB W099 International Conference Modeling Building Health Safety, Singapura (2012)

Bargstädt, H.: Challenges of BIM for construction site operations. Procedia Eng. **117**, 52–59 (2015). https://doi.org/10.1016/j.proeng.2015.08.123

Benjaoran, V., Bhokha, S.: An integrated safety management with construction management using 4D CAD model. Saf. Sci. **48**(3), 395–403 (2010). https://doi.org/10.1016/j.ssci.2009.09.009

Cassano, M., Trani, M.: LOD standardization for construction site elements. Procedia Eng. **196**, 1057–1064 (2017). https://doi.org/10.1016/j.proeng.2017.08.062

Chantawit, D., Hadikusumo, B., Charoenngam, C., Rowlinson, S.: 4DCAD-Safety: visualizing project scheduling and safety planning. Constr. Innov. **5**(2), 99–114 (2005). https://doi.org/10.1108/14714170510815203

Chau, K., Anson, M., Zhang, J.: Four-dimensional visualization of construction scheduling and site utilization. J. Constr. Eng. Manag. **130**(4), 598–606 (2004). https://doi.org/10.1061/(ASCE)0733-9364(2004)130:4(598)

Chi, S., Hampson, K., Biggs, H.: Using BIM for smarter and safer scaffolding and formwork construction: a preliminary methodology. In: Paper presented at the CIB WO99 International Conference on Modelling and Building Health and Safety Singapore (2012)

Choe, S., Leite, F.: Construction safety planning: site-specific temporal and spatial information integration. Autom. Constr. **84**, 335–344 (2017). https://doi.org/10.1016/j.autcon.2017.09.007

Deng, L., Zhong, M., Liao, L., Lai, S., Peng, L.: Research on safety management application of dangerous sources in engineering construction based on BIM technology. Adv. Civ. Eng. **3**, 1–10 (2019). https://doi.org/10.1155/2019/7450426

Eastman, C., Teicholz, P., Sacks, R., Liston, K.: BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors: Wiley (2011)

Fargnoli, M., Lombardi, M.: Building Information Modelling (BIM) to enhance occupational safety in construction activities: research trends emerging from one decade of studies. Buildings **10**(6) (2020). https://doi.org/10.3390/buildings10060098

Feng, C., Lu, S.: Using BIM to automate scaffolding planning for risk analysis at construction sites. In: Paper presented at the 34th International Symposium on Automation and Robotics in Construction, Taipe, Taiwan (2017)

Ganah, A., Goudfard, J.: Integrating building information modeling and health and safety for onsite construction. Saf. Health Work **6**(1), 39–45 (2015). https://doi.org/10.1016/j.shaw.2014.10.002

Getuli, V., Ventura, S., Capone, P., Ciribini, A.: BIM-based code checking for construction health and safety. Procedia Eng. **196**, 454–461 (2017). https://doi.org/10.1016/j.proeng.2017.07.224

Godfaurd, J., Abdulkadir, G.: Integrating BIM and planning software for health and safety site induction. In: Paper presented at the The Royal Institution of Chartered Surveyors International Research Conference, University of Salford, Inglaterra (2011)

Gyorgy, P., Fogarasi, I.: Management of effective use of urban underground space. In: Kolic, D. (ed.) SEE Tunnel: Promoting tunneling in SEE Region, pp. 694–695. Hubitg, Dubrovnik, Croácia (2015)

Hallowell, M., Hardison, D., Desvignes, M.: Information technology and safety: integrating empirical safety risk data with building information modeling, sensing, and visualization technologies. Constr. Innov. **16**(3), 323–347 (2016). https://doi.org/10.1108/CI-09-2015-0047

Hongling, G., Yantao, Y., Weisheng, Z., Yan, L.: BIM and safety rules based automated identification of unsafe design factors in construction. Procedia Eng. **164**, 467–472 (2016)

Hossain, M., Ahmed, S.: Developing an automated safety checking system using BIM: a case study in the Bangladeshi construction industry. Int. J. Constr. Manag. (2019). https://doi.org/10.1080/15623599.2019.1686833

Jin, R., Zou, P., Piroozfar, P., Wood, H., Yang, Y., Yan, L., Han, Y.: A science mapping approach based review of construction safety research. Saf. Sci. **113**, 285–297 (2019). https://doi.org/10.1016/j.ssci.2018.12.006

Kamardeen, I.: 8D BIM modelling tool for accident prevention through design. In: Paper presented at the 26th Annual ARCOM Conference, Leeds, Inglaterra (2010)
Kiviniemi, M., Sulankivi, K., Kähkönen, K., Mäkelä, T., Merivirta, M.: BIM-based safety management and communication for building construction (2011)
Malekitabar, H., Ardeshir, A., Sebt, M., Stouffs, R.: Construction safety risk drivers: a BIM approach. Saf. Sci. **82**, 445–455 (2016)
Marks, E., Shen, X.: Near miss information visualization application for BIM - Final report. Retrieved from Silver Spring, USA (2016). https://www.elcosh.org/document/4246/d001527/Near%2BMiss%2BInformation%2BVisualization%2BApplication%2Bfor%2BBIM-%2BFinal%2BReport.html
Martínez-Aires, M., López-Alonso, M., Martínez-Rojas, M.: Building information modeling and safety management: a systematic review. Saf. Sci. **101**, 11–18 (2018). https://doi.org/10.1016/j.ssci.2017.08.015
Marzouk, M., Daour, I.: Planning labor evacuation for construction sites using BIM and agent-based simulation. Saf. Sci. **109**, 174–185 (2018)
Mihić, M., Ceric, A., Završki, I.: Developing construction hazard database for automated hazard identification process. Tehnicki Vjesnik **25**(6), 1761–1769 (2018). https://doi.org/10.17559/TV-20180417105624
Mihić, M., Vukomanović, M., Završki, I.: Review of previous applications of innovative information technologies in construction health and safety. Organ. Technol. Manag. Constr. **11**, 1952–1967 (2019). https://doi.org/10.2478/otmcj-2019-0004
New York County Buildings: Building Information Modeling Site Safety Submission Guidelines and Standards. New York City Department of Buildings, New York (2013)
Pérez, A., Muriel, P., Pérez, J.: Guía para la integración del subproceso coordinacíín de seguridad y salud en fase de diseño en el proceso de elaboración de un proyecto de edificación desarrollado con metodología BIM. Spain (2017)
Qi, J., Issa, R., Hinze, J., Olbina, S.: Integration of safety in design through the use of building information modeling. Computing in Civil Engineering, pp. 698–705 (2011)
Schwabe, K., Teizer, J., König, M.: Applying rule-based model-checking to construction site layout planning tasks. Autom. Constr. **97**, 205–219 (2019). https://doi.org/10.1016/j.autcon.2018.10.012
Shih, S., Sher, W., Gibb, A., Smolders, J.: BIM and OHS - Designer and design coordinator adoption in the UK and Australia. In: Paper Presented at the CIB W099 International Conference on Modelling and Building Health and Safety', Singapore (2012)
Sulankivi, K., Kähkönen, K., Mäkelä, T., Kiviniemi, M.: 4D-BIM for construction safety planning. In: Paper Presented at the Proceedings of W099-Special Track 18th CIB World Building Congress, Manchester (2010)
Sulankivi, K., Mäkelä, T., Kiviniemi, M.: BIM-based site layout and safety planning. Presented at the (2009)
Sulankivi, K., Zhang, S., Teizer, J., Eastman, C., Kiviniemi, M., Romo, I., Granholm, L.: Utilization of BIM-based automated safety checking in construction planning. In: Paper presented at the CIB World Congress, Brisbane, Australia, 05–09 May 2013 (2013)
Trani, M., Bossi, B., Cassano, M., Todaro, D.: BIM oriented equipment choice on construction site. In: Proceedings of International Structural Engineering and Construction (2) (2015). https://doi.org/10.14455/ISEC.res.2015.209
Vimonsatit, V., Lim, M.: Use of BIM tools for site layout planning. In: Press, I. (ed.) Sustainable Solutions in Structural Engineering and Construction (2014)
Wang, J., Zhang, S., Teizer, J.: Geotechnical and safety protective equipment planning using range point cloud data and rule checking in building information modeling. Autom. Constr. **49**, 250–261 (2015)
Wang, Q.: Automatic checks from 3D point cloud data for safety regulation compliance for scaffold work platforms. Autom. Constr. **104**, 38–51 (2019). https://doi.org/10.1016/j.autcon.2019.04.008

Winch, G., North, S.: Critical space analysis. J. Constr. Eng. Manag. **132**(5), 473–481 (2006)
Yi, S., Zhang, X., Calvo, M.: Construction safety management of building project based on BIM. J. Mech. Eng. Res. Dev. **38**(1) (2015)
Zhang, S., Teizer, J., Lee, J., Eastman, C., Venugopal, M.: Building information modeling (BIM) and safety: automatic safety checking of construction models and schedules. Autom. Constr. **29**, 183–195 (2012). https://doi.org/10.1016/j.autcon.2012.05.006
Zhang, S., Teizer, J., Pradhananga, N., Eastman, C.: Workforce location tracking to model, visualize and analyze workspace requirements in building information models for construction safety planning. Autom. Constr. **60**, 74–86 (2015)
Zhou, W., Whyte, J., Sacks, R.: Construction safety and digital design: a review. Autom. Constr. **22**, 102–111 (2012). https://doi.org/10.1016/j.autcon.2011.07.005
Zou, Y., Kiviniemi, A., Jones, S.: A review of risk management through BIM and BIM-related technologies. Saf. Sci. **97**, 88–98 (2017). https://doi.org/10.1016/j.ssci.2015.12.027

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Integrating Occupational Health and Safety Data Digitally Using Building Information Modelling—Uses of BIM for OHS Management

Manuel Tender, João Pedro Couto, and Paul Fuller

Abstract Utilization of BIM (Building Information Modelling) for Occupational Health and Safety (OHS) purposes is a current trend but, as yet, there is not a complete list of its uses and potential. The main objective of this paper is to gather information about the main uses of BIM for improving OHS management. A methodlogy was adopted based on requirements defined in a European Directive covering the implementation of minimum safety and health requirements at temporary construction sites. As a result of the analysis carried out the following main findings were drawn. Integrating OHS data digitally using BIM is a task that requires the efforts of all stakeholders. The results of the study conducted show that this approach can revolutionize the integration of OHS information through the use of BIM for managing data in the areas identified. Revealing ways in which BIM can be used for improving OHS management will provide construction stakeholders with a better understanding of BIM in terms of the benefits, limitations, and barriers. This has the potential to result in a paradigm shift in the prevention of work accidents.

Keywords BIM · Health · Safety · Uses

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1 Introduction

1.1 Overview

This chapter covers the influence of Industry 4.0 on Occupational Health and Safety (OHS) i.e. the trend towards processes of automation and data exchange utilizing new technologies to support the process and the impact on OHS outcomes in construction. The authors' combined experience in the sector as researchers and/or practitioners spans more than three decades. They have observed at first-hand how OHS processes have developed over time to accommodate the adoption of modern technological practices.

The main objective of this paper, based on the technical-scientific gaps identified in the literature, is to analyze and systemize the main uses of BIM for improving OHS management. The identification of the ways in which BIM can be used for improving OHS management will provide construction stakeholders with a better understanding of BIM and related technologies including knowledge of the benefits, limitations, and barriers. This will help to encourage these stakeholders to increasingly adopt new solutions based on BIM which is especially relevant for smaller contractors (known to be more resistant to change). In this way, safety performance throughout the construction industry will be improved.

2 Materials and Methods

In order to establish the OHS management areas where BIM can provide support the starting point used was the Council Directive 92/57/EEC on the implementation of minimum safety and health requirements in temporary construction sites. After an analysis of these documents, the requirements were grouped and then analyzed in respect of the potential of BIM to improve outcomes. To cover all the requirements of the legislation a total of six groups were identified: documentation/contractual management; risk identification and assessment; training; site planning; task planning and monitoring; emergency planning; and, work accident investigation.

3 Results and Discussion

3.1 Documentation/contractual Management

The information related to the whole lifecycle of a project is usually taken from various disconnected, uncategorized hard copy and digital sources. This often leads to information inefficiencies e.g. duplication, over processing, reworking, lost time.

This lack of communication among project stakeholders can lead to a poor collaborative working environment which in turn results in poor project performance and an increase in accidents and occupational diseases.

Cloud-based solutions that are used to create collaborative environments, also known as a Common Data Environment (CDE), consist of platforms for automated, structured, centralized, and open document management. These provide a standards compliant environment to speci-fy, collect, safe-keep, store, present, and manage BIM information in a spirit of collaboration during the projects' lifecycle (UK Government BIM Working Group - CDE Sub Group 2018). A CDE allows users to identify, mitigate, manage, and communicate risks throughout the project which improves the processing/transmission flows of information (Health and Safety Executive 2018). A CDE is useful for documenting risk management and subsequent archiving of documentation e.g. the health and safety plan in the project phase; health and safety plan development for the construction phase; approval of subcontractors, workers, and equipment; and, the health and safety file.

The first phase where BIM is relevant for establishing how OHS information can be inputted in digital model data is during the setting up of the contractual arrangements. The following types of OHS information are usually covered in this phase:

- The Employer's Information Requirements (EIR) is a new document stemming from the use of a BIM based approach which expresses the client's ambitions in terms of how BIM will be used during the contracting process. The BIM elements typically covered include: software platforms; exchange format data; type and level of information; training; roles and responsibilities, security; clash-detection process; collaboration processes; health and safety management; systems performance; compliance plan; strategy deliverables; and, skills assessment;
- The BIM Execution Plan (BEP) is the subcontractor's response to the EIR defined in the tender phase.

Another important element of contractual management (in terms of OHS) is cost control. BIM enables quantification of costs and budgeting through the use of simulation models and the advantages include:

- The ability to analyse costs during the whole project lifecycle resulting in revised budget estimates, improved financial control and more accurate costs;
- A reduction in the time spent in quantity take-off and estimation from weeks to minutes (Kamardeen 2010);
- The identification and measurement of OHS equipment e.g. construction fences, signage, guardrails, etc. early and automatically. This results in quicker production of cost estimates for each activity (Martínez-Aires et al. 2018). It also reduces the time spent on budgeting and the number of future financial disputes;
- Easier correction of costs and budgets whenever a change is made in the project in terms of construction solutions, materials, equipment, and labour. This also allows the comparison, in terms of costs, different scenarios and solutions (Eastman et al. 2011);

- The automated extraction of quantities provides a fast listing of preventive elements installed or assembled at any given moment. This is not possible in the traditional approach and is particularly important when there are changes in the construction site structure, equipment, or work planning. If unit costs are then linked to that list, a complete budget can be swiftly assembled (Tender et al. 2018);
- The ability to know what material is needed at any time and at any stage of the work. Also the estimated final cost can be forecast related to each activity which improves financial management particularly in relation to suppliers (Tender et al. 2018);
- The automation of the costing of protective equipment to be used makes it possible to separate the different types of protective equipment to be used rather than use the usual "bulk price" of an article. This addresses the problem of not being able to quantify the items related to prevention which can reduce the potential for unfair competition (Tender et al. 2018);
- The various OHS solutions and scenarios from an can be tested virtually leading to better projection of financial costs which will assist in the optimization and control costs;
- the provision of a mechanism to understand where significant costs occur and their timing;
- The accuracy of estimates are improved (Kamardeen 2010);
- The reduction in the construction life cycle cost (Matarneh et al. 2019) especially considering that the O&M phase lasts much longer than the design and construction phases (Pishdad-Bozorgi et al. 2018).

3.2 Risk Identification and Assessment

The usual OHS approach to risk identification, based on personal experience, is generally verbal using two-dimensional drawings and the results obtained are often prone to error due to subjective assessments (Tender et al. 2018). In addition, OHS is generally viewed as separate from planning and this perspective makes it difficult to identify the preventive measures which are needed when and where they will need to be implemented.

BIM has several advantages when it is used for the identification of hazards and risks including:

- The optimization of risk management with a better identification of hazards and risks (Cheng and Teizer 2013). Also the identification of zones or time periods where there is a higher level of risk;
- Improved risk perception and communication between stakeholders making it possible to model and analyse alternative scenarios and solutions. This results in immediate problem solving (Buildings 2013) which can save time and reduce costs;

- Improved visualization (Hayne et al. 2014) and early simulation (Tender et al. 2018) of actual working conditions (Azhar and Behringer 2013) to identify, anticipate, and minimize risks before problems appear on the ground;
- Faster notification of the risks that could not be avoided in the design phase as well as the corresponding preventive measures and conditions on the site and surrounding area;
- The need for more work in the design phase as a result of using a BIM based approach. This increases the likelihood that risks will be detected in this phase (Mordue and Finch 2019);
- The use of BIM from the early stages of the project onwards has been linked to an improvement in safety conditions through a more effective connection to the production process (Azhar and Behringer 2013). It has also led to a decrease in the accident rate in recent years and to general savings of time and effort on the part of the stakeholders (Martínez-Aires et al. 2018);
- Giving designers suggestions on how to alter their designs to make them safer to build (Mihić et al. 2019);
- Automation and optimization of the assessment process and decision flow using specific plugins such as Dynamo (Cortés et al. 2017);
- The integration of safety planning and project planning which enables safety managers to recognize when, where, and why safety measures on the safety plans must be used (Irizarry et al. 2014);
- The identification of preventive measures being more automated (Martínez-Aires et al. 2018);
- Compatibility between specialities and elements is increased in the construction and O&M phases e.g. the installation of collective protections such as guardrails or others;
- The establishment of safety perimeters for operations with mechanical cargo handling equipment;
- The use of rule-checkers which enables identification of unsafe factors and safety hazards that would not be noticed by OHS actors using a conventional approach.

3.3 Training

"Traditional" training methods often fail to achieve the desired objectives due to their significant pedagogical limitations. Training has been the focus of some researchers who have identified where BIM for training and information provision is beneficial due to the following:

– Visual communication is considered to be one of the oldest and very high impact ways to communicate. The first versions of writing were, after all, pictures (Merivirta et al. 2011);

– Visualization can help in the perception of how each task is carried out as well as in the development of new ways of understanding the dangers(Mordue and Finch 2019);
– Better information increases safety by making the people on site more aware of what is going on there (Merivirta et al. 2011);
– The ability to easily overcome the language barrier (Azhar and Behringer 2013), improving communication between participants (Choe and Leite 2017) and the outputs obtained are easily used for training purposes (Martínez-Aires et al. 2018);
– Improved use and transmission of preventive information from the design phase to the construction phase which maximizes the optimization and interconnection between information (Mordue and Finch 2019);
– The simplification of the training process should improve the workers' attitude towards consulting safety information and positively change the paradigm (Wetzel and Thabet 2015).

3.4 Site Planning

Site facilities management usually presents several OHS related issues:

– Sites are often designed only once before construction starts without due consideration of the dynamic nature of supply issues (Yu et al. 2016); - Designers typically overlook safety considerations in temporary facilities design (Kim and Ahn 2011);
– Although some construction plans include important temporary facilities late in the construction planning process they are often installed at construction sites when needed but without sufficient planning effort (Kim and Teizer 2014).
  BIM has the following potential to improve site planning:
– Visualization of site arrangements is possible at different points in time (Sulankivi et al. 2009);
– More illustrative site plans for communication (Sulankivi et al. 2009);
– More robust schedules, site layout and logistic plans can be generated to improve productivity (Kamardeen 2010);
– Risk zones used as safety perimeters can be visualized through e.g. cylinders in 3D model creating a better notion of what crane jib could hit (Sulankivi et al. 2009) and reducing hidden dangers such as lifting injury accident, objects hitting, and collapses during the construction process (Yi et al. 2015);
– It facilitates the site material supply scheme (Yu et al. 2016);
– It shows great potential for facilitating validation/approval by the Project Owner or City Halls (Tender et al. 2018);
– Animations can provide a quick general understanding of the site and can be used for virtual sightseeing when introducing the project to site staff or to clients (Sulankivi et al. 2009);

– The visual link between the schedule and construction site conditions is capable of facilitating decision making during both the planning and the construction stages (Chau et al. 2004);
– Use of reality capture technologies such as 3D laser scanning or aerial drone photo-grammetry allows the site to be explored in more detail.

3.5 Task Planning

The planning of work from an OHS viewpoint presents several difficulties which can include:

– Safety planning is usually done separately from the construction planning process, which leads to weaknesses in the connection between safety and work execution and planning (Azhar and Behringer 2013);
– Traditional safety planning is carried out by manual means which is labour-intensive, tends to be error-prone and is often highly inefficient (Getuli et al. 2017);
– The 2D approach to safety planning leads to a lack of accuracy in drawings (Getuli et al. 2017);
– Monitoring depends on several factors, namely the size/complexity of the construction site, the means assigned to monitoring (e.g., the number of safety technicians) and the type of documents that used. Additionally, site monitoring is traditionally based on text-based standalone checklists which are neither sufficiently timely nor adequate and accurate enough to successfully manage construction safety by identifying and recording breaches. In the absence of technological support, it is not possible to monitor the whole site simultaneously, due to its large size.

BIM has the following advantages, in terms of work planning:

– 3D tools are more effective for safety planning than static 2D drawings since they adequately simulate real working conditions, allowing their visual assessment (Azhar and Behringer 2013), identification of hazards and optimizing the communicationof safety measures to workers;
– Design solutions can be conceived and assessed without exposing workers to risk (Health and Safety Executive 2018);
– It can enable a better safety distance and people related flow management needed due to the Coronavirus in order to reduce infection risks;
– The upfront simulation of the sequence of tasks leads to the early identification of various scenarios, with their opportunities, problems, constraints, and dangers, allowing to evaluate the advantages and disadvantages of each scenario (Mordue and Finch 2019). This is especially important in situations resulting from changes in the site organization that affect the work or the environment (Tender et al. 2018) or at critical times when there is an increase of the level of risks due to overlapping activities. Also in cases where there is a time or space incompatibility of tasks

(Choe and Leite 2017) since anticipating several scenarios has great potential for decreasing improvisation in site options (Martínez-Aires et al. 2018);

- Algorithms can automatically generate detailed schedules for temporary structures installation i.e. scaffolding which are not shown in the original contractor's schedule program e.g. scaffolding (Kim et al. 2016);
- It allows comparison between what is planned and what is done, within the scope of OHS e.g., setting up of collective protection;
- It allows to swiftly translate planning changes into safety related changes (Tender et al. 2018).

BIM has the following potential advantages for monitoring and inspection:

- Visualization of what is foreseen in safety procedures, for each work front (Mordue and Finch 2019);
- The comparison of future work and work performed optimizes the collection of data resulting from monitoring and inspections (Mordue and Finch 2019);
- It allows real time management of non conformities;
- Point cloud data has the potential to help comparing work planned and work done, namely in scaffolds (Wang et al. 2004).

3.6 Emergency Planning and Work Accident Investigation

The first step for minimizing damage due to emergencies is to establish a contingency plan for each possible scenario (Tender et al. 2017). One of the main focuses of this contingency plan is preparing emergency evacuation paths according to changing construction site configurations and construction progress. Predicting the evacuation time required for the workers to get out is the major goal when preparing the evacuation plan for construction sites (Marzouk and Daour 2018). However, creating evacuation paths for all the crews for each day can be an extremely labour-intensive task if done manually.

BIM has potential advantages for the purpose of improving emergency planning including:

- Using simulations the workers can experience emergency scenarios and evacuation operations;
- Automated visualization of escape routes and shelters;
- Better location of firefighting equipment.

Faced with the risk of occurrence of an unfavourable event such as a work accident or a near miss, BIM can be used to investigate work accidents in several ways including:

- Assisting in the investigation of unfavourable events (Martínez-Aires et al. 2018) by providing a better understanding of the tasks that were taking place, the tasks that were being carried out, and the tasks which preceded the event (Azhar and Behringer 2013);

- The recreation of the sequence of events that gave rise to the unfavourable event (Azhar and Behringer 2013) and to easily illustrate the flaws found (Azhar 2011);
- The detection of incompatibilities between activities leading to a reduction in near misses and potential accidents (Mordue and Finch 2019);—Helping OHS actors to identify high-frequency and high severity events within a construction site which can then be mitigated or hazards removal techniques applied (Marks and Shen 2016);
- Giving OHS actors a simple way to identify locations where most near misses are occurring and being reported (Marks and Shen 2016).

4 Conclusions

This paper examined the use of BIM to improve OHS management. As a result of the analysis and findings a number of conclusions can be drawn:

- Integrating OHS in digital data through BIM proves to be a task that requires the efforts of all stakeholders especially in scenarios characterized by the multidisciplinary nature of the work teams and a multi-organizational structure;
- In recent years there has been an increase in the understanding and application of BIM to real cases of construction with companies, mainly large companies and multinationals, already making substantial efforts to implement BIM for OHS purposes in real scenarios;
- The adoption of these digital technologies is increasing and opens the way for a better safety management system and a greater speed and perception of prevention planning. It also provides a stronger link between production and safety;
- The results obtained show that this approach can revolutionize the integration of OHS information through the use of digital technologies for managing data and the corresponding changes to the process of delivery, validation, and approval of key documentation (EIR, BEP, Health and Safety Plans and Technical Compilation). This has the potential to result in a paradigm shift in the prevention of work accidents.

The study had some limitations as the topic areas covered a wide field which limited the opportunity to discuss certain sub-themes. It did, however, cover the essential topics and describe the importance of each of these in the context of the main area of study.

Further research is needed to explore the advantages that were identified in order to establish their validity using suitable case studies. The possibilities of using BIM with other emerging technologies for OHS purposes also needs to be explored.

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References

Azhar, S.: Building Information Modeling (BIM): Trends, benefits, risks and challenges for the AEC industry. J. Leadersh. Manag. Eng. Sci. **11**(3) (2011). https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Azhar, S., Behringer, A.: A BIM-based approach for communicating and implementing a construction site safety plan. In: Paper presented at the 49th ASC Annual International Conference Proceedings, Califórnia, EUA (2013)

Chau, K., Anson, M., Zhang, J.: Four-dimensional visualization of construction scheduling and site utilization. J. Constr. Eng. Manag. **130**(4), 598–606 (2004). https://doi.org/10.1061/(ASCE)0733-9364(2004)130:4(598)

Cheng, T., Teizer, J.: Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications. Autom. Constr. **34**, 3–15 (2013). https://doi.org/10.1016/j.autcon.2012.10.017

Choe, S., Leite, F.: Construction safety planning: site-specific temporal and spatial information integration. Autom. Constr. **84**, 335–344 (2017). https://doi.org/10.1016/j.autcon.2017.09.007

Cortés, A., Muriel, P., Cortés, J.: Guía para la integración del subproceso coordinación de seguridad y salud en fase de diseño en el proceso de elaboración de un proyecto de edificación desarrollado con metodología BIM (Guide for the integration of the safety and health coordination subprocess in the design phase in the elaboration process of a building project developed with BIM methodology). Universidad de Extremadura (University of Extremadura, Spain) (2017)

Eastman, C., Teicholz, P., Sacks, R., Liston, K.: BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. Wiley (2011)

Getuli, V., Ventura, S., Capone, P., Ciribini, A.: BIM-based code checking for construction health and safety. Proc. Eng. **196**, 454–461 (2017). https://doi.org/10.1016/j.proeng.2017.07.224

Hayne, G., Kumar, B., Hare, B.: The development of a framework for a design for safety BIM tool. In: Paper presented at the International Conference on Computing in Civil and Building Engineering, Florida, USA (2014)

Health and Safety Executive: Improving health and safety outcomes in construction - Making the case for Building Information Modelling (BIM) (2018). Accessed from https://www.hse.gov.uk/construction/lwit/assets/downloads/improving-health-and-safety-outcomes-in-construction.pdf

Irizarry, J., Zolfagharian, S., Ressang, A., Nourbakhsh, M., Gheisari, M.: Automated safety planning approach for residential construction sites in Malasiya. Int. J. Constr. Manag. **14**, 134–147 (2014). https://doi.org/10.1080/15623599.2014.926190

Kamardeen, I.: 8D BIM modelling tool for accident prevention through design Paper presented at the 26th Annual ARCOM Conference. Leeds, Inglaterra (2010)

Kim, H., Ahn, H.: Temporary facility planning of a construction project using BIM (Building Information Modeling) Computing in Civil Engineering, pp. 627–634 (2011)

Kim, K., Cho, Y., Zhang, S.: Integrating work sequences and temporary structures into safety planning: automated scaffolding-related safety hazard identification and prevention in BIM. Autom. Constr. **70**, 128–142 (2016). https://doi.org/10.1016/j.autcon.2016.06.012

Kim, K., Teizer, J.: Automatic design and planning of scaffolding systems using building information modeling. Adv. Eng. Inform. **28**(1), 66–80 (2014). https://doi.org/10.1016/j.aei.2013.12.002

Marks, E., Shen, X.: Near miss information visualization application for BIM - Final report. Retrieved from Silver Spring, USA (2016). https://www.elcosh.org/document/4246/d001527/Near%2BMiss%2BInformation%2BVisualization%2BApplication%2Bfor%2BBIM-%2BFinal%2BReport.html

Martínez-Aires, M., López-Alonso, M., Martínez-Rojas, M.: Building information modeling and safety management: a systematic review. Saf. Sci. **101**, 11–18 (2018). https://doi.org/10.1016/j.ssci.2017.08.015

Marzouk, M., Daour, I.: Planning labor evacuation for construction sites using BIM and agent-based simulation. Saf. Sci. **109**, 174–185 (2018)

Matarneh, S., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., Matarneh, R.: Building information modeling for facilities management: A literature review and future research directions. J. Build. Eng. **24** (2019). https://doi.org/10.1016/j.jobe.2019.100755
Merivirta, M., Mäkelä, T., Kiviniemi, M., Kähkönen, K., Sulankivi, K., Koppinen, T.: Exploitation of BIM based information displays for construction site safety communication. In: Paper presented at the CIB W099 Conference, Washington, DC, Washington DC, USA (2011)
Mihić, M., Vukomanović, M., Završki, I.: Review of previous applications of innovative information technologies in construction health and safety. Organ. Technol. Manag. Constr. **11**, 1952–1967 (2019). https://doi.org/10.2478/otmcj-2019-0004
Mordue, S., Finch, R.: BIM for construction health and safety: Routledge (2019)
Buildings, New York County.: Building Information Modeling Site Safety Submission Guidelines and Standards. New York City Department of Buildings, New York (2013)
Pishdad-Bozorgi, P., Gao, X., Eastman, C., Self, A.P.: Planning and developing facility management-enabled building information model (FM-enabled BIM). Autom. Constr. **87**, 22–38 (2018). https://doi.org/10.1016/j.autcon.2017.12.004
Sulankivi, K., Mäkelä, T., Kiviniemi, M.: BIM-based site layout and safety planning. Presented at the (2009)
Tender, M., Couto, J.P., Fernandes, J.: Using BIM for risk management on a construction site. In: Arezes et al. (ed.), Occupational Safety and Hygiene V, pp. 269–272. CRC Press/Balkema, Londres, Inglaterra (2017)
Tender, M., Couto, J.:P., Lopes, C., Cunha, T., Reis, R.: BIM (Building Information Modelling) as a prevention tool in the design and construction phases. In: A. e. al (ed.) Occupational Safety and Hygiene VI. Taylor& Francis, Londres (2018)
Tender, M., Couto, J.P., Reis, R., Monteiro, P., Rocha, T., Delgado, T., Vicente, G.: BIM as a 3D, 4D and 5D management tool in a construction site. In: Paper presented at the 2nd Portuguese BIM Congress, Lisbon, Portugal (2018)
UK Government BIM Working Group - CDE Sub Group: Asset information management - Common Data Environment functional requirements (2018). Accessed from https://www.cdbb.cam.ac.uk/system/files/documents/BIMLevel2AIMCDEFunctionalRequirements20181.pdf
Wang, H., Zhang, J., Chau, K., Anson, M.: 4D dynamic management for construction planning and resource utilization. Autom. Constr. **13**(5), 575–589 (2004)
Wetzel, E., Thabet, W.: The use of a BIM-based framework to support safe facility management processes. Autom. Constr. **60**, 12–24 (2015). https://doi.org/10.1016/j.autcon.2015.09.004
Yi, S., Zhang, X., Calvo, M.: Construction safety management of building project based on BIM. J. Mech. Eng. Res. Dev. **38**(1) (2015)
Yu, Q., Li, K., Luo, H.: A BIM-based dynamic model for site material supply. Proc. Eng. **164**, 526–533 (2016). https://doi.org/10.1016/j.proeng.2016.11.654

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Achieving a Safer Construction Environment with BIM for Safety Framework

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Abstract The current research aims to provide a general framework of a BIM-based safety system. The safety verification system intends to improve the safety status in the construction field. This study provides the main components of the current approach. Background: Among the high-risk industries, the construction industry bears many fatalities and injuries each year. Thus, to have a practical site inspection, monitoring, and training, the AECO (Architecture, Engineering, Construction, and operation) is gradually integrating new digital technologies such as building information modelling (BIM), automatic rule checking, Augmented and Virtual Reality (AR/VR). Method: The Framework is divided into two main approaches, a fully automated and a fully manual method, adopting Automated rule checking and AR/VR, respectively. Following international standards and regulations. Results: Digital technologies can help with safety prevention, inspection, monitoring, and training from the design phase to the operation and management. The integration of the digital tools in a standardised manner could ease the adoption of the framework. The owner will gain more control over the safety aspects of the project, identify specific tasks for each stakeholder, and involve safety measures from the beginning of the project. Conclusion: limitations are found in implementing new tools since every tool represents a standalone solution. The digital tools are not involved in the standards and regulations. Workers and safety professionals lack the experience of using such tools, low demand from the owners, incompatibility of software and data format exchange, especially between different appointed parties, and the time spent preparing the BIM model.

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1 Introduction

The Architecture, Engineering, Construction, and Operation (AECO) industry is distinguished for its expanding complexity and competitiveness due to rigorous schedules, complex activities, and strict budgets (Sidani et al. 2019). Consequently, construction accidents are becoming a significant concern worldwide (Zhang et al. 2013).

In 2019 the Occupational Safety and Health Administration (OSHA) recorded 199,200 injuries and illnesses in the construction industry. 58.6% of the worker's death is due to the fatal four construction accidents including falls, struck-by-objects, electrocution, and stuck-in (U.S. Department of Labor; Bureau of Labor Statistics 2019).

There is no clear cause that leads to construction accidents, and various preventive approaches to mitigate accidents are being evaluated. According to Chim, the managers and the workers' negligence for health and safety is the leading cause of accidents on the construction site (Chim et al. 2018). Abdelhamid identified three factors: not recognising a dangerous condition related to a particular job, overlooking an unsafe situation, continuing with the action, or behaving unsafely in any task and environment (Abdelhamid and Everett 2000). Concerning accident prevention methods, Chim stated that construction members must carefully supervise the construction site, facilitating accident reduction. However, manual monitoring and supervisions are prone to error due to the complex and dynamic environment (Sidani et al. 2018). Thus, the construction site requires consistent and innovative monitoring and supervision. In addition, new workers must be trained carefully before starting to work at a construction site to avoid unsafe actions. Subsequently, to assist the site monitoring, supervisors, visual inspection and training, automated safety management technologies such as Building Information Modelling (BIM) is adopted by the AECO sector (Eleftheriadis et al. 2017). Implementing BIM appears promising and can be effectively improved several aspects of the construction processes, such as reducing health and safety challenges, improving the project's quality, and enhancing collaboration. Recently, in the AECO sector, technologies are being linked with BIM models to improve decision making, visual evaluations, on-site and off-site training, risk monitoring and prevention automated safety rule checking, among Others, the lifecycle of the construction project (Sidani et al. 2017, 2019, 2018a, b, 2020, 2021b, c; Soeiro et al. 2020; Wang and Chong 2015) (Enshassi et al. 2016). There is significant interest in improving safety through design also know as prevention through Design (PtD) using BIM by implementing safety planning throughout the project (Enshassi et al. 2016). BIM enables workers, safety specialists and engineers to digitally visualise and monitor construction sites and identify hazards (Azhar et al.

2012; Enshassi et al. 2016). Consequently, in conjunction with the progress of BIM and the project lifecycle in one holistic environment, most of the Health and Safety information can be generated in a particular environment (Kim et al. 2015; Schwegler 2010). 4D-BIM means improved chances to make alternative preliminary plans of different construction stages and tasks, linking them more to safety (Ganah and John 2015).

The AECO sector is acknowledged for driving the search for automated and technological solutions (Chan et al. 2004; Pham et al. 2017). Digitalisation has presented this sector the requirements to pursue higher performance and accuracy, thus reducing costs and improving operations. Implementing BIM methodology has benefited the AECO sector in collaboration, scheduling, 3D drawings, management, quantity, and material sorting. Consequently, various countries are adopting BIM. For European countries, BIM adoption is reinforced by Directive 2014/E.U., Article 22 (European Comission 2014), which refer to BIM application for civic procurement and by the contemporary international standard for BIM EN ISO 19650 1 (BS EN ISO 19650-1, 2018). The AECO sector is currently implementing several tools and methodologies to assist BIM, such as Automated Rule checking, Augmented Reality (AR), Virtual Reality (VR) (Sidani et al. 2021a, d).

2 Materials and Methods

The proposed BIM for Safety framework Fig. 1 merges the mentioned digital technologies producing a BIM for Safety Verification System Fig. 2. This system can be divided into Fully manual or Fully Automated approaches Fig. 2. According to Zhai, three aspects need to be improved to elevate the levels of health and safety and reduce risks: identifying dangerous areas at a specific time, monitoring and inspection, and training (Zhai et al. 2009).

The system is made of a well-identified and structured BIM model. The model then could be introduced to automated rule checking for fully automated risk checking.

Automated Rule checking aims to cover most of the risks. However, many hazards are too complex and interrelated to be automated such as handling equipment and heavy machinery, installations, material control, among others. The manual approach is divided into off-site risk checking by using VR and on-site by using AR.

VR will help in identifying risks starting from the design phase up until operation and management. VR can also assist in Health and Safety training. In comparison, AR will be mainly used for on-site inspection, monitoring, and training. To achieve this framework, the BIM model should be prepared with the essential requirements. The data will be transferred to an intermediate converter (e.g., Tridify) to transfer the BIM elements to a readable game engine (e.g., Unity) format. Finally, the BIM data could be transferred and viewed in a Virtual Environment.

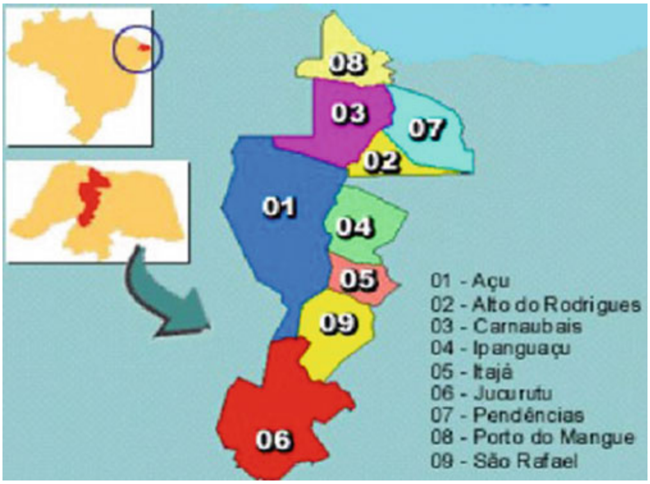

Fig. 1 BIM for safety framework

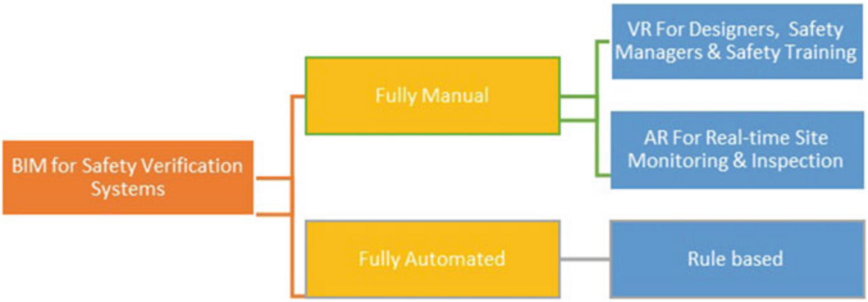

Fig. 2 BIM for safety verification system

2.1 Expected Results

The proposed BIM for Safety verification system aims to improve the previously mentioned aspects, identifying dangerous areas, inspection, monitoring, and training. One of the main problems of construction health and safety is that it is impossible to eliminate all risks due to the dynamic and complex aspects of the construction site. Consequently, several risks scenarios will be identified and analysed at an earlier stage, categorising them based on their Probability, severity, and exposure. Moreover, the rules for each risk will be illustrated. Hence, developing the BIM model with adequate requirements and Level of Development (LOD) facilitates automated rule checking Fig. 3.

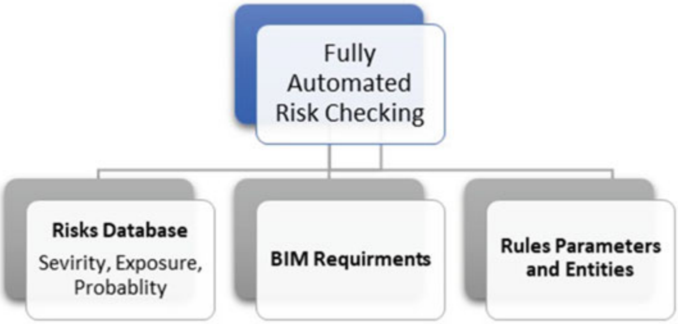

Fig. 3 Fully automated rule checking components

2.2 *Fully Automated Verification Systems (Rule Checking)*

Rule-based checking systems have been designed for BIM models as an element of the new BIM technology 3D and 4D simulations to improve construction operation. These are some of the features embedded in BIM, allowing effective health and safety planning throughout the project's lifecycle (Eastman et al. 2009). Such technologies can improve health and safety through automated risk identification at an earlier stage and offer economical and straightforward alternatives for unsafe situations. According to Zhang, analysing construction data such as work breakdown, schedules, structure, resource allocation can be linked to a BIM model allowing to generate a rule-based health and safety framework that facilitates safer design, and planning and execution of work tasks (Zhang et al. 2013b). At the same time, data fusion of safety rules by OSHA, and geometric project data can create information that once applied, will create knowledge that can enhance safety education and training at the design and construction stage (Zhang et al. 2013b).

Safety standards and codes are the basis of construction risk detection. It is essential to link BIM elements or behaviors with relevant safety regulations and codes to carry out automatic risk identification. According to Guo Hongling (Hongling et al. 2016), a safety rule procedure is thus built by: Categorising construction safety data, building a safety rule system, and finally, translating a safety rule system to machine-readable language.

Various standards may classify unsafe design aspects from distinct perceptions and describe the similar rule in a changed structure. The reorganisation of the rules with a specific format and methods facilitates rule checking (Hongling et al. 2016). However, all these standards can be categorized into design computation, safety protection, and design checking. As the rules are used to prevent accidents, the model safety-related information is updated corresponding to accident-related attributes. An organised and well-structured safety rule system can be established (Hongling et al. 2016).

2.3 *Fully Manual Verification Systems*

2.3.1 Augmented Reality

BIM-based AR advancements within the AECO sector, providing an array of applications. Azuma describes AR as a variation of VR, which provides a natural environment incorporating virtual objects (Azuma 1997).

Recently, AR is a context-aware system capable to incorporate the surrounding environment (Sidani et al. 2019). However, recent advances in context-aware tools such as Wikitude, Google's Project Tango, ARCore and ARKit, may advance the technology used on mobile devices, given the improving processing capabilities of portable devices (Sidani et al. 2021a). Moreover, Data Cloud computing environments have been accepted in server-based applications and a wide variety of applied localisation technologies, dependent on the specifics of the system and the application or assignment itself. Concurrently, the potential of gesture-based interfaces and Head Mounted Displays (HMDs) were also registered (e.g., applications based on Microsoft HoloLens). BIM tools such as ArchiCAD, Revit and game engines (e.g., Unity) are used to assist data transfer and the creation of virtual environments (Sidani et al. 2021a).

AR is primarily applied in construction to visualise and extract live information from the construction site. BIM-based AR in construction can support activities completion and lower cognitive workload, reduce construction errors, gain more access to project information, improve collaboration, manage construction schedules and costs, safety training, job orientation, and improve productivity (Bae et al. 2013; Jiao et al. 2013; Park et al. 2013; Pour Rahimian et al. 2019). Explicitly, for Civil Engineering and Architecture, AR can reduce the time of project design review as well reduce construction errors, improved communication, time-savings (working hours) and cost reduction (Charef et al. 2018).

Moreover, the importance of conducting field tests should not be disregarded from AR implementation, as such an approach may ascertain improved user-friendliness and may also contribute to fostering acceptance and long-term use (Berkemeier et al. 2019). A compromise must be made between the development team's know-how, state-of-the-art technology to the extent that possible difficulties in developing the solution can be reduced, and cost and economic aspects.

Finally, Fig. 4 represents a summary of a systematic review of articles related to BIM-based AR carried out by Sidani et al., including the targeted groups, the primary BIM dimensions, stakeholders, the applied technologies, and the fields selected for implementation (Sidani et al. 2021a).

2.3.2 Virtual Reality

VR has shown promising advancements as the prices become lower and computational power increases (Martín-Gutiérrez et al. 2017). Recently, VR research has

Fig. 4 Summary of BIM-based AR usage (Sidani et al. 2021a)

focused on the AECO sectors, showing possible benefits in many applications, particularly taking advantage of accuracy and information comprised in BIM models. Consequently, BIM-based VR applications have shown many advantages to enhance design review, decision making, team collaboration, among others. The core idea behind VR application is to enable collaboration and communication, allowing people with different expertise to access BIM information (Sidani et al. 2021a).

The majority of BIM-based VR tools utilise a three-layer system architecture comprising a BIM authoring tool, a visual enhancement module, and a game engine. Moreover, some studies expand to a fourth layer, a database, to exchange non-geometric information (Sidani et al. 2021a). The Construction Safety—improved the construction safety through increased awareness and design simulation and inspection (Sidani et al. 2021a).

3 Discussion

The proposed BIM for Safety framework combines automated rule checking, VR and AR with a BIM model. The proposed Safety framework is in line with international standards and regulations such as EN ISO 19650 1, PAS 1192-6:2018, and Directive 92/57/EEC on implementing minimum safety and health requirements at temporary or mobile construction sites. Combining the standards and regulations will facilitate and standardise the adoption of the framework and ensure effective implementation and utilisation. This system is divided into Fully manual or Fully Automated approaches. The system aims to improve health and safety levels and reduce risks by detecting dangerous areas, monitoring and inspection, and training.

3.1 Limitations

The framework is composed of several digital systems. Each of these systems represents some limitation. The framework's significant limitations are the workers' lack of expertise using digital tools, lack of collaboration between appointed parties, low demand from the owners, incompatibility of data transfer between appointed parties.

The common stereotype of BIM usage and the sluggish mindset of professionals toward validating the facts are delaying the AECO sector from fully integrating BIM technology. Additionally, the AECO sector is too comfortable and is not willing to change the current procedures. Concerning BIM-based AR, limitations were primarily present in the data transfer due to the construction site's low connectivity levels involving internet and GPS connections. Nevertheless, there are still drawbacks concerning non-geometric information being implemented in AR systems. Concerning BIM-based VR, software compatibility, the need to create an algorithm to allows the scan of building objects and parameters, the level of realism of the models, and the application of an IFC interface to build a universal data elements adopt different BIM packages. The lack of exportation features for the collaboration solutions. Moreover, the time spent preparing the BIM model is still a relevant limitation.

4 Conclusions

The integration of BIM models with Automated Rule checking, AR, and VR can specify the model's requirement and the level of development (LOD), which is a set of specifications that aims for permitting professionals in the AECO sector to register, manipulate and specify the content of BIM effectively. Serving as an industry guideline, LOD defines the development stages of different systems in BIM. Afterwards, the suggested BIM for Safety general framework Fig. 4 will be based on the established construction principles, such as EN ISO 19650-1 standard, an international benchmark for operating data over the project's life cycle using BIM. It includes principles and high-level requirements as UK governments BIM level 2 and is aligned with UK 1192 standards (Panteli et al. 2020).

Furthermore, the integration PAS 1192-6:2018 "Specification for collaborative sharing and use of structured Health and Safety information using BIM". PAS 1192-6:2018 specifies requirements for the cooperative sharing of structured health and safety information throughout the project's life cycles. It supports the development of structured health and safety data for construction projects gradually from the start. It offers guidance on how Health and safety information is generated, flows, and can be used throughout the project's lifecycle. While all Health and safety risk information can be incorporated within an information model, PAS requires the contextualisation and categorising hazards and risks to highlight the elevated risks that are critical. It also establishes a risk information cycle framework to apply health and safety information through BIM processes and applications. The requirements of PAS can be applied equally to non-BIM projects. PAS identifies how to use Health and safety data to:

- Offer a safer and healthier environment for end-users;
- Mitigate hazards and risks across the project's lifecycle;
- Improve construction Health and safety performance;
- Provide relevant health and safety information to the right people at the right time;
- Reduce construction and operational costs.

Finally, Directive 92/57/EEC on implementing minimum safety and health requirements at temporary or mobile construction sites will be associated with the framework. The Directive lists the minimum Health and safety requirements for construction sites.

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References

Azhar, S., Khalfan, M., Maqsood, T.: Building information modelling (BIM): now and beyond. Aust. J. Constr. Econ. Build. **12**(4), 15 (2012). https://doi.org/10.5130/ajceb.v12i4.3032

Azuma, R.T.: A survey of augmented reality. Presence: Teleoperators Virtual Environ. **6**(4), 355–385 (1997). https://doi.org/10.1162/pres.1997.6.4.355

Bae, H., Golparvar-Fard, M., White, J.:. High-precision vision-based mobile augmented reality system for context-aware architectural, engineering, construction and facility management (AEC/FM) applications. Vis. Eng. **1**(1) (2013). https://doi.org/10.1186/2213-7459-1-3

Berkemeier, L., Zobel, B., Werning, S., Ickerott, I., Thomas, O.: Engineering of augmented reality-based information systems: design and implementation for intralogistics services. Bus. Inf. Syst. Eng. **61**(1), 67–89 (2019). https://doi.org/10.1007/s12599-019-00575-6

BS EN ISO 19650–1.: Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling. Bs En Iso **19650–1**(2018), 1–46 (2018)

Chan, A.P.C., Scott, D., Chan, A.P.L.: Factors affecting the success of a construction project. J. Constr. Eng. Manag. **130**(1), 153–155 (2004). https://doi.org/10.1061/(ASCE)0733-9364(2004)130:1(153)

Charef, R., Alaka, H., Emmitt, S.: Beyond the third dimension of BIM: a systematic review of literature and assessment of professional views. J. Build. Eng. **19**, 242–257 (2018). https://doi.org/10.1016/J.JOBE.2018.04.028

Chim, B.L.H., Chun, C.J., Wah, F.K.: Accidents in construction sites: a study on the causes and preventive approaches to mitigate accident rate. Int. J. **1**(3), 1–12 (2018)

Eastman, C., Lee, J., Min, J., Suk, Y.L., Kook, J.: Automatic rule-based checking of building designs. Autom. Constr. **18**(8), 1011–1033 (2009). https://doi.org/10.1016/j.autcon.2009.07.002

Eleftheriadis, S., Mumovic, D., Greening, P.: Life cycle energy efficiency in building structures: a review of current developments and future outlooks based on bim capabilities. Renew. Sustain. Energy Rev. **67**, 811–825 (2017). https://doi.org/10.1016/j.rser.2016.09.028

Enshassi, A., Ayyash, A., Choudhry, R.M.: BIM for construction safety improvement in Gaza strip: awareness, applications and barriers. Int. J. Constr. Manag. **16**(3), 249–265 (2016). https://doi.org/10.1080/15623599.2016.1167367

European Comission: COUNCIL REGULATION (EU) No 216/2013 of 7 March 2013. , Official Journal of the European Union §(2014)

Ganah, A., John, G.A.: Integrating building information modeling and health and safety for onsite construction. Saf. Health Work **6**(1), 39–45 (2015). https://doi.org/10.1016/J.SHAW.2014.10.002

Hongling, G., Yantao, Y., Weisheng, Z., Yan, L.: BIM and safety rules based automated identification of unsafe design factors in construction. Proc. Eng. **164**, 467–472 (2016). https://doi.org/10.1016/j.proeng.2016.11.646

Jiao, Y., Zhang, S., Li, Y., Wang, Y., Yang, B.: Towards cloud Augmented Reality for construction application by BIM and SNS integration. Autom. Constr. **33**, 37–47 (2013). https://doi.org/10.03248/j.autcon.2012.09.018

Kim, J.B., Jeong, W., Clayton, M.J., Haberl, J.S., Yan, W.: Developing a physical BIM library for building thermal energy simulation. Autom. Constr. **50**(C), 16–28 (2015). https://doi.org/10.1016/j.autcon.2014.10.011

Martín-Gutiérrez, J., Mora, C. E., Añorbe-Díaz, B., González-Marrero, A.: Virtual technologies trends in education. Eur. J. Math. Sci. Technol. Edu. **13**(2), 469–486 (2017). https://doi.org/10.12973/eurasia.2017.00626a

Park, C.S., Lee, D.Y., Kwon, O.S., Wang, X.: A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. Autom. Constr. **33**, 61–71 (2013). https://doi.org/10.1016/j.autcon.2012.09.010

Pham, H.C., Pedro, A., Le, Q.T., Lee, D.Y., Park, C.S.: Interactive safety education using building anatomy modelling. Universal Access in the Information Society, pp. 1–17 (2017). https://doi.org/10.1007/s10209-017-0596-y

Pour Rahimian, F., Chavdarova, V., Oliver, S., Chamo, F.: OpenBIM-Tango integrated virtual showroom for off-site manufactured production of self-build housing. Autom. Constr. **102**, 1–16 (2019). https://doi.org/10.1016/j.autcon.2019.02.009

Schwegler, B.: Green BIM: successful sustainable design with building information modeling by Eddy Krygiel and Bradley Nies. J. Ind. Ecol. **14**(5), 859–860 (2010). https://doi.org/10.1111/j.1530-9290.2010.00270.x

Sidani, A.Z., Duarte, J., Dinis, F.M., Santos Baptista, J., Martins, J.P., Soeiro, A.: The Impact of BIM-based virtual and augmented reality interfaces on health and safety in construction projects: protocol for a systematic review. Int. J. Occupat. Environ. Saf. **2**(1), 67–74 (2018). https://doi.org/10.24840/2184-0954_002.001_0008

Sidani, A., Santos Baptista, J.: Relationship between the effectiveness of BIM methods and construction safety and health (Systematic Review). Doctoral Congress (2017

Sidani, Adeeb, Dinis, F.M., Sanhudo, L., Duarte, J., Santos Baptista, J., Poças Martins, J., Soeiro, A.: Recent tools and techniques of BIM-based virtual reality: a systematic review. Arch. Comput. Methods Eng. **28**(2), 449–462 (2021a). https://doi.org/10.1007/s11831-019-09386-0

Sidani, Adeeb, Dinis, F., Sanhudo, L., Duarte, J., Calvetti, D., Poças Martins, J., Soeiro, A.: Impact of BIM-based augmented reality interfaces on construction projects: protocol for a systematic review. Int. J. Occupat. Environ. Saf. **3**(2), 38–45 (2019). https://doi.org/10.24840/2184-0954_003.002_0006

Sidani, A., Duarte, J., Baptista, J.S., Martins, J.P., Soeiro, A.: Improving construction safety using BIM-Based sensor technologies. 2o Congresso Português de Building Information Modelling, pp. 161-169 (2018a). https://www.mendeley.com/catalogue/67267424-1560-3be3-83e1-edbf31772e54/?utm_source=desktop&utm_medium=1.19.8&utm_campaign=open_catalog&userDocumentId=%7Bb99fcc37-7df4-3541-85c3-4fafbf49a88b%7D

Sidani, A., Duarte, J., Baptista, J.S., Martins, J.P., Soeiro, A.: Improving construction safety using BIM-Based sensor technologies. 2o Congresso Português de Building Information Modelling, (1), 161–169 (2018b). https://www.constructconnect.com/blog/construction-news/construction-leads-industries-

Sidani, A., Duarte, J., Dinis, F., Sanhudo, L., Santos Baptista, J., Poças Martins, J., Soeiro, A.: Virtual Reality and the future of construction. 46–50 (2020). https://doi.org/10.24840/978-972-752-260-6_0046-0050

Sidani, A., Duarte, J., Santos Baptista, J., Vaz, M., Poças Martins, J., Soeiro, A.: BIM-based sensors technologies implemented in the construction site: protocol for a systematic review. Int. J. Occupat. Environ. Saf. **5**(1), 25–31 (2021b). https://doi.org/10.24840/2184-0954_005.001_0003

Sidani, Adeeb, Duarte, J., Santos Baptista, J., Vaz, M., Poças Martins, J., Soeiro, A.: BIM-based sensors technologies implemented in the construction site: protocol for a systematic review. Int. J. Occupat. Environ. Saf. **5**(1), 25–31 (2021). https://doi.org/10.24840/2184-0954_005.001_0003

Sidani, Adeeb, Matoseiro Dinis, F., Duarte, J., Sanhudo, L., Calvetti, D., Santos Baptista, J., Soeiro, A.: Recent tools and techniques of BIM-Based Augmented Reality: A systematic review. J. Build. Eng. **42**, 102500 (2021d). https://doi.org/10.1016/j.jobe.2021.102500

Soeiro, A., Poças Martins, J., Zavrski, I., Theodossiou, N., Meszaros, P., Sidani, A.: CSETIR-Construction Safety with Education and Training Using Immersive Reality. (2020). https://doi.org/10.1007/978-3-030-41486-3_6

U.S. Department of Labor, Bureau of Labor Statistics: National Census of Fatal Occupational Injuries in 2019 (2019). www.bls.gov/iif

Wang, X., Chong, H.-Y.: Setting new trends of integrated Building Information Modelling (BIM) for construction industry. Constr. Innov. **15**(1), 2–6 (2015). https://doi.org/10.1108/CI-10-2014-0049

Zhai, D., Goodrum, P.M., Haas, C.T., Caldas, C.H.: Relationship between automation and integration of construction information systems and labor productivity. J. Constr. Eng. Manag. **135**(8), 746–753 (2009). https://doi.org/10.1061/(asce)co.1943-7862.0000024

Zhang, S., Teizer, J., Lee, J.K., Eastman, C.M., Venugopal, M.: Building Information Modeling (BIM) and safety: automatic safety checking of construction models and schedules. Autom. Constr. **29**, 183–195 (2013). https://doi.org/10.1016/j.autcon.2012.05.006

New Approaches of Near-Miss Management in Industry: A Systematic Review

Maria Helena Pedrosa, J. C. Guedes, Isabel Dias, and Ana Salazar

Abstract Background: Considering that more than half of the world's population is economically active, safe working environments are vital to improving their overall quality of life. Workplace incidents can and should be investigated, those with consequences (work accidents) and those with no effects but with intrinsic potential (near-misses). New approaches to Near-miss Management in the Industry will help to prevent occupational accidents in the future. Objective: This research aims to obtain innovative characteristics relative to procedures within the near-miss management in the Industry. Method: This review followed the guidelines of the PRISMA Statement. Seven databases, namely: Scopus, Web of Science, ScienceDirect, Academic Search Ultimate, SpringerLink, Wiley Online Library, and IEEE Xplore, were used to develop a data search based on the defined keywords. Results: A total of 15 publications were included in the systematic review. Topics such as type of Industry, study sample, type of study research, and main innovative findings regarding the original near-miss management were analysed. Conclusion: New approaches of Near-miss Management systems in the Industry were explored with results that can be very useful in a future design of a Near-miss Management system in a more specific sector such as the traditional manufacturing sector.

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Keywords Near-miss reporting · Near-miss procedure · Near-miss management · Industry

1 Introduction

In the past, lagging indicators related to work accidents and illnesses drove safety performance. Nowadays, leading indicators, such as the reporting of near-misses, must be followed (Awolusi and Marks 2015).

Near-miss (NM) is "an opportunity to improve environmental, health and safety practice based on a condition or an incident with potential for a more serious consequence" (Phimister et al. 2003). Near-misses could provide the opportunity to learn from free lessons proactively (Zhou et al. 2019).

Near-miss Management Systems (NMSs) are mandatory on the Major Accident Hazard (MAH) legislations (Gnoni et al. 2013; van der Schaaf 1995). However, in other sectors, such as the manufacturing industry, it is not currently required employers to report near-miss (Awolusi and Marks 2015; Occupational Safety and Health Administration n.d.). Nevertheless, it is essential to manage efficiently near-misses to improve risk prevention in a company (Gnoni et al. 2013). If near-misses are reported, and people learn from them, they will eventually get to the point where near-miss occurrence reduces and, later, accidents (Jones et al. 1999). The common cause hypothesis relies on the assumption regarding some causal relations between near-misses and accidents (Raviv et al. 2020). The normalisation of deviance happens when risky behaviour becomes commonplace because there seem to be no apparent negative consequences (Madsen et al. 2016; Vaughan and Diane 1996). A near-miss shows the system's vulnerability, but on the other hand, its resilience in overcoming the problem. Thus, to maintain a robust process safety culture, near-misses should be regarded as opportunities to reinforce a sense of vulnerability for all employees (Dee et al. 2013).

The goal of NMS should be to stimulate near-miss reporting and learn lessons, reduce accidents, and improve safety performance (Phimister et al. 2003), proving that NMS is a key leading indicator of process safety performance (Konstandinidou et al. 2011).

Three aspects are essential for implementing an NMS: top-level commitment; employees reporting unbiased; support for middle-management who are responsible for the analysis of reported event (van der Schaaf 1995).

A seven-stage framework for the management of near-misses was first presented (van der Schaaf and Tjerk 1992; van der Schaaf 1995). This procedure will be considered as the original framework (Gnoni and Lettera 2012; Phimister et al. 2003). Afterwards, some innovation is introduced to this initial procedure other than just a pure historical evolution.

Therefore, the main objective of this systematic review is the search for evidence of innovation in NMS approaches in Industry.

2 Materials and Methods

This systematic review was conducted following the guidelines of The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Statement (Moher et al. 2009), and it aims to focus on literature that addresses the most relevant information of NMS approaches in the Industry.

The search was developed through seven databases and based on two groups of keywords: ("near-miss reporting" OR "near miss procedure" OR "near-miss management" OR "near-miss programme") AND "industry".

The search was initially conducted by inserting the combination and selecting, when possible, "Article title, Abstract, Keywords". Three phases of exclusion were applied. The first phase was spread through the search filters of the databases to obtain relevant results. The date was not a criterion. It was essential to search for an original consensual procedure, from which others innovated somehow. The following criterion was "Document type": only Articles and Reviews were filtered. However, reviews were only considered as a source of complementary information. When applying the "Source Type" filter, only Journals were chosen. Finally, all articles but those written in English were excluded. The paper, not retrieved full-text, would be excluded. Afterwards, duplicates were removed. Lastly, the third phase in the screening process (on-topic) followed these guidelines: Title and abstract were analysed. Studies were excluded if one of these conditions was met: (1) Studies that do not apply Industry; (2) Studies that only consider qualitative data; (3) Studies that do not refer to innovative findings regarding the considered as the original procedure of NMS.

Selected studies were full-text analysed whenever the title and abstract did not provide enough information to determine if the selection criteria were met. If the following conditions were not met, articles would be deleted: Quantitative studies that include innovative features to manage near misses in Industry.

3 Results and Discussion

After a database search, 534 items were identified, from which 320 were removed after search filters and ten excluded due to not full text retrieved, leaving a total of 204 items.

Forty-one duplicates were removed, leading to a total of 163 publications being screened. From this phase, a total of 20 articles was selected to be assessed for eligibility. Five articles were excluded after full-text assessment, leaving 15 articles to be included in the quantitative synthesis. Figure 1 shows the flowchart of the systematic review stages.

The main innovative findings of the selected 15 studies are presented in Tables 1, 2 and 3.

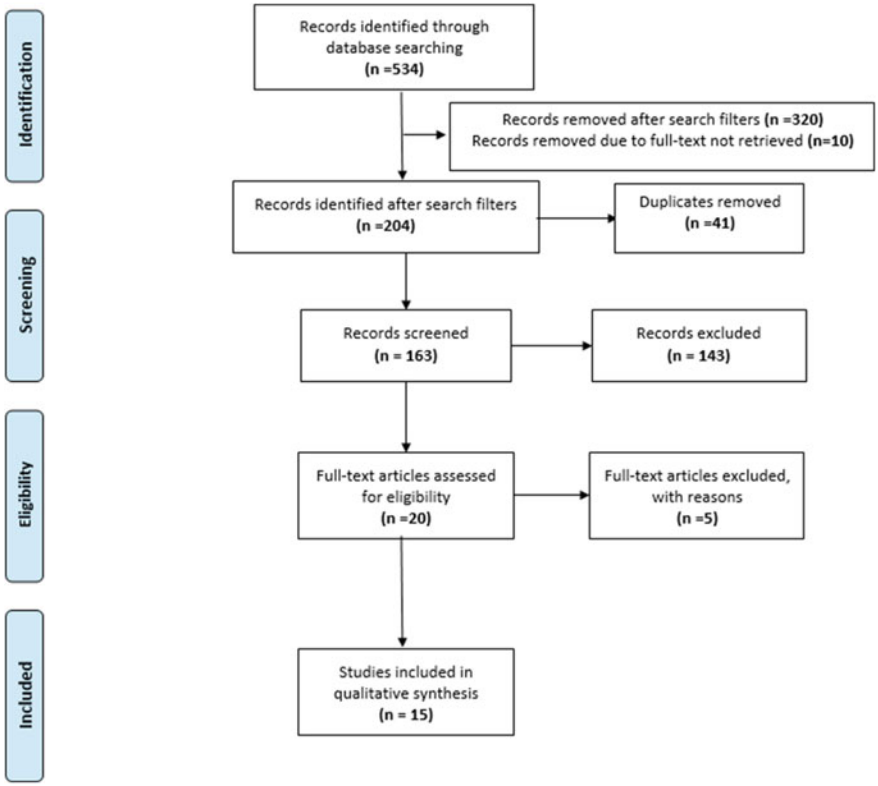

Fig. 1 Systematic review Stages (Moher et al. 2009)

The expected outcomes of this research show innovative characteristics in different NMS approach to Industry relating to a considered "original" procedure. Van der Schaaf van der Schaaf 1995 procedure was considered the former procedure mentioned by researchers when presenting a historical revision of NMS (Gnoni and Lettera 2012; Phimister et al. 2003; Thoroman et al. 2018). Thus, this procedure itself can be considered innovative.

In Phimister et al. (2003), a seven-step procedure is used as in the original procedure. Still, a broader concept of near-miss as an opportunity can be considered innovative for the time, as only with the new ISO45001: (2018), an incident is viewed as an opportunity to improve OH&S performance (requirement 6.1.1).

Goraya et al. (2004) refer to an NM methodology with a design quite different from the rest of the presented studies. It groups the various steps into four stages according to the Plan-Do-Check-Act (PDCA) concept. The OH&S management system in ISO45001: (2018) relies on the PDCA. This concept is an iterative process used by organisations to achieve continual improvement (ISO45001: 2018). For identifying causes, a checklist based on four safety guidewords (minimise, substitute,

Table 1 Main innovative findings within the selected 15 studies regarding Near-Miss System (NMS) Design

Author	Year	Near-Miss System (NMS) Design
Van Der Schaaf T.W.	1995	"Original" NMS applied within the dutch chemical industry: 1- Detection (usually based on voluntary reporting by employees); 2- Selection of the reports with the highest informative value; 3- Description of the selected event, using qualitative fault tree technique. 4- Classification of each of the many primary causes; 5- Computation with the statistical analysis of an extensive database of incidents. 6- Interpretation of the statistical results to achieve suggestions for management actions; 7- Evaluation of the effectiveness of the suggested actions
Phimister J.R. et al.	2003	A seven-stage NMS, but slightly different from the "original" NMS procedure presented above, was applied within the American chemical process industry: 1-Identification of near misses; 2-Reporting; 3-Prioritisation of near-misses and Distribution of information; 4-Causal analysis; 5-Solutions Identification; 6-Dissemination to relevant parties; 7-Resolution implementing and evaluating corrective actions
Goraya A. et al.	2004	The four stages procedure follows the essential management functions of: "plan, do, check, act" was applied within the American chemical industry
Kleindorfer P. et al.	2012	Eight-step NMS based on Phimister et al. 2003: 1- Identification; 2- reporting, 3- prioritisation; 4- distribution; 5- Causal analysis; 6- Solution Identification; 7- Dissemination; 8- Resolution
Gnoni M.G. et al.	2013	Based on the original procedure of NMS as part of the lean management, a three stages NMS was applied in an Italian Automotive manufacturing supplier firm, which is still rare: 1- Identification and Reporting; 2- Event Analysis and Resolution; 3- Dissemination
Awolusi I., Marks E.	2015	Proposed within the American manufacturing steel industry with five stages: Data collection (1- Identification and 2- Reporting). Data analysis (3- Root-cause analysis and 4- Solution Determination). Knowledge and information management (5-Dissemination and Information Management)
Whiteoak, J.W., et al.	2019	In an Australian construction company, a six stages NMS: 1- NM recognition based on established conditions; 2. Worker reporting; 3- Reports enter database with daily reports for high-risk events; 4- Analysis of events; 5- Corrective actions, 6- Learning incorporated into training procedures
Zhou Z. et al.	2019	A well defined NMS is designed with eight stages: discovery, reporting, identification (these three to make NM explicit), prioritisation, causal analysis, solution, dissemination, and evaluation (these five to manage NM information in a database)

Table 2 Main innovative findings within the selected 15 studies regarding Near-miss: definition and/or examples

Author	Year	Near-miss: definition and/or examples
Phimister J.R. et al.	2003	An opportunity to improve
Dee S.J. et al.	2013	NM being perceived either as vulnerability or of the resiliency of the system
Wincek J. C.	2016	NM original examples are presented in this article
Champion J. et al.	2017	In an American chemical company: the highest potential PSNM event (HP PSNM) was introduced
Whiteoak J.W. et al.	2019	NM is defined as "bloody close"
Zhou Z. et al.	2019	Within the Chinese construction industry, NM was seen as incidents with the potential to engender accidents

moderate and simplify) is used, reminding ISO45001: (2018) hierarchy of control. Recommendations are also referred to as "layers". The third layer corresponds to suggestions to improve the management system (leadership) as Kletz et al.(2001. As Champion et al. (2017), leadership plays an essential role in the NMS. A critical goal must be to foster a culture that encourages workers to report continually.

Mcquiston et al. 2012 refer to a "TOP" program created under the union and management leadership. The union seeks solutions that comprehend a higher level in the hierarchy controls than the usual behaviour-based safety approaches, as reflected on ISO45001: (2018). In this innovative study, the union proved the true essence of its existence: to be the guardian of workers' rights and working conditions.

Kleindorfer et al. (2012) associate the "five neglects" identified by Berger et al. (2010) for rational decision-making and considers that NMS helps correct such biases, improves institutional memory, and focus on emerging hazardous conditions. Kletz (1993) refers to it for accidents that cannot be forgotten with time. They have to be identified and passed to all interested parties as organisations have no memory; only people have it, and they move on, taking information with them. Knowledge and its spread must be an opportunity so that accidents do not happen again. Similar accidents often occur repeatedly (Dodshon and Hassall 2017; Kletz 2009).

Dee et al. (2013) introduce a methodology based on the game theory and infer that the NM investigation must be faced as learning opportunities to prevent biases. ISO45001:2018 and Phimister et al. (2003) also consider NM as opportunities to improve and generate knowledge, institutional memory (Dodshon and Hassall 2017; Kletz 2009, 1993).

Table 3 Main innovative findings within the selected 15 studies regarding Near-miss: characteristics

Author	Year	Near-Miss System characteristics
Goraya A. et al.	2004	Use of four safety guidewords for causes identification
McQuiston T.H. et al.	2012	The Triangle of Prevention (TOP) program was created under the union and management leadership to prevent accidents within the American chemical atomic oil industry and avoid considering all incidents as "human error". After employees reporting the NM to the TOP representative (paid by the company but accountable to the local union), a team of union and management will investigate it
Kleindorfer P. et al.	2012	A new concept: "potential safety profit loss", is introduced to calculate the potential monetary losses due to unexpected shutdowns and accidents. The "five neglects" must be considered for rational decision making. An NMS improves institutional memory
Dee S.J. et al.	2013	Within the American chemical industry, a game theory perspective, developed previously by Meel et al. (2008) with hypothetical data, is used to understand the factors that drive NM identification, reporting, and implementation of their corrective actions
Gnoni M.G. et al.	2013	This NMS uses Learning from Experience (LFE) concepts. It eliminates the absolute need for H&S department involvement in the assessment phase. That department would only support the supervisor in this activity if required, optimising the information flow
Kadri S. et al.	2013	Within the American chemical industry, a company used a harmonised Process Safety Events program with other companies of the same Industry. Still, the company adapted the list, customised it to its reality to improve safety performance
Andriulo S. et al.	2014	Andriulo et al. measures, for the first time, the global effectiveness of a previously applied NMS in Gnoni et al. 2013
Awolusi I., Marks E.	2015	In the Dissemination: NM information should also be shared with other companies of the same sector to bring synergy among all companies
Madsen P. et al.	2016	In an American airline company, even a trivial NM must be reported, so resources must be spent in investigating how to lower data collection costs and not in determining the cost/benefit of reporting all NM. Normalisation of deviance must be recognised by workers through training, as all events must be reported. An apparently "overcollection" of NM today may turn out valuable data in the future
Wincek J. C.	2016	NM identified mainly through employees' reporting; if not, the process control system can automatically identify some of the NM, reviewed firstly by supervisors and secondly by engineers. NM communication through a Safety Alert distributed to other facilities. When analysing NM, root causes, and measures, new questions must be posed, leading to a safer system
Champion J. et al.	2017	A Learning Experience Report is developed for global distribution with challenging questions to motivate readers internalising event learnings. "Influencers" are chosen to lead others towards good practices. A PS corporate memory in training can assist in preventing significant events and create a continuum of crucial knowledge. Positive recognition for the team identifying and reporting an HP PSNM
Whiteoak J.W. et al.	2019	The program was tied to managers' key performance indicators (KPI) to reinforce management commitment. An automated telephone number was created to collect the data. Employees can leave a confidential recorded message regarding the NM

Gnoni et al. (2013) applied a lean version of the original NMS in a manufacturing firm using Learning from Experience (LFE) and demanding workers' and direct supervisors' autonomy. Saurin et al. (2008) also refer to the importance of learning, flexibility, and awareness. Singh and Verma (2019) mention that if the safety training is excellent, the Safety Climate will reduce accidents. This LFE requires the management's effort, as near-misses are many more than accidents, so they need a high level of resource effort(Gnoni and Lettera 2012).

Kadri et al. (2014) used a harmonised Process Safety Events program with other similar companies. Such benchmarking is essential for similar companies learning from each other and not remaining closed. Nevertheless, the company adapted the list to its reality. Awolusi and Marks (2015) refer to using existing approved lists for categorising root causes adapted to the environment or the organisation.

Andriulo and Gnoni (2014) verify the global effectiveness of an existing NMS. Fabiano and Currò (2012) and Konstandinidou et al. (2011) have proposed a cross-analysis between injuries and near-misses in a high-risk sector based on large databases, not a structured approach for analysing data derived directly from the field like Andriulo's.

Awolusi and Marks (2015) propose an NMS with fewer stages where the NM information should also be shared with other companies to bring synergy and integrate lessons learned into existing training. Champion et al. (2017) refer that corporate memory in training can assist in avoiding significant events and create crucial knowledge.

Madsen et al. (2016) refer that all near-misses must be reported. It also refers to the normalisation of deviance (Vaughan and Diane 1996) when unacceptable events become "acceptable" repeatedly. A near-miss may provide evidence for hazard threat and proof for system resilience, underestimating the danger (March et al. 2003). Workers may not report their errors if they believe they can recover (Der Schaaf and Tjerk, and Lisette Kanse. 2004).

Wincek and John (2020) presents some different examples of NM as: "Regarding Management of Change", failure to complete a change safely and timely is considered a Near-miss. " ISO45001:2018 in requirement 8.1.3 says: "The organisation shall establish a process(es) for the implementation and control of planned temporary and permanent changes that impact OH&S performance." Therefore, the organisation should review the consequences of unintended changes and mitigate any adverse effects, as changes can result in risks (or opportunities).

Champion et al. (2017) refer to sharing process safety collaboration networks, creating corporate memory in training, choosing "influencers ", recognition for reporting an HP PSNM, among others. Gnoni et al. (2013) value the involvement of all: employees and managers together in safety improvement. An effective NMS is everyone's responsibility (Kleindorfer et al. 2012). Workers' autonomy is based on learning, flexibility, and awareness (Saurin et al. 2008). Depending on how fast the worker can react, avoid the hazard, or interrupt the flow of events, the incident may be a near-miss (Mitropoulos et al. 2005). It is essential identifying key people among workers for implementing more effective behaviour-based safety practices (Xiong et al. 2018). Rewarding employees for good safety practices is not new, as in Phimister et al.

(2003) or Whiteoak and John (2019). However, in this study, the positive recognition goes to the team identifying and reporting an HP PSNM.

Whiteoak and John (2019) refers to some recommendations: senior management commitment, data-driven reidentification process, official recognition procedures. Anonymity, no punitive action, transparent communication, and processes developed to manage and act on NM reports are fundamental principles in the NMS. The program was tied to managers' key performance indicators (KPIs), reinforcing management commitment. Management Commitment has a positive effect on the Safety Climate (Singh and Verma 2019). If employees trust the efficacy of safety procedures, the organisation's safety improves. Usually, rewards to promote reporting are assigned to workers, but Champion et al. (2017) refer to a positive recognition for the team when identifying specific NM. ISO45001: (2018) refers in requirement 5.4 c) that the organisation shall remove obstacles to participation and minimise those that cannot be removed". Obstacles can include, among others, reprisals and practices that discourage or penalise worker participation. This study suggests leaving a confidential recorded message of near-misses.

Zhou et al. (2019) use an eight-stage NMS slightly different from the previously presented in Gnoni et al. (2013). Kleindorfer et al. (2012) also found it helpful to use an eight-stage NMS, referring that all eight steps should be performed fully and completely to get the full benefit from an NMS.

4 Conclusions

Since the development of the original procedure, authors adapted it introducing changes to its design and innovative characteristics. Although in some of the presented cases, those may be considered relatively minor, incremental, they represent an added value in terms of NM management and a vital know-how resource in a future adaptation of a similar procedure to different work situations and studied sectors. Different definitions and examples of near-misses were also introduced.

NMS can be crucial to prevent future accidents and consolidating a transversal culture of prevention. Safety culture is fundamental in any organisation willing to improve safety performance and start with the leadership and spread across the organisation. Therefore, knowledge is crucial to anticipate risk and to improve worker's autonomy. Workers will understand the importance of correct near-miss reporting and adhere voluntarily to it if they believe that it will also be taken seriously by management and lead to an effective improvement of safety at work. A culture that encourages workers to increasingly reporting near misses must be considered as a critical leadership goal.

A suggestion for future works would be the application of an NMS to the traditional manufacturing industry.

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References

Andriulo, S., Gnoni, M.G.: Measuring the effectiveness of a near-miss management system: an application in an automotive firm supplier. Reliab. Eng. Syst. Saf. **132**, 154–62 (2014)

Awolusi, Ibukun, Marks, Eric: Near-miss reporting to enhance safety in the steel industry. Iron Steel Technol. **12**(10), 62–68 (2015)

Berger, A., Carolyn K., Richard Z.: 5- The Five Neglects: Risks Gone Amiss (2010)

Champion, J., Van Geffen, S., Borrousch, L.: Reducing process safety events: an approach proven by sustainable results. Process Saf. Prog. **36**(4), 326–37 (2017). https://doi.org/10.1002/prs.11941

Dee, S.J., Cox, B.L., Ogle,R.A.: Using near misses to improve risk management decisions. Process Saf. Prog. **32**(4), 322–27 (2013). https://doi.org/10.1002/prs.11632

Dodshon, Philippa, Hassall, Maureen E.: Practitioners' perspectives on incident investigations. Saf. Sci. **93**, 187–98 (2017)

Fabiano, B., Currò, F.: From a survey on accidents in the downstream oil industry to the development of a detailed near-miss reporting system. Process Saf. Environ. Protect. **90**(5), 357–67 (2012)

Gnoni, M., Andriulo, S., Maggio, G., Nardone, P.: Lean occupational' safety: an application for a near-miss management system design. Saf. Sci. **12**, 13 (2013)

Gnoni, M., Lettera, G.: Near-miss management systems: a methodological comparison. J. Loss Prevent. Process Ind. **25**(3), 609–16 (2012)

Goraya, A., Amyotte, P.R., Khan, F.I.: An inherent safety-based incident investigation methodology. Process Saf. Prog. **23**(3), 197–205 (2004). https://doi.org/10.1002/prs.10032 (January 26, 2021)

ISO: Occupational Health and Safety Management Systems – Requirements with Guidance for Use (ISO Standard No. 45001) (2018)

Jones, Simon, Kirchsteiger, Christian, Bjerke, Willy: The importance of near miss reporting to further improve safety performance. J. Loss Prevent. Process Ind. **12**(1), 59–67 (1999)

Kadri, S. et al.: So we all have been implementing process safety metrics-what next?. Process Saf. Prog. **33**(2), 172–78 (2014). https://doi.org/10.1002/prs.11645 (January 11, 2021)

Kleindorfer, Paul, Oktem, Ulku G., Pariyani, Ankur, Seider, Warren D.: Assessment of catastrophe risk and potential losses in industry. Comput. Chem. Eng. **47**, 85–96 (2012)

Kletz, T.: Lessons from Disaster: How Organizations Have No Memory and Accidents Recur (1993). https://books.google.pt/books?hl=pt-PT&lr=&id=bnvLyTcwDE0C&oi=fnd&pg=PR3&dq=Kletz,+T.,+1993.+Lessons+From+Disaster:+How+Organizations+Have+No+Memory+and+Accidents+Recur.&ots=f-LNNFLljX&sig=CbnnNL-b8iczUVYZs7xrewTS7WY&redir_esc=y#v=onepage&q=Kletz%2CT.%2C (July 14, 2020)

Kletz, T.: What Went Wrong?: Case Histories of Process Plant Disasters and How They ... - (2009). https://books.google.pt/books?hl=pt-PT&lr=&id=zvabDwAAQBAJ&oi=fnd&pg=PP1&dq=%5BLIVRO%5D+What+went+wrong%3F:+case+histories+of+process+plant+disasters+and+how+they+could+have+been+avoided&ots=F7iCuItyTb&sig=ekhGnCdVLwocyD9toiSGIQcUsx8&redir_esc=y#v=onepage (July 14, 2020)

Konstandinidou, Myrto, Nivolianitou, Zoe, Kefalogianni, Eirini, Caroni, Chrys: In-depth analysis of the causal factors of incidents reported in the greek petrochemical industry. Reliab. Eng. Syst. Saf. **96**(11), 1448–55 (2011)

Madsen, P., Dillon, R.L., Tinsley, C.H.: Airline Safety Improvement Through Experience with Near-Misses: A Cautionary Tale. In Risk Analysis, pp. 1054–66. Blackwell Publishing Inc., (2016). http://doi.wiley.com/10.1111/risa.12503 (January 25, 2021)

March, J.G., Sproull, L.S., Tamuz, M.: Learning from samples of one or fewer. Quality Saf. Health Care **12**(6), 465-71 (2003). www.qshc.com (February 5, 2021)
Mcquiston, T.H., Lessin, N., Cable, S., Ouellette, D.: "Triangle of prevention: a union's experience promoting a systems-of-safety health and safety program. New Solutions **22**(3), 343–63 (2012). http://baywood.com (January 15, 2021)
Mitropoulos, P., Abdelhamid, T.S., Howell, G.A.: Systems model of construction accident causation. J. Constr. Eng. Manag. **131**(7), 816–25 (2005). http://ascelibrary.org/doi/10.1061/%28ASCE%290733-9364%282005%29131%3A7%28816%29 (February 21, 2020)
Moher, David, Liberati, Alessandro, Tetzlaff, Jennifer, Altman, Douglas G.: Preferred Reporting items for systematic reviews and meta-analyses: the PRISMA statement. J. Clin. Epidemiol. **62**(10), 1006–12 (2009)
Occupational Safety and Health Administration: OSHA Injury and Illness Recordkeeping and Reporting Requirements. https://www.osha.gov/recordkeeping/ (March 30, 2020)
Phimister, J.R., Oktem, U., Kleindorfer, P.R., Kunreuther, H.: Near-miss incident management in the chemical process industry. Risk Anal. **23**(3), 445–59 (2003). http://doi.wiley.com/10.1111/1539-6924.00326 (February 20, 2020)
Raviv, G., Shapira, A.: Systematic approach to crane-related near-miss analysis in the construction industry. Int. J. Constr. Manag. **18**(4), 310–20 (2018). https://www.tandfonline.com/doi/full/10.1080/15623599.2017.1382067 (February 20, 2020)
Saurin, Tarcisio Abreu, Formoso, Carlos Torres, Cambraia, Fabricio Borges: An analysis of construction safety best practices from a cognitive systems engineering perspective. Saf. Sci. **46**(8), 1169–83 (2008)
van der Schaaf, Tjerk, W., Kanse, L.: Biases in incident reporting databases: an empirical study in the chemical process industry. Saf. Sci. **42**(1), 57–67 (2004)
van der Schaaf, Tjerk, W.: Near Miss Reporting in the Chemical Process Industry - Ph.D. Thesis Eindhoven University of Technology (1992). https://doi.org/10.6100/IR384344 Accessed 8 Dec 2020
van der Schaaf, Tjerk W.: Near miss reporting in the chemical process industry: an overview. Microelectron. Reliab. **35**(9–10), 1233–43 (1995)
Singh, Vedant, Verma, Anita: Influence of respondent type on relationships between safety climate and safety performance in manufacturing firm. Proc. Inst. Mech. Eng. Part O: J. Risk Reliab. **233**(2), 268–84 (2019)
Thoroman, Brian, Goode, Natassia, Salmon, Paul: System thinking applied to near misses: a review of industry-wide near miss reporting systems. Theor.l Issues Ergon. Sci. **19**(6), 712–37 (2018)
Vaughan, D.: The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA 1996. https://books.google.com.br/books?hl=pt-PT&lr=&id=6f6LrdOXO6wC&oi=fnd&pg=PR9&dq=Vaughan+D.+The+Challenger+Launch+Decision:+Risky+Technology,+Culture,+and+Deviance+at+NASA.&ots=yfKTBoQLHV&sig=3TcG3tD03RtWChgdFsUPyPIc34E#v=onepage&q=VaughanD. The Challenge (January 25, 2021)
Whiteoak, J.: Mate, That Was Bloody Close! A Case History of a near-Miss Program in the Australian Construction Industry (2019). https://www.researchgate.net/publication/333935042. Accessed 4 Jan 2021
Wincek, J.C.: Amiss, a Miss, a near Miss. Process Saf. Prog. **35**(2), 137–42 (2016). https://doi.org/10.1002/prs.11757
Xiong, C., Liang, K., Luo, H., Fung, I.W.H.: Identification of safety-related opinion leaders among construction workers: evidence from scaffolders of metro construction in Wuhan, China. Int. J. Environ. Res. Public Health **15**(10) (2018)
Zhou, Z., Li, C., Mi, C., Qian, L.: Exploring the potential use of near-miss information to improve construction safety performance. Sustainability (Switzerland) **11**(5) 2019

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Occupational Risks Identification in the Red Ceramics Manufacturing Process

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Abstract Red ceramics manufacturing is a field that is strongly driven by the growth of construction that has great importance within the Brazilian economy. However, the companies involved in the production are usually small and work with outdated technologies, besides the lack of qualification of its workforce. Thus, workers get exposed to precarious working conditions, causing countless accidents. The objective of this study was to identify and evaluate the risks in the red ceramic manufacturing process. The survey embraced eight ceramic companies in northeastern Brazil, with 131 employees. Also, it was applied a checklist with safety items of Brazilian regulations to identify the degree of compliance of these companies. The checklist's results showed that all companies had safety items in disagreement with Brazilian law. It was possible to confirm that the workplace exposed workers to a high incidence of heat, noise, and dust, besides unprotected machinery, high physical effort, accidents risks, presenting a high degree of risk for workers.

Keywords Construction industry · Risk of accidents · Occupational safety

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1 Introduction

The Brazilian red ceramic industry is the main supplier of materials for masonry, roofing, and sanitation, whose main products are bricks, tiles, structural and sealing blocks, tubes, among other materials (Brazilian Support for Micro and Small Companies – SEBRAE 2015). According to the latest data from the Brazilian Association of Ceramic Industry—ANICER, the red ceramic industry represents 4,8% of civil construction in Brazil, and it is estimated that there are more than 9.000 companies of this segment in the Brazilian market. Also, it is responsible for about 300 thousand direct jobs and 1,5 million indirect jobs, with annual sales of around 18 billion Reais. Additionally, this segment is also characterized by the intense use of the labor force, since most companies are small and use processes without technology. Thus, these companies are providing a workplace with aspects that can directly influence workers' health and safety (Silva et al. 2017).

While other production processes became modernized, the red ceramics sector did not have significant progress in this area. Therefore, workers continue to face intense working hours and are being exposed to several risks with the potential to cause occupational diseases and work-related accidents (Morais 2015). According to Figueiredo (2015), the red ceramic workers can be exposed to several environmental factors that affect their health, such as dust, noise, inadequate lighting, excessive heat, difficulty in communication due to noise, musculoskeletal injuries; the latest is the red ceramic industry's main reason for absence from work. Additionally, Rocha (2013) reported that the lack of machine protection, fast production to attend the market, excessive heat and dust caused by geographical conditions, in addition to the lack of personal and collective protection equipment, worker's improper posture are the major issues that affect workers in red ceramic's industry.

Nevertheless, the safety issue has a bigger representation in companies budget due to technological development and processes modernization to avoid damage to workers health and labor charges, since it is known that work-related accidents can cause adverse impacts: to the worker, that become partially or totally disable; to organizations, that lose physical and human capital; to society, with people depending on social assistance (Ivascu & Cioca 2019). In addition, accident prevention is considered the result of processes that aim to eliminate or minimize occupational risks and injuries caused by them. In other words, it aims to protect employees from harmful conditions that might be caused by various reasons during the execution of work in the workplace (ILBAHAR 2018).

Further, to avoid work-related accidents and their negative impacts it's necessary to investigate all the possibilities to determine their causes and effects then set the instrument's capability to prevent and control them (Vasconcelos & Barkokébas Junior 2015). Kester (2015) says that the first thing to do to avoid accidents is to know which factors can cause them; if threats are known and the risks are considered, it is possible to plan the actions. Therefore, to know the threats, it is necessary to analyze all parts of the production process, including machinery and roles involved. Also, it is important to listen to the workers and their complaints as a part of the process to truly understand how the activity is impacting the lives of all involved. In addition, organizational members may have knowledge gaps that can be filled in with frontline workers' information (Oswald & Lingard 2019).

The Occupational Health and Safety (OHS) can decrease the number of work-related accidents and diseases), when applied in some productive sectors. Also, it has the potential to positively affect companies' performance, because workers in healthy environments tend to be more productive. Thus, contributing to a profit raise and increasing the company's competitiveness in the market (Gopang et al. 2017). In addition, the high number of events of work-related accidents in the ceramic industries and the lack of practices to avoid it highlights the necessity to study the safety and health conditions of the laborers.

2 Materials and Methods

The research methods comprehended the analysis of the risks of activities part of red ceramics productive process, through local inspections, checklist application with safety items provided by Brazilian law about this sector, and workers interviews. It is important to highlight that Brazilian law is very similar to Portuguese law, and this similarity is since both arise from international regulations, like North American and European (Katuki 2016).

The checklist was applied in eight ceramic sector companies, about 73% of companies in Assú's Valley micro-region (Fig. 1). This micro-region has 9 cities, among them Assú e Itajá, located in Rio Grande do Norte State—RN, northeast region of Brazil. The cities of Assú e Itajá were chosen for the fact they're the biggest red ceramic producers in Assú's Valley, also considered a big ceramics producer in the northeast of Brazil (SEBRAE, 2015).

It was interviewed 43,2% of these 8 companies employees, with a total of 131 people, with age between 18 and 35 years old, in the roles of production assistant, panel controller, loader, burner, oven filler, oven dryer, truck loader, mechanic and production manager. Furthermore, the steps of the ceramics production process have been identified (Fig. 2): extraction of raw material (clay); clay preparation; materials homogenization and mixing; materials extrusion; cutting the pieces; drying (dryer, shed, and patio); burning (ovens); storage and shipping (final product).

After collecting the companies information, data analysis and interpretation were carried out to identify the degree of compliance with Brazilian standards and occupational risks involved in the red ceramic manufacturing process, as reported incidents and complaints from employees.

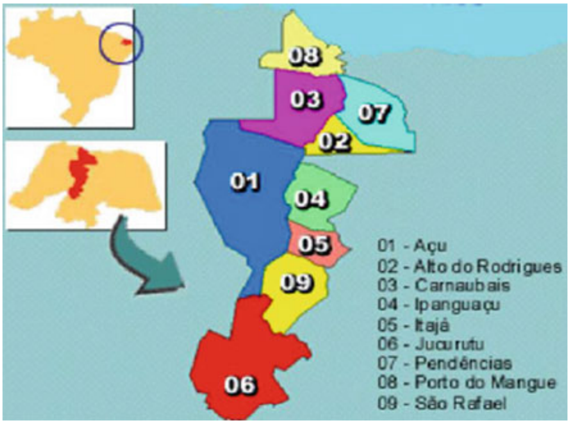

Fig. 1 Assú's Valley micro-region (Cunha Neto 2013)

3 Results and Discussion

Regarding the companies visited, it was seen that the number of employees per company varied from 26 to 90 people and their performance period varied from 8 to 44 years of activity. The companies also produced bricks, tiles, and structural blocks, with the tile the most produced material among them. However, tiles production is the activity that demands more physical wear for workers in the frontline because it requires a lot of repetitive movements and in an accelerated way. The types of ovens used by companies in the burning stage were also identified, which were the types Câmara, Hoffman, and Paulistinha, whose wood and firewood residues were used as fuel. The use of semi-continuous ovens (Câmara and Hoffman) is a positive factor in workers' exposure to risk, as it reduces exposure to high temperatures and the inhalation of burning smoke particles, in addition, to reduce environmental damage due to the use of sawdust instead of the firewood extraction.

It was found that all companies performed quantitative analyzes of lighting, temperature, and noise in the workplace, however, in 6 of the 8 companies there wasn't adequate lighting, and in 2 of these 6, there were very dark workplaces, a factor that causes discomfort and work accidents. Regarding the temperature, half of the companies were above the tolerable limits provided by Brazilian law, and the other half, which showed values below these limits, used to work with Câmara ovens, considered safer ovens. As for noise analysis, it was found that 5 companies exceeded the tolerable limits provided by Brazilian law. In this sector, it is common to have contact and inhalation of clay dust, in addition to inhalation and direct exposure to burning smoke, which leads to respiratory problems in workers, besides eye and skin irritation (Gottardo 2013). However, it wasn't identified quantitative analysis of dust in all companies visited. Although in all stages of red ceramic manufacturing, there are inadequate body movements, such as inclined body, repetitive movements, weight lifting, pull and push, and sudden movements (Silva et al. 2017), it was seen that in

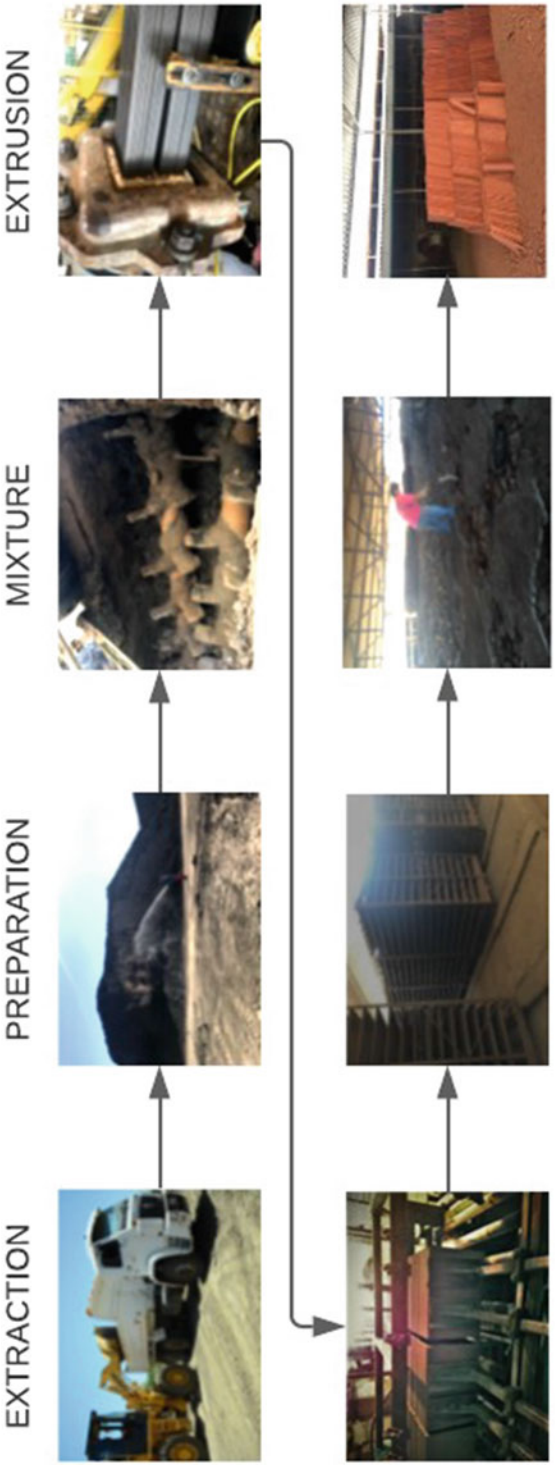

Fig. 2 Steps of the ceramics production process (Author 2019)

6 of 8 visited companies did not promote activities related to workers ergonomics posture.

During the visits, it was also possible to observe the precariousness of the facilities where the ceramic activities are developed, including the living areas. In 6 of the 8 places visited, the buildings' structure was old and didn't have maintenance, which can lead to accident risks. This shows that the companies structures, the safety conditions in the workplace, and the production process are not appropriate to the activities carried out by workers.

The interview with 131 employees of the 8 companies was able to prove how the lack of OHS actions in the workplace can negatively impact workers' safety and health. Many workers already had an allergic reaction caused by dust and/or smoke in the workplace, which can be detected by skin irritation, and eye irritation, sinusitis, asthma, and sneezing crisis. It was also asked if the workers felt pain due to physical effort and repetitive movements on the roles performed, and many answers obtained were related to pain in the arms and shoulders, pain in the legs and feet, and pain in the back and lower back. The vast majority of employees who did not feel pain were younger workers and participants from companies that perform labor gymnastics at least once every 15 days.

Regarding work-related accidents, it was found that 40.5% of the 131 employees have suffered accidents, such as lower and upper limbs cuts, lower and upper limbs fractures, fingers crushed in machinery, electric shock, and other types of accidents, such as burial, accidents in the way to work and herniated discs (Fig. 3). Demirkesen (2019) stated that the high number of work-related accidents indicates that current safety measures are not good enough to improve safety performance, so it brings up the need for different approaches and applications in construction safety.

Incorrect installation can cause electric shock and short circuits, resulting in severe damage to the employee, and can also be a big factor in fire within the workplace. It was possible to notice in the visits the precariousness of the electrical installations in most of the companies, a proven problem due to the workers' complaints about electric shock in the machines. Also, half of the companies did not have signs for the circulation areas where the machines and equipment are located. This absence can cause serious accidents due to unauthorized persons stepping into the production site for machinery and equipment.

Risks of falls on equipment, moving parts, loose objects along the floor, and falls of the same and different levels were the main risks found in the visited companies, which are risks mainly related to technical and organizational issues. The protection in the machinery was the requirement that presented the worst result; historically are the ones that have the highest accident rate within a company if the appropriate measures are not taken. Most companies did not attend to what is established in the Brazilian law about machinery and equipment, regarding the protection such the moving parts of the equipment as its ways of access, which can cause minimal injuries, loss of limbs, and loss of life. More than half of the visited companies that use top's supply ovens did not attend the items of stairs and protection against falling from a height, admitted in Brazilian standards, whereas the other types of ovens used showed an old structure and with the need for maintenance.

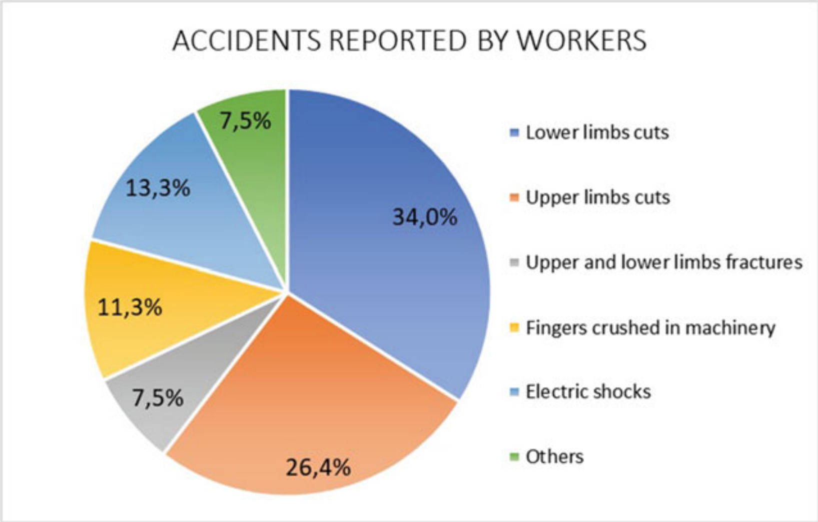

Fig. 3 Accidents reported by workers (Author 2019)

The question of ergonomics must also be reevaluated and corrected, as it was evident that workers perform activities with a huge physical effort and overweight, especially in the roles of oven filler, oven dryer, and truck loader. These efforts can cause fatigue, stress, and spinal problems such as low back pain (Morais 2015), a reality confirmed in the companies evaluated due to workers' complaints about physical effort and lower back pain.

4 Conclusions

The survey was applied in 8 ceramic companies of Assús's Valley, with a total of 131 people, about 43,2% of these companies employees, with age between 18 and 35 years old, in the roles of production assistant, panel controller, loader, burner, oven filler, oven dryer, truck loader, mechanic and production manager. The 8 companies studied have been in operation for more than 8 years and the material most produced for them were tiles. The evaluations carried out indicated several differences between the correct way of operating a production process in the ceramic sector and the way that companies and workers are behaving in the face of this process. In most of the companies evaluated, the working conditions were considered precarious. Additionally, it was observed failures in attending Brazilian law in all companies and low involvement of workers in activities related to OSH.

The main workers' complaints were lower back pain caused by physical effort and repetitive movements, in addition to the excessive heat caused by the oven's high temperatures and the region's hot climate, factors presented in the entire production process of red ceramics. The activities related to the manufacture of red ceramics expose the workers to a high incidence of heat, noise, and dust, unprotected machinery, high physical effort with repetitive movements, risk of accidents, disorganization in the workplace, inadequate facilities, intense dirt, lack of safety signs, etc., which presents a high degree of risk for workers.

Fundamentally, companies should improve the working conditions of their workplaces to prevent and minimize potential risks during labor activities and seek to perform risk management plans through organizational and technical actions and employee training.

References

Brazilian Association of Ceramic Industry—ANICER: Sector data (2015). https://www.anicer.com.br/anicer/setor/

Brazilian Support for Micro and Small Companies – SEBRAE. Intelligence bulletin (2015). http://www.bibliotecas.sebrae.com.br/chronus/ARQUIVOS_CHRONUS/bds/bds.nsf/b877f9b38e787b32594c8b6e5c39b244/$File/5846.pdf

Cunha Neto, F.A.: (Un)sustainable development of red ceramics industry of micro-region of Vale-do-Açu/RN, p. 2013. Federal University of Rio Grande do Norte, Natal (2013)

Demirkesen, S.: Measuring the impact of Lean implementation on construction safety performance: a structural equation model. Product. Plan. Control **31**, (5), 412–433, 2020 (2019). https://doi.org/10.1080/09537287.2019.1675914

Figueiredo, M.P.: Ergonomics Work Analysis—Ceramics Industry. Federal University of Paraná, Curitiba (2015)

Gopang, M.A. et al.: An empirical investigation. An assessment of occupational health and safety measures and performance of SMEs. Saf. Sci. **93**, 127–133 (2017). https://doi.org/10.1016/j.ssci.2016.11.024

Gottardo, I.A.: Occupational risks analysis of red ceramics industry in west Santa Catarina. Santa Catarina's Western University, São Miguel do Oeste (2013)

Ilbahar, E., et al.: A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system. Saf. Sci. **103**, 124–136 (2018). https://doi.org/10.1016/j.ssci.2017.10.025

Ivascu, L., Cioca, L. (2019). Occupational accidents assessment by field of activity and investigation model for prevention and control. Safety **5**(1), 12 (2019). https://doi.org/10.3390/safety5010012

Katuki, D.K.: Comparative analysis between the safety rules of the Brazilian and Portuguese work on the site of construction. Federal Technological University of Paraná, Campo Mourão (2016)

Kester, L.V.: Safety work management system evaluation: comparative studies between two red ceramic companies in the eastern of Rondônia, p. 2015. Federal University of Rondônia, Cacoal (2015)

de Morais, M.M.: Waste management in red ceramics industry: a multiple case study in developing region of Pernambuco, p. 2015. Federal Rural University of Pernambuco, Recife (2015)

Oswald, D., Lingard, H.: Development of a frontline H&S leadership maturity model in the construction industry. Saf. Sci. **118**, 674–686 (2019). https://doi.org/10.1016/j.ssci.2019.06.005

Rocha, F.R.F.: Worker's safety in red ceramics industry in Itajá/RN city. Federal Rural University of Semi-Árido, Angicos (2013)

Silva, E.J. et al.: Ergonomic perspective of red ceramic productive process: case study. In: Production Engineering National Meeting—ENEGEP, vol. 37, pp. 1–25, Joinville (2017)

Silva, M.M.N. et al.: Environmental risk analysis of ceramic activity in Encanto/RN city. In: Production Engineer Symposium, João Pessoa, vol. 3, pp. 1–15 (2015)
Vasconcelos, B., Barkokébas, B. Jr.: The causes of workplace accidents and their relation to construction equipment design. Procedia Manuf. **3**, 4392–4399 (2015). https://doi.org/10.1016/j.promfg.2015.07.437

Risk Assessment at the Connection from Mondim de Basto to EN210

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Abstract The main objective of this paper is to analyze the occupational hazards and risks associated with intervention works and the construction. The connection from Mondim de Basto to EN210 is a building project that will provide new accesses from the municipality of Celorico de Basto to the municipality of Mondim de Basto, bringing together two important districts of Portugal through a new road with two new bridges. The risk analysis focuses on building one of them, which is the bridge that will pass over the Tâmega River. Based on Legislation no. 273/2003 of October 29, which is the primary law regarding the safety and health of construction projects, along with the risk assessment which applied to three of the existent tasks located on the Map of Work Quantities. After the risk analysis, preventive measures were proposed through applying protection methods, including supervision. Overall, the methodology showed positive results regarding the risk assessment for each task and the proper measures to avoid any possible accident, ensuring the safety of the worksite.

Keywords Construction · Safety · Accident · Prevention

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1 Introduction

The execution of such interventions like the connection from Mondim de Basto to EN210 supported statistical analysis, developed by the National Institute of Statistics (INE) in 2018, which reported a 4,0% increase in the national light vehicle fleet and a 5,8% in heavy-duty vehicles. This data indicates an aggravated vehicle flow, which directly impacts the logistics sector by delaying economic activities that depend on road transport. Thus, the establishment of the bridge represents a considerable advantage for citizens who use the highway as their main transport system, significantly reducing the travel time between Celorico de Basto and the A4 highway.

First and foremost, Cohen & Palmer (2004) defines risk as "[...] simply the potential for complications and problems with respect to the completion of a task and the achievement of a project goal.", which impacts directly on the management of a project (Schieg 2006), causing disparity at the financial, duration and quality areas (Akintoye & MacLeod 1997). This project alone is not different and has multiple difficult assignments to perform. Given its complexity, these activities may also have many possible risks of accidents associated with them, as described by Nieto-Morote & Ruz-Vila (2011) about construction projects.

According to Cardoso (2009) and Lima (2004), the construction sector is one of the most dangerous activities due to its high probability of the occurrence of any type of accident. Therefore, based on Legislation no. 273/2003 of October 29, this article aims to evaluate the intervention, focusing on hazards implicated on three of the construction's tasks of the bridge over the Tâmega river because these tasks were considered the most critical ones.

To do that, the content of this paperwork was divided into an overview of the whole project and its information; the specific attributes and characteristics of the studied bridge; all the required works and processes of the building; its related risks; the assessment of these risks through the applied methodology; the preventive measures, based on the review of dangers and the analysis of the contingency plan, including the information of the infection agent, the symptoms, the contamination, and the prevention methods.

1.1 Overview of the Intervention

The execution project, known as "Ligação de Mondim de Basto à EN210", is an intervention located in the county of Celorico de Basto (Braga District) in which there is a development of a new junction between the national road EN210 and the county of Mondim de Basto (Vila Real District). The project includes an alternative path with the primary purpose of reducing the distance between these two municipalities. The building has the company CENOR—Consulting Engineers as the designer, RRC—Ramalho Rosa Cobetar, SA as the contractor, and IP—Infraestruturas de Portugal, SA as the surveillance organ and the project owner.

Fig. 1 Bridge over Veade River (personal source, 2020)

The connection consists of a road that starts at the EN210, passes through EN304, and finishes in Mondim de Basto, with a length of '3600 meters long. It contains three roundabouts and three crossroads to the main road system together with two bridges. The first bridge is established over the north hillside of the Veade River, and it connects to EN304, as seen in Fig. 1. Nonetheless, the second bridge (Fig. 2), which is what this article is centered on, starts at the EN304, passes over the Tâmega River, and finishes in Mondim de Basto, at the same EN304.

Bridge over Tâmega River: The bridge over Tâmega River (Fig. 2) is considered the final zone of the intervention's layout, based on the execution project. As mentioned before, this article adopts this bridge as the main study object. It connects EN304 at km 3+475 to the consolidated urban zone in Mondim de Basto at km 3+646. Concerning the main width, the traffic lane is 6.0m wide, 0.25m for the roadside, the sidewalk on the right side is 1.60m and the bicycle path on the left side is 2.45m wide, with a road barricade 0,40m wide between the bicycle path and the traffic lane.

As for the structural solution, the pillars are an average of 44.50m high in reinforced concrete with an empty stem; as for the bridge deck, it's made in a "π" shape in prestressed reinforced concrete at the longitudinal direction and reinforced concrete at the transversal direction, with a beamed slab with two longitudinal beams of 2.60m high. The bridge's deck is 11.00m wide through all its extension.

Fig. 2 Bridge over Tâmega River (*Source* Infraestruturas de Portugal, 2020)

1.2 Intervention Works

After acknowledging the project, the proposed intervention was classified and separated into specific areas that are the primary duties that interdepend on each other, respecting the order that every task requires to move to the next one. This is represented by the following list, provided by Infraestruturas de Portugal, which is denominated as the Map of Work Quantities (MQT), based on the project of the bridge. A detailed description of every task was considered unnecessary and would make the paper too lengthy, justifying a summary submission. 1. Assembly/Exploration/Disassembly of the Worksite; 2. Deforestation; 3. Demolitions; 4. Earthworks, Excavation and Embankment; 5. Gabion walls; 6. Reinforced Concrete Structures; 7. Pre-stress application; 8. Assembly, usage and disassembly of the centering and special scaffolding; 9. Assembly, usage and disassembly of the movable scaffolding system; 10. Assembly, use and disassembly of current scaffolding; 11. Transport and assembly of prefabricated elements; 12. Drainage; 13. Paving; 14. Landscape Integration; 15. Technical Road Channel (CTR); 16. Public lighting; 17. Slope stabilization; 18. Signage and Safety Equipment; 19. Seals; 20. Transport and lifting of materials; 21. Assembly of metallic structure, guardrails and finishes (works of art); 22. Temporary traffic detour; 23. Affected services, Public Services Networks.

2 Methodology

It is essential to have a preventive plan and a proper usage of the most successful protection methods against accidents to guarantee and obtain security for the construction workers and personnel involved (Dziadosz, 2015). Legislation no. 273/2003

Table 1 Characterization of task and risks in the bridge

Task	Risks
Reinforced concrete structures	Burial (M) Soil Slippage (M) Falling (H) Equipment drops (H) Falling materials (H) Crushing due to falling materials (H) Instability/collapse (H) Noise (M) Vibrations (M) Dermatoses (H) Projection of particles or materials (M) Electrocution/electrification (M) Perforation/cuts (H) Flood/drowning (M) Musculoskeletal injuries (M)
Assembly, usage and disassembly of the centering and special scaffolding Assembly, usage and disassembly of the movable scaffolding system*	Falling (H) Falling materials (H) Fall at the same level (M) Instability/collapse (H) Flood/entrainment (M) Perforation/cuts (H)

of October 29 is the legislation in Portugal that both recommends and ensures all the safety and health procedures that are effective when a potential casualty happens in the work environment.

Risk Identification and Analysis: identifying and analyzing the potential risks is the initial process to "[...] determine the actions to avert the threats on any project" (Mhetre et al. 2016). Map of Work Quantities (MQT) deals with risk management in this project, which has all the project definitions related to the intervention in Table 1. This map displays multiple types of positions and materials necessary to build all the different parts of the bridge. Therefore, the first step is to evaluate and rank the risks associated with every work (El-Sayegh 2008; Williams 1995) through the Non-Exhaustive List of Works with Special Risks. This list labels the risks of each assignment according to the potential danger. The labels are Low (L), Mid (M), and High (H) danger.

It is important to emphasize that all the construction works of the bridge were carefully analyzed through this methodology, according to its risks and potential danger, as mentioned before. However, only three of all the positions described by "Intervention works" were exhibited in this article due to the results' extension produced by this methodology. Works are selected based on the highest complexity, danger level, and the number of risks to evaluate all tasks.

Assembly, usage and disassembly of the centering and special scaffolding and Assembly, usage and disassembly of the movable scaffolding system are similar tasks and have the same risks. As this paper had the objective of focusing more on

Table 2 Characterization of degrees of probability and severity

Level	Probability	Severity
1	Rarely happens	Almost no damage
2	Happens sporadically	The damage is light
3	Happens many times	The damage is significant
4	Happens almost every time	The damage is very significant

Table 3 Quantification of degrees of probability and severity

	Probability				
		1	2	3	4
	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
Severity	4	4	8	12	16

risks than on tasks and to show the assessment and application of the methodology, it wasn't described the works within each activity, nor the preventive actions, nor the IPEs, to facilitate reading and understanding of the risk assessment.

Prevention measures: After acknowledging the risks involved in each construction task of the bridge, the next step is to define adequate preventive measures to maintain the safest environment at the worksite (Barroso 2005). Procedures are all planned and tested to prevent accidents or injuries at the worksite, even though it is difficult to find all the potential risks and correct them with a suitable method.

Therefore, to do that, the methodology that was used during this study is simple but an efficient procedure, approved and implemented by the Security Coordinator of Infraestruturas de Portugal. This method has a similar format used by Eliana Capinteiro (2018), Rui Pinto (2013), He Zhi (1995), Williams (1993), and Felipe Meretti (2020), by applying, according to the Specific Plan of Monitorization and Prevention (SPMP), the characterization and quantification of the danger to its Probability (P) and Severity (S) (Pinto 2002; McGeorge and Zou 2012; Windapo 2013) presented in Tables 2 and 3. In Table 2, specifically, the temporal scale would have "rarely happens" (1) representing an infrequent occurrence, "happens sporadically" (2) representing an event likely to occur occasionally in a week, "happens many times" (3) representing an event of a daily occurrence and "happens almost every time" (4) representing an event that occurs continuously or several times a day.

As $RL = P \times S$, RL being RISK LEVEL.

Then, at the Table 4, the previously quantified risks are classified according to the risk level, the correct meaning of the risk and the right intervention. Finally, the Table 5 shows the division of the many works which will occur, its potential risks of each work, the probability of happening, the severity and its correction urgency, as classified by the previous tables.

Table 4 Risk level assessment criteria

Risk Level	Meaning	Intervention
12–16	Unacceptable	Urgent correction
6–9	Important	Fix and add control actions
3–4	Moderate	Stablish control actions
1–2	Acceptable	No need of a short-term intervention

Through the methodology, it is clear to notice in Table 5 which of the potential dangers are most likely to happen by observing the Risk Level (RL). Therefore, based on this information, these items provide the right direction of the most efficient preventive actions to correct and certify the safety of each work. The list below displays only the main proposed method for each associated risk following the order of Tables 1 and 5, even though there are more procedures that are not presented in this paper, as it would make it too lengthy.

- Appropriate clothing—The utilization of the Personal Protection Equipment (PPE) are mandatory, like helmets, steel-toe boots and reflective jacket;
- Allocate the loads in a stable and properly tied way;
- Always apply the usage of the fall protection equipment and keep a safe distance from high edges;
- Respect the load limits and respect the safe perimeter of the utilization of the equipment;
- Create a safe perimeter and never overfly the materials above any person and allocate the loads in a stable and properly tied way;
- Allocate the loads in a stable and properly tied way and appropriate clothing (PPE's);
- Utilization of the appropriate clothing and accomplish of the right execution phases of each element of the reinforced concrete;
- Utilization of the appropriate hearing protection;
- Utilization of the appropriate clothing (PPE's) and take regular breaks during the work;
- Utilization of the appropriate clothing (PPE's) and be extra cautious at the manipulation of chemical substances;
- All the pipeline, specially the high-pressure ones, must resist all the external and internal loads and firmly attached and protected;
- Keep all the electrical cables out of the path of workers and equipment. Also, implement electrical grounding to all metallic structures, equipment and electricity grid;
- Utilization of the appropriate clothing (PPE's), protection of any sharp edges and organization of the worksite;
- There must be a safety float or any quick rescue equipment;

Table 5 Risk level

Assemblage of the worksite				
Works	Potential risks	P	S	RL
Reinforced concrete structures	Burial	1	2	2
	Soil Slippage	1	3	3
	Falling	2	3	6
	Equipment drops	2	2	4
	Falling materials	1	3	3
	Crushing due to falling materials	1	3	3
	Instability/collapse	2	2	4
	Noise	3	2	6
	Vibrations	2	2	4
	Dermatoses	2	2	4
	Projection of particles or materials	1	3	3
	Electrocution/ electrification	2	3	6
	Perforation/cuts	2	2	4
	Flood/drowning	2	4	8
	Musculoskeletal injuries	3	2	6
Assembly, usage and disassembly of the centering and special scaffolding and movable scaffolding system	Falling	2	3	6
	Falling materials	1	3	3
	Fall at the same level	2	2	4
	Instability/ collapse	2	2	4
	Flood/entrainment	2	4	8
	Perforation/cuts	2	2	4

- Right utilization of the work tools and adoption of ergonomically correct working postures;
- Always apply the usage of the fall protection equipment and keep a safe distance from high edges;
- Create a safe perimeter and never overfly the materials above any person and allocate the loads in a stable and properly tied way;

• Do not obstruct the circulation path with material and keep the worksite organized;

• The structure must fully respect the project and accomplish the assemblage plan; also fulfill the installation cycle;

• There must be a safety float or any quick rescue equipment;

• Utilization of the appropriate clothing (PPE's), protection of any sharp edges, and the worksites organization.

3 Results

Succeeding the analysis of the risks based on the visits at this intervention following the methodology of the risk assessment and proper safety precautions. It was acknowledged that all the risks were avoided through the listed measures and in the Specific Plan of Monitorization and Prevention (SPMP). It was not found any risks there were not covered by this plan. All of the protection measures (foreseen in the plan) were implemented and followed by the workers. It is important to highlight that the protective measures for each investigated task of this article are according to Legislation no. 273/2003 of October 29. According to the Security Coordinator, the project owner (Infraestruturas de Portugal) used this methodology because it presented total efficiency, as proven by the results of no accidents, neither fatal nor non-fatal, nor irregularities throughout this entire project.

4 Conclusion

After analyzing the existent information from this intervention, the fundamental construction processes at the Map of Work Quantities done for the bridge over the Tâmega river and the potential risks of each work needed. However, this made it indispensable to search and figure out all the protective measures, challenging risks, and best preventive method to avoid accidents and keep these workers safe. Legislation no. 273/2003 of October 29, besides being a decree-law, is reasonable due to the instructions and requirements that indicate the guideline to have safe construction work. Its accuracy and responsible instructions are very detailed. Hence, all the entities involved in this construction followed the requisitions for a safe worksite.

Although the methodology was straightforward, it showed positive results regarding the risk evaluation, the probability of happening, the severity in case of accidental occurrence, and the precise moment for intervention to avoid danger for the workers.

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References

Akintoye, A.S., MacLeod, M.J.: Risk analysis and management in construction. Int. J. Proj. Manag. **15**(1), 31–38 (1997)
Barroso, L.M.D.S.: Levantamento das necessidades de formação em prevenção e segurança dos trabalhadores na construção civil: estudo de caso. Estudos **II**, 187–213 (2005)
Cardoso, P.S.R.: Modelo de prevenção de acidentes na construção (2009)
Carpinteiro, L., Reis, C.M., Paula, S., Correia, J., Ferreira, J., Oliveira, C.: Risk analysis in the execution of the Águas Santas Tunnel. In: Occupational safety and hygiene VI—Selected, Extended and Revised Contributions from the International Symposium Occupational Safety and Hygiene, pp. 595–600. CR Press Taylor & Francis Group (2018). ISBN: 978-1-138-54203-7 (Hardback) ISBN: 978-1-351-00888-4 (eBook)
Cohen, M.W., Palmer, G.R.: Project risk identification and management. AACE Int. Trans. IN11 (2004)
Decreto-Lei n.º 273/2003 (2003). Diário da República n.º 251/2003, Série I-A de 2003-10-29. https://dre.pt/pesquisa/-/search/466181/details/maximized
Dziadosz, A., Rejment, M.: Risk analysis in construction project-chosen methods. Procedia Eng. **122**, 258–265 (2015)
El-Sayegh, S.M.: Risk assessment and allocation in the UAE construction industry. Int. J. Proj. Manag. **26**, 431–438 (2008)
Instituto Nacional de Estatística - Estatísticas dos Transportes e Comunicações: 2018. Lisboa : INE (2019). https://www.ine.pt/xurl/pub/358630755. ISSN 0377-2292. ISBN 978-989-25-0507-7
Lima, T.M.: Trabalho e risco no sector da construção civil em Portugal: Desafios a uma cultura de prevenção. Oficina do CES **211**, 1–13 (2004)
McGeorge, D., Zou, P.X.: Construction Management: New Directions. Wiley (2012)
Meretti, F.S., Reis, C., Baptista, J.J.F., Fernandes, L.S., Oliveira, C. (2020). Safety at rehabilitation works of the Cavez Bridge Over Tâmega River. In: Occupational and Environmental Safety and Health II, pp. 105–113. Springer, Cham
Mhetre, K., Konnur, B.A., Landage, A.B.: Risk management in construction industry. Int. J. Eng. Res. **5**(1), 153–155 (2016)
Nieto-Morote, A., Ruz-Vila, F.: A fuzzy approach to construction project risk assessment. Int. J. Proj. Manag. **29**(2), 220–231 (2011)
Pinto, J.K.: Project management 2002. Res.-Technol. Manag. **45**(2), 22–37 (2002)
Pinto, R.M.D.L.F.: Avaliação e controlo de riscos na execução de uma ponte com recurso a carros de avanço (Doctoral dissertation) (2013)
Schieg, M.: Risk management in construction project management. J. Bus. Econ. Manag. **7**(2), 77–83 (2006)
Williams, T.M.: Risk-management infrastructures. Int. J. Proj. Manag. **11**(1), 5–10 (1993)
Williams, T.M.: A classified bibliography of recent research relating to project risk management. Eur. J. Oper. Res. **85**, 18–38 (1995)
Windapo, A.O.: Relationship between degree of risk, cost and level of compliance to occupational health and safety regulations in construction. Construct. Econ. Build. **13**(2), 67–82 (2013)
Zhi, H.: Risk management for overseas construction projects. Int. J. Proj. Manag. **13**(4), 231–237 (1995)

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Occupational and Environmental Hygiene

Analysis of Whole-Body Vibration Transmitted in Ready Mix Concrete Delivery Operations

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Abstract Objective: The aim of this study was to identify and analyse whole-body vibration (WBV) exposure in the ready mix concrete (RMC) industry. Several assessment methods have been compared to determine whether the criteria predict similar health risks of WBV exposure. Background: Professional drivers are exposed to high levels of vibrations during different activities. Continued exposure to WBV may cause musculoskeletal disorders and degenerative changes in the lumbar spine. Method: WBV exposure was measured and assessed in accordance with EU Directive 2002/44/CE and ISO2631-5:2018. Results: Drivers who perform RMC delivery with trucks are exposed to a high level of WBV. The average velocity and the type of surfaces are factors that influence the magnitude of the WBV exposure. Conclusion: Ensuring the health and safety of workers exposed to WBV on a daily basis requires analysis of the exposure patterns. A database containing the lifetime WBV exposure history of drivers is key information to estimate more accurately the probability of adverse health effects associated with long-term WBV exposure. Application: This study is a step forward in current efforts to encourage companies to improve the management of WBV exposure to prevent musculoskeletal disorders.

Keywords Whole-body vibration exposure · Physical agent · Directive 2002/44/ec · ISO2631-5 · 2018

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1 Introduction

Musculoskeletal disorders (MSDs) are a global health problem that affects more than half of the European workforce (EU-OSHA 2019) and a third of the worldwide population (Briggs et al. 2018). Indeed, MSDs are the leading causes of years lived with disability (16% of all years lived with disability) according to the 2017 Global Burden Disease study (James et al. 2018). Low back pain, which is a type of MSD, has also been the main single cause of disability since 1990 (James et al. 2018; Vos et al. 2012). Consequently, MSDs are also the most expensive form of work disability and, hence, exert important socioeconomic consequences (Russo et al. 2020).

Several epidemiological studies have provided evidence of a causal relationship between the development of work-related musculoskeletal disorders and whole-body vibration (WBV) exposure (Eurofound 2015; EU-OSHA 2019). MSDs include diseases such as low back pain (Raffler et al. 2017), degenerative changes in the lumbar spine (Singh et al. 2019; Wahlström et al. 2018), sciatica (Burström et al. 2015) and disorders such as motor performance (Costa et al. 2014). These health problems have severe consequences on the workers' health, and these effects substantially deteriorate their physical and emotional health, work productivity (Nelson & Hughes 2009; Punnett & Wegman 2004; Wahlström 2005) and even cause chronic disability and sick leave absence (Briggs et al. 2018).

Previous research has shown that not all occupational sectors are equally affected by MSDs (Hagberg et al. 2012). Indeed, the construction industry is one occupational sector in which workers present a higher prevalence of work-related MSDs (Nielsen et al. 2018; EU-OSHA 2020). Physical hazards, such as exposure to WBV due to the operation of construction machinery, are one of the main factors attributed to the high prevalence of MSDs in the construction sector (EU-OSHA 2020). This situation is aggravated by economic crises that have affected the sector. The inability to purchase new equipment (construction machinery and vehicles) means that the average age of vehicles in use has increased and, consequently, the risks related to obsolescence such as exposure to higher WBV have increased (EU-OSHA (2020)). These vehicles may be used on a daily basis by operators, resulting in workers being exposed to WBV while performing the tasks of driving heavy equipment or vehicles (De la Hoz-Torres et al. 2020; Krajnak 2018). The use of these types of vehicles is not limited to construction sites. In fact, 30% of tonnage carried within cities is generated by urban freight transport activities by specific market segments of the construction sector (Guerlain et al. 2019). In various sub-sectors of the construction industry—ready mixed concrete (RMC), cement, building materials, etc.—workers are exposed to WBV throughout the working day by driving delivery vehicles.

Among all the sub-sectors, RMC is one of the most important in the construction industry because this material is one of the most required for modern buildings. In 2018, the total average RMC production in the European Union (EU) was 250.43 million m3. Despite the high level of activity generated by the sub-sector, there have been few academic studies about how RMC operations affect the safety and health of workers (Akboğa & Baradan 2016). Because the activities performed by drivers can involve biomechanical risk, they must be analysed to obtain a proper risk assessment and to guarantee drivers' safety (EU-OSHA 2020). In this context, the aim of this study was to evaluate the level of WBV exposure during delivering RMC to construction sites. For this purpose, in situ measurements were taken from real RMC delivery operations. The methods defined in EU Directive 2002/44/EC for daily vibration exposure assessment (defined in ISO2631-1:1997) and the method defined in ISO 2631-5:2018 for long-term WBV exposure assessment were applied. The results were then used to determine whether drivers are exposed to WBV levels that exceed those set in the standard during a normal working day.

2 Materials and Methods

2.1 Instrument and Experimental Procedure

To characterize the health risks associated with RMC truck driving, an interview was conducted with truck drivers of an RMC company. Among the workers interviewed, the driver with the most years of experience and without current pain and history of MSDs was selected for the field study. He had more than 20 years of operation time (experience as a truck driver), was 1.85 m tall and weighed 118 kg. The selected vehicle was a MAN TGS 35.420 8 $\times$ 4 BB Concrete Mixer Truck. The worker uses this vehicle on a regular basis.
WBV exposure was measured during normal RMC delivery operations. For this purpose, acceleration was measured at the driver/seat interface. The instruments used for this purpose were the Human Vibration Meter and Analyzer SVAN 106 and the triaxial seat pad accelerometer SV 38V manufactured by SVANTEK. These instruments meet the requirements of ISO 5349-1&2 and ISO 2631-1&5. At the same time that the acceleration was recorded, the time and position of the vehicle were recorded using a Global Positioning System (GPS).

2.2 Methodology

From the data obtained in the *in situ* measurement, the WBV assessment methods defined in EU Directive 2002/44/EC and ISO 2631-5:2018 were applied. EU Directive 2002/44/EC was published by the European Parliament to ensure the health and safety of each worker and to create a minimum basis of protection for all community workers by timely detection of adverse health effects arising or likely to arise from exposure to mechanical vibration, especially MSDs. For this purpose, the Directive states that the method defined in ISO2631-1 (the daily exposure [A(8)] and vibration dose value [VDV]) must be used to evaluate the risk associated with WBV exposure. In this study, both methods were used to assess WBV exposure in the workplace.

A(8) is calculated based on the root mean square (rms_w) of the weighted averaged acceleration measured in the seat surface (Eq. 1). The daily exposure value A(8) in each axis is calculated using Eq. 2.

$$rms_w = \frac{1}{T}\left[\int_0^T a_{iw}^2(t)\,dt\right]^{\frac{1}{2}} \tag{1}$$

$$A(8)_i = k_i \cdot rms_{iw} \cdot \sqrt{\frac{T_{exp}}{T_0}} \tag{2}$$

In the above equations, i denotes the x-axis, y-axis or z-axis; a_w is the frequency-weighted instantaneous acceleration (W_d on the x-axis and y-axis, W_k on the z-axis); T is the time duration of the measurement; k denotes the multiplication factor defined for each axis ($k_{x,y} = 1.4$ and $k_z = 1$); T_meas is the measurement period; and T_0 is the reference duration of 8 h.

VDV is calculated based on the vibration dose value (VDV_w) the acceleration measured in the seat surface. $vdvw$ is calculated as the fourth power of the acceleration time history (Eq. 3). VDV for each axis is then calculated as follows.

$$vdv_w = \left[\int_0^T a_w^4(t)\,dt\right]^{\frac{1}{4}} \tag{3}$$

$$VDV_i = k_i \cdot vdv_{iw} \cdot \sqrt[4]{\frac{T_{exp}}{T_{meas}}} \tag{4}$$

In Eq. 4, T_{exp} is the daily duration of exposure to the vibrations and T_{meas} is the measurement period. Subsequently, the highest of the three single axis values can be compared with the daily exposure action value (EAV) ($A(8) = 0.50\,m/s^2$ and $VDV = 9.10\,m/s^{1.75}$) and the daily exposure limit value (ELV) ($A(8) = 1.50\,m/s^2$ and $VDV = 21.00\,m/s^{1.75}$) defined in EU Directive 2002/44/EC.

In addition, the method defined by ISO 2631-5:2018 as 'less severe conditions' was implemented. This method is applied to WBV exposures without free-fall events and where the subject does not lose contact with the seat surface due to the shock. This method is based on the raw acceleration values measured from the seat surface and the backrest surface (if the data from the backrest is not available, the acceleration measured in the seat surface can be used as input). The method also requires identification of the posture of the drivers (classified based on the posture group in ISO2631-5:2018), the anthropometric characteristics of the driver (body mass and height) and the exposure time periods (hours per day and per year). From these data, the intervertebral compressive forces and the maximum daily compressive dose for the six disc levels of the lumbar spine (T12/L1, L1/L2, L2/L3, L3/L4, L4/L5 and L5/S1) are calculated using Eq. 5. The equivalent daily compressive dose (s_dA)

(MPa) is calculated using Eq. 6 considering the total duration of the exposure during a day.

$$S^A = \left(\sum_i \left(\frac{d_d yn, i}{B}\right)^6\right)^{\frac{1}{6}} \tag{5}$$

$$S_d^A = \left(\sum_j^n S_j^{A6} \frac{t_{dj}}{t_{mj}}\right) \tag{6}$$

In the above equations, $c_{dyn,i}(N)$ stands for the sum of peak compressive forces acting on the vertebral endplate, $B(mm^2)$ is the area of the vertebral endplate, S_j^A is the dynamic compressive stress of the lumbar spine due to vibration exposure to condition j , t_{dj} is the time period of the daily vibration exposure to condition j, t_{mj} is the time period over which S_j^A has been measured, j is the j-th operation that exposes the worker to WBV and n is the total number of operation which expose worker to WBV.

Subsequently, the risk factor R^A for every disc level is estimated based on S_d^A . This parameter is define for the assessment of an adverse health effect related to the daily compressive dose S_d^A.

$$R^A = \left(\sum_{i=1}^n \left(\frac{s_d^A N_i^{\frac{1}{6}}}{S_{u,i}^A - S_{stat,i}^A}\right)^6\right)^{\frac{1}{6}} \tag{7}$$

$$S_{u,i}^A = 6.765024\, MPa - 0.067184\, MPa \cdot (b + i) \tag{8}$$

Equations (7) and (8), i is the year counter; N_i is the number of exposure days per year i ; n is the number of exposure years; and $S_{u,i}^A$ is the ultimate strength of the lumbar spine for a person of age $(b + i)$ years, with b being the age at which the exposure started. $S_{stat,i}^A$ is the mean value of the compressive-decompressive force divided by the area of a vertebral endplate B (mm2) for year i . S_d^A varies with the bone density of the vertebrae, which normally is reduced with age. ISO 2631-5:2018 defines intervals for R^A and S_d^A to indicate the probability of an adverse health effect from WBV exposure. Table 1 shows the limit values.

Table 1 Intervals of probability of an adverse health effect defined in Annex E of ISO 2631-5:2018

Probability of anadverse health effect	Daily compressive dose	Risk factor
Low	$S_d^A < 0.5\, MPa$	$R_A < 0.8$
Moderate	$S_d^A > 0.5\, MPa$ and $S_d^A < 0.8\, MPa$	$R_A > 0.8$ and $R_A < 1.2$
High	$S_d^A > 0.8\, MPa$	$R_A > 1.2$

3 Results and Discussion

A total of 20 measured data sets were obtained from this experimental field study. The nature of the surface (asphalt or unpaved road) was taken into account in the analysis. It should be noted that because unpaved road has an uneven surface, the average travel velocity on it was lower (10.16 km/h) than on asphalt road (63.48 km/h).

Based on these data, it is then possible to apply the methods described in the Materials and Methods. The time of exposure was normalized to a typical daily exposure of 4 h with the aim to compare different exposures. Figure 1 and Fig. 2 show the results obtained for A8 and VDV, respectively, according to ISO 2631-1.

The results indicate that RMC truck drivers are exposed to a high level of WBV. A comparison of the values obtained with the limit values established in EU Directive 2002/44/EC shows that WBV exposure is higher for operations on asphalt roads than

Fig. 1 A(8) method results

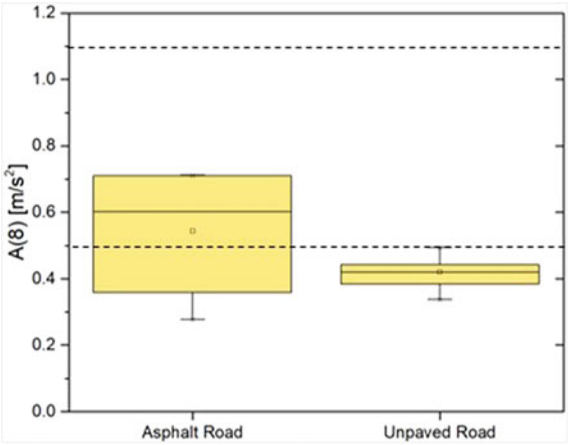
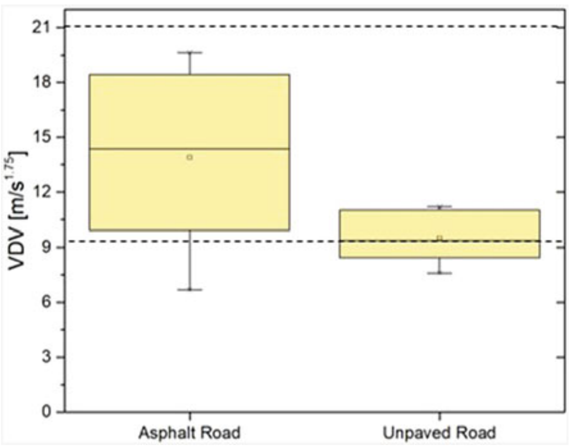


Fig. 2 VDV method results



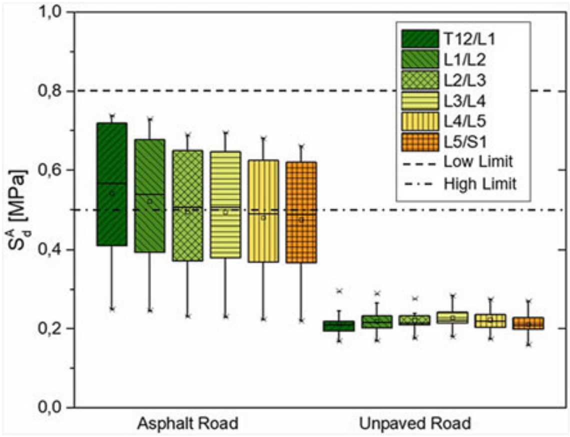


Fig. 3 Equivalent daily compressive dose for each vertebral level

on unpaved roads. The VDV results obtained for the asphalt road are above the VLA as well as more than a half of the A(8) results obtained. However, none of the values obtained exceeded the ELV in the operations on either type of surfaces. Regarding the data obtained on unpaved roads, none of the A(8) values exceeded the VLA limit. However, this is not the case when comparing the VDVs obtained with the VLA. Because the VDV is calculated from the fourth power of the acceleration time history, it is more sensitive to peaks than the A(8) method, which is calculated from the root mean square of acceleration. Furthermore, unpaved road is an uneven surface and it may result in greater shocks and peaks contained in the exposure; therefore, the VDV method is more restrictive than the A(8) method. The evaluation carried out according to ISO 2631-5:2018 also shows higher values for travel operations on asphalt than on unpaved surfaces. Figure 3 shows the equivalent daily compressive dose for the six disc levels of the lumbar spine, according to the less severe method defined in ISO 2631-5:2018. The most unfavourable value obtained in operations on asphalt roads is the vertebral level T12/L1. While there are values that exceed the limit of low probability of an adverse health effect, none of them presents a high probability. Regarding unpaved roads, all the values obtained show a low probability of an adverse health effect.

Because the driver's lifetime exposure history to WBV was not available, the most unfavourable exposure conditions were considered: the exposure lasts from the age of 20 to 65 years for 240 days per year. The average S_d^A for each vertebral level was used to estimate the risk factor R^A, which was calculated sequentially taking into account increased age. As a result, the highest R^A values were 0.71 and 0.32 for asphalt and unpaved roads, respectively. As both values are lower than 0.8, according to the intervals provided by ISO2631-5:2018 (Table 1), the probability of an adverse health effect is low.

In addition, if we compare the exposure results associated with both surfaces, the average results obtained in all the assessment methods is lower for unpaved roads. Although this surface is more uneven than asphalt roads, travelling operations on unpaved roads are performed at a lower travel velocity (approximately six times lower compared with the average travel velocity on asphalt road). Consequently, the driver is exposed to lower WBV in operations on unpaved roads than on asphalt roads.

It should be noted that the exposure time (4 h) for the standardization and comparison of the data set obtained was selected because the driver claims that it was the average time of driving during a typical working day. However, the number of total driving hours per day depends on the total volume of RMC ordered by clients, the distance to the construction site (from the RMC production plant) and logistics management. These factors condition the exposure time, which can often exceed 4 h. Furthermore, a more accurate assessment of long-term WBV exposure could have been conducted if the company had provided the driver's lifetime exposure history. For this reason, companies are encouraged to develop a database with the WBV exposure patterns (duration of the several exposures/exposure pattern per day and number of days of all exposures/exposure pattern per year).

4 Conclusions

MSDs are a prevalent problem in the construction sector. WBV exposure, one of the factors that leads to MSDs, is a physical exposure present in multiple operations carried out by workers in the construction sector. In this context, workers who are continuously exposed on a daily basis to WBV from driving vehicles and machinery are particularly vulnerable. Such exposure is very common in sub-sectors such as the RMC industry. This field study was conducted to analyse the level of WBV exposure associated with the use of RMC trucks to deliver RMC from the production plant to the construction site. The WBV assessment was carried out according to EU Directive 2002/44/CE and ISO2631-5:2018. The results showed that drivers who perform RMC delivery with trucks are exposed to a high level of WBV. It should be noted that factors such as the type of surface and travel velocity influence the magnitude of vibrations transmitted to the worker. Although a more irregular surface contributes to an increase in the number of shocks and the magnitude of vibrations to which the worker is exposed, because travel velocity is also an important variable, operations on more uneven surfaces will not always result in greater exposure. More measurements are necessary to obtain a more detailed assessment of these factors.

This study is a step forward in current efforts to encourage companies to improve the management of WBV exposure to prevent MSDs. The creation of a database of a driver's lifetime history of exposure to VBM will enable a more accurate assessment of long-term WBV exposure.

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References

Akboğa, Ö., Baradan, S.: Safety in ready mixed concrete industry: descriptive analysis of injuries and development of preventive measures. Ind. Health. (2016). https://doi.org/10.2486/indhealth.2016-0083

Briggs, A.M., Woolf, A.D., Dreinhöfer, K., Homb, N., Hoy, D.G., Kopansky-Giles, D., Åkesson, K., March, L.: Reducing the global burden of musculoskeletal conditions. Bull. World Health Organ. **96**(5), 366 (2018). https://doi.org/10.2471/BLT.17.204891

Burström, L., Nilsson, T., Wahlström, J.: Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis. Int. Arch. Occup. Environ. Health **88**(4), 403–418 (2015). https://doi.org/10.1007/s00420-014-0971-4

Costa, N., Arezes, P., Melo, R.: Effects of occupational vibration exposure on cognitive/motor performance. Int. J. Ind. Ergon. **44**(5), 654–661 (2014). https://doi.org/10.1016/j.ergon.2014.07.005

De la Hoz-Torres, M., Aguilar-Aguilera, A.J., Martínez-Aires, M., Ruiz, D.P.: Practical use of noise mapping to reduce noise exposure in the construction Industry. In: Occupational and Environmental Safety and Health II, pp. 209–216. Springer (2020). https://doi.org/10.1007/978-3-030-41486-3_23

Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risksarising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

Eurofound: Sixth European Working Conditions Survey. Luxembourg: 2017 Update. Publications Office of the European Union (2015)

EU-OSHA: Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. European Risk Observatory (2019). Resort. ISSN: 1831-9343

EU-OSHA: Prevention of Musculoskeletal Disorders in the construction sector: examples from the inail incentive schemes (2020)

Guerlain, C., Renault, S., Ferrero, F.: Understanding construction logistics in urban areas and lowering its environmental impact: a focus on construction consolidation centres. Sustainability **11**(21), 6118 (2019). https://doi.org/10.3390/su11216118

Hagberg, M., Violante, F. S., Bonfiglioli, R., Descatha, A., Gold, J., Evanoff, B., Sluiter, J.K.: Prevention of musculoskeletal disorders in workers: classification and health surveillance–statements of the scientific committee on musculoskeletal disorders of the international commission on occupational Health. BMC Musculoskelet. Disord. **13**(1), 1–6 (2012). https://doi.org/10.1186/1471-2474-13-109

ISO 2631-1:1997: Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration—Part 1: General requirements

ISO 2631-5:2018: Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration—Part 5: Method for evaluation of vibration containing multiple shocks

ISO 5349-1:2001. Mechanical vibration - Measurement and evaluation of human exposure to hand—transmitted vibration—Part 1: General requirements

ISO 5349-2:2001: Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration—Part 2: Practical guidance for measurement at the workplace

James, S.L., Abate, D., Abate, K.H., Abay, S.M., Abbafati, C., Abbasi, N., Abbastabar, H., Abd-Allah, F., Abdela, J., Abdelalim, A.: Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet **392**(10159), 1789–1858 (2018). https://doi.org/10.1016/S0140-6736(18)32279-7

Krajnak, K.: Health effects associated with occupational exposure to hand-arm or whole body vibration. J. Toxicol. Env. Health-Pt b **21**(5), 320–334 (2018). https://doi.org/10.1080/10937404.2018.1557576

Nelson, N. A., Hughes, R.E.: Quantifying relationships between selected work-related risk factors and back pain: a systematic review of objective biomechanical measures and cost-related health outcomes. Int. J. Ind. Ergon. **39**(1), 202–210 (2009). https://doi.org/10.1016/j.ergon.2008.06.003
Nielsen, K., Jørgensen, M. B., Milczarek, M., Munar, L.: Healthy workers, thriving companies–a practical guide to wellbeing at work Tackling psychosocial risks and musculoskeletal disorders in small businesses. Report. Publications Office of the European Union , Luxembourg (2018). ISSN 978-92-9496-935-4 102. https://doi.org/10.2802/237140
Punnett, L., Wegman, D.H.: Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. J. Electromyogr. Kinesiol. **14**(1), 13–23. (2004) https://doi.org/10.1016/j.jelekin.2003.09.015
Raffler, N., Rissler, J., Ellegast, R., Schikowsky, C., Kraus, T., Ochsmann, E.: Combined exposures of whole-body vibration and awkward posture: a cross sectional investigation among occupational drivers by means of simultaneous field measurements. Ergonomics **60**(11), 1564–1575 (2017). https://doi.org/10.1080/00140139.2017.1314554
Russo, F., Di Tecco, C., Fontana, L., Adamo, G., Papale, A., Denaro, V., Iavicoli, S.: Prevalence of work related musculoskeletal disorders in Italian workers: is there an underestimation of the related occupational risk factors? BMC Musculoskelet. Disord. **21**(1), 1–16 (2020). https://doi.org/10.1186/s12891-020-03742-z
Singh, A., Nawayseh, N., Singh, L., Singh, S., Singh, H.: Investigation of compressive stress on lumbar spine due to whole body vibration exposure in rotary tillage operation. Int. J. Automot. Mech. Eng. **16**(2), 6684–6696 (2019). https://doi.org/10.15282/ijame.16.2.2019.16.0503
Vos, T.20, Flaxman, A.D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M., Shibuya, K., Salomon, J.A., Abdalla, S., Aboyans, V.: Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet **380**(9859), 2163–2196 (2012). https://doi.org/10.1016/S0140-6736(12)61729-2
Wahlström, J.: Ergonomics, musculoskeletal disorders and computer work. Occup. Med. **55**(3), 168–176 (2005). https://doi.org/10.1093/occmed/kqi083
Wahlström, J., Burström, L., Johnson, P.W., Nilsson, T., Järvholm, B.: Exposure to whole-body vibration and hospitalization due to lumbar disc herniation. Int. Arch. Occup. Environ. Health **91**(6), 689–694 (2018). https://doi.org/10.1007/s00420-018-1316-5

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Occupational Exposure to Noise in the Extractive Industry and Earthworks—Short Review

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Abstract Background: Occupational noise is still a significant issue having severe impacts on the worker's health. This problem is relevant in the extractive industry since it endangers the worker and the surrounding communities. Objective: This short review aimed to identify the occupational exposure to noise setting within the extractive sector and earthworks. Methodology: The Preferred reporting items for systematic reviews and meta-analyses were used to conduct the search. "Noise" was combined with "extractive industry" (and similar terms) and "earthworks" in multidisciplinary databases and journals. A set of exclusion criteria was determined to filter the information of this first phase, and the results were fully appraised on a narrative basis. Results and discussion: From the 1148 papers primarily identified, only 15 met all the criteria and were included in this work. The data were categorised and divided into activity, equipment, job category and working area. Despite being able to provide some insight into each category, no detail related to experimental methodology was reported, being the main limitation in analysing the results. Conclusions: Although this research met the proposed topic, further work needs to be carried out, namely the inclusion of more relevant articles and statistical analysis.

Keywords Noise level · Activity · Equipment · Job category · Mining

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1 Introduction

Noise is a physical phenomenon with complex behaviour. It depends not only on its physical characteristics—sound pressure level and frequency—but also on the individuals' (physical and physiological) features. For example, a study from Asady et al. (2021) refers that there are significant differences between how men and women perceive sound and how the masculine earing canal exponentiates the sound pressure level. Noise-induced hearing loss occurs after prolonged exposure to high noise levels (Golmohammadi & Darvishi 2020) and can be divided into two types: a permanent threshold shift or, in the best-case scenario, a temporary threshold shift (Alfaro Degan et al. 2019).

Regarding the industrial environment, this matter becomes worse as noise is present almost everywhere. The consequences are related to disease burden and financial aspects for the worker and overall society (Chen et al. 2020). Despite all technological advancements, occupational noise-induced hearing loss (ONIHL) is still considered a significant health hazard worldwide (Zhou et al. 2020). General health effects related to this issue include sleep disturbance (Ntlhakana et al. 2020), speech interference (Dzhambov & Dimitrova 2017; Golmohammadi & Darvishi 2020), distraction (Hon et al. 2020), hypertension (Bolm-Audorff et al. 2020), cardiovascular effects (Asady et al. 2021; Hon et al. 2020), type 2 diabetes (Asady et al. 2021), among several others. In the literature, noise exposure has been associated with accident occurrence, relation to fatigue, and the annoyance effect that can cloud judgment and endanger action (Hon et al. 2020; Li et al. 2019). A 2021 occupational health study, analysing 11,800 subjects exposed to noise in China, concluded that workers whose occupation is related to the mining industry have a higher risk of developing hearing abnormalities than workers in any other sector (Zhao et al. 2021). This tendency is accompanied in the United States, where mining and wood products industries are associated with a high risk of hearing damage (Sliwinska-Kowalska 2020). But what makes this industry different? The operations, especially in surface exploitation, impact the worker and the surrounding populations (Lokhande et al. 2017): heavy machinery movement, drilling, blasting are high-level noise sources (Wichers et al. 2018). Additionally, the used equipment such as excavators, trucks, bulldozers, crushers, mills, screens, just to name a few, are intrinsically noisy (Lilic et al. 2018). Earthworks are included in this category due to the similarity of operations and equipment (Lee et al. 2019; Xiao et al. 2016).

Bringing all the prior facts together, this short review aimed to identify the context of occupational exposure to noise within the extractive industry and earthworks in literature.

2 Methodology

This research was completed according to the guidelines proposed by the Preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Page et al. 2021) and the methodology built by Duarte et al. (2020).

The first step to conduct the search for information is to define the keywords. In this case, the combinations were between “noise” and “quarry”, “open pit”, “open cast”, “surface mining”, “open-cut mining”, “extractive industry”, and “earthworks”. These were used in the most adequate multidisciplinary journals and databases—Dimensions, Directory of Open Access Journals, Science Direct, Emerald, IEEE Xplore, INSPEC, SAGE journals, Scopus, Taylor and Francis, Current Contents and Web of Science, in the fields Title/Abstract/Keywords. In order to filter the information in the first stage, general exclusion criteria were defined as follows:

1. Publication year—papers published before 2010;
2. Document type—reviews, conference papers, white and grey literature;
3. Source type—every source other than journals and trade publications;
4. Language—non-English written documents.

The result was sought for possible inclusion, which means that only papers in occupational context and providing field data underwent the following stage. The eligible articles were classified according to the measurement setting. The information analysis was carried out in a narrative way. This research was carried out in February 2021.

3 Results

In the identification phase, 1148 results were found. Applying the previously referred exclusion criteria, 547 papers were removed due to publication year, 146 because of the document type, 12 concerning source type and 25 were excluded considering publication language. From the analysis title and abstract, 360 more papers were disregarded as they did not comply with the inclusion criteria. Of the remaining 58 records, 25 were duplicates and removed, and 7 were not available. Aftermath, 26 articles were full-text screened for assessment and discussion, leading to the exclusion of 11 more records. At the end of this process, 15 papers were included in this short review.

Table 1 summarises the studies’ general information, including origin country, main activity, type of exploitation, and exploited commodity. Except for one study that takes place in the construction field (Lee et al. 2019), every other paper set is related to the mining industry, where the exploited commodities varied between ornamental rock (marble) to aggregates and andesite, limestone, coal and lignite), chromite, copper and iron. Regarding countries, only three studies take part in European Union (EU) setting (Kosała & Stępień 2016; Mihut 2019; Simion et al. 2017), therefore are regulated by Directive 2003/10/EC (Directive 2003/10/EC, 2003).

Table 1 Studies' general information

Author, year	Activity	Type of exploitation	Exploited commodity	Country
Srivastava et al. (2010)	Mining	Open cast	Lignite	India
Gupta et al. (2012)	Mining	Quarry (7)	Granite	India
Kerketta et al. (2012)	Mining	Open cast	Chromite	India
Melo Neto et al. (2012)	Mining	Quarry	Marble	Brazil
Onder et al. (2012)	Mining	Quarry	Aggregates	Turkey
Cinar, I., & Sensogut (2013)	Mining	Quarry, mine	Lignite, feldspar	Turkey
Gyamfi et al. (2016)	Mining	Quarry (5)	Not mentioned	Ghana
Kosała & Stępień (2016)	Mining	Quarry	Andesite	Poland
Lokhande et al. (2017)	Mining	Mine	Iron	India
Simion et al. (2017)	Mining	Surface	Coal	Romania
Lilic et al. (2018)	Mining	Open-pit	Copper	Serbia
Wichers et al. (2018)	Mining	Quarry	Not mentioned	Brazil
Çınar & Şensöğüt (2019)	Mining	Quarry	Limestone	Turkey
Lee et al. (2019)	Construction	Not applicable	Not applicable	Korea
Mihut (2019)	Mining	Open-cast	Not mentioned	Romania

Each of the 15 articles was analysed regarding their experimental protocol and was classified according to the measurement setting. According to the taxonomy, Table 2 displays the result of that classification: activity, equipment, job category and working area. It is included the specifications inside each category. From the selected studies, two presented their data in graphic form (Gupta et al. 2012; Wichers et al. 2018). Despite having different measurement parameters, every other grouped tables, for instance, weighted sound exposure level, equivalent weighted sound pressure, and peak sound pressure level.

Additionally, each study has its particular experimental protocol, which will be detailed whenever pertinent. This conjugation of factors made it almost impossible to compare the results across studies.

The only studied activity was blasting (Kosała & Stępień 2016; Srivastava et al. 2010). Both studies analysed this operation at different distances and. They concluded

Table 2 Studies' classification according to measurement set

Author, year	Activity	Equipment	Job category	Working area
Srivastava et al. (2010)	Blasting	No	No	No
Gupta et al. (2012)	No	Jackhammer drill	No	No
Kerketta et al. (2012)	No	No	No	Industrial area, commercial area, work zone
Melo Neto et al. (2012)	No	No	Polisher, cutter, office assistant, director	No
Onder et al. (2012)	No	No	Cook, crusher worker, drilling operator, driver, mining machine operator, weighter, worksite chief	No
Cinar, I., & Sensogut (2013)	No	Bulldozer, cone crusher, excavator, grader, hydraulic hammer, jaw crusher, mill, siever, truck	No	No
Gyamfi et al. (2016)	No	Drilling machine, tyre wrench, lathe machine, block making machine, generator set, crusher machine, primary processing machine, secondary processing machine, excavator machine, air compressor	No	No
Kosała & Stępień (2016)	Blasting	Crusher, siever, vibrating feeder, wheel conveyor, conveyor, dispenser aggregate for the loading silo	No	No
Lokhande et al. (2017)	No	No	No	Industrial zone, commercial zone, mines, haulage road
Simion et al. (2017)	No	Bucket-wheel excavator	No	No
Lilic et al. (2018)	No	Truck, shovel, bulldozer, drilling rig, grader, crusher, belt conveyor	No	No
Wichers et al. (2018)	No	Asphalt mixer, drilling rig, crushing plant	No	No
Çınar & Şensöğüt (2019)	No	No	No	No
Lee et al. (2019)	No	Air compressor, breaker, bulldozer, compactor, crusher, drill, excavator, grader, jackhammer, loader, roller	No	No
Mihut (2019)	No	Truck, tractor, motor hacksaw, charger, bulldozer, excavator	No	No

that increasing distance led to lower noise levels, despite the setting. Nonetheless, the peak sound pressure level at 200 metres was 132 dB and 56 dB at 6000 metres (Srivastava et al. 2010). During the explosion, the pressure peak was 132.9 dB, 109.2 dB and 106.3 at 86, 155, 186 metres, correspondently (Kosała & Stępień 2016) and the equivalent A-weighted sound pressure level calculated for an 8-hour period, considering the same distances was 53.3 dB, 37.2 dB and 31.0 dB. According to the Directive 2003/10/EC (Directive 2003/10/EC, 2003), these values fall below the daily exposure noise levels, even when considering the lower exposure action values (80 dB (A)).

Figure 1 shows the different measurements of noise levels considering the studied equipment. Every measurement is presented in dB(A); however, the results have different meanings: two correspond to equivalent noise level (Cinar, I., & Sensogut 2013; Lee et al. 2019), and two mentioned "noise level" without any other clarification (Gyamfi et al. 2016; Lilic et al. 2018). It is important to state that, in the picture, whenever a result is not depicted (for a specific author), that particular study did not analyse that equipment. Despite the various studied equipment, no data regarding operating condition, age, performed tasks, among other essential factors, were included in the different studies, positing a severe limitation of the interpretation of results.

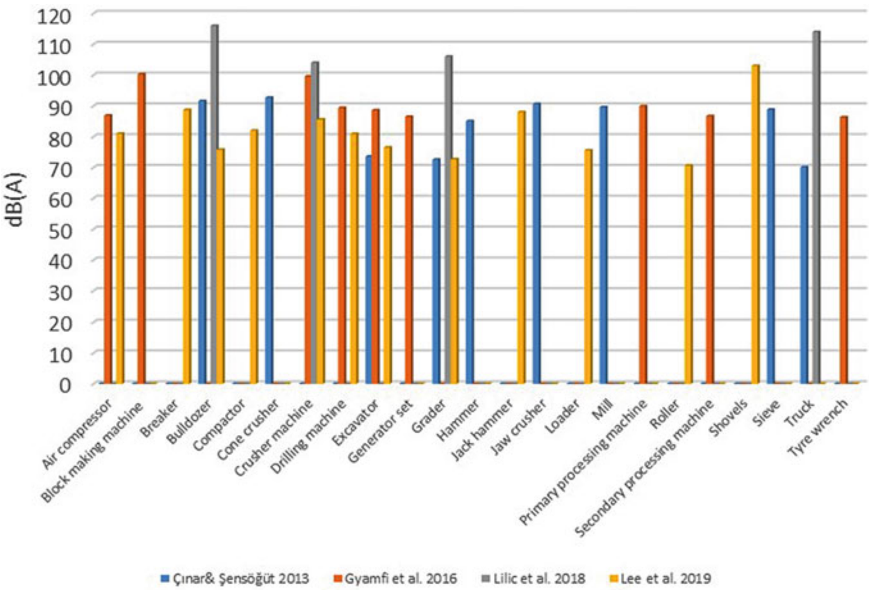

Fig. 1 Measured noise levels for different equipment

Çınar & Şensöğt (2013) collected noise measurements at four different contexts: Ilgin lignite plant, Eyak Mining and quarrying operation, Polat mining feldspar ore preparation plant and Uyar mining coal preparation plant. An interesting point regarding this last location is that machines with noise levels above 100 dB(A) suffered a repair action, and the noise level was measured afterwards. The difference in results varied between 4.9 and 12.9 dB (lowered). In the study of Lee et al. (2019), measurements were carried out with relation to 24 pieces of equipment and at 15 metres from the source, but. Still, only machinery similar to the ones used in the extractive industry were included in this analysis. The results of the measurements of the study of Gyamfi et al. (2016) ranged between 85.5 dB(A) and 102.7 dB(A). Lilic et al. (2018) results ranged between 65 dB(A) (belt conveyor) and 114 dB(A) (trucks).

Only two studies analysed the workers' exposure to dust (Melo Neto et al. 2012; Onder et al. 2012). Melo Neto et al. (2012) assessed two marble finishing plants, considering both operators and administrative workers. On site 1, polisher workers were exposed to an equivalent continuous sound level of 105.3 dB(A) and 99.0 dB(A) for sections A (five workers) and C (four workers), correspondently, and cutter workers to 101.1 dB(A) for section B (ten workers). The office assistant group (two workers) were exposed to 84.9 dB(A). As for site 2, divided into production

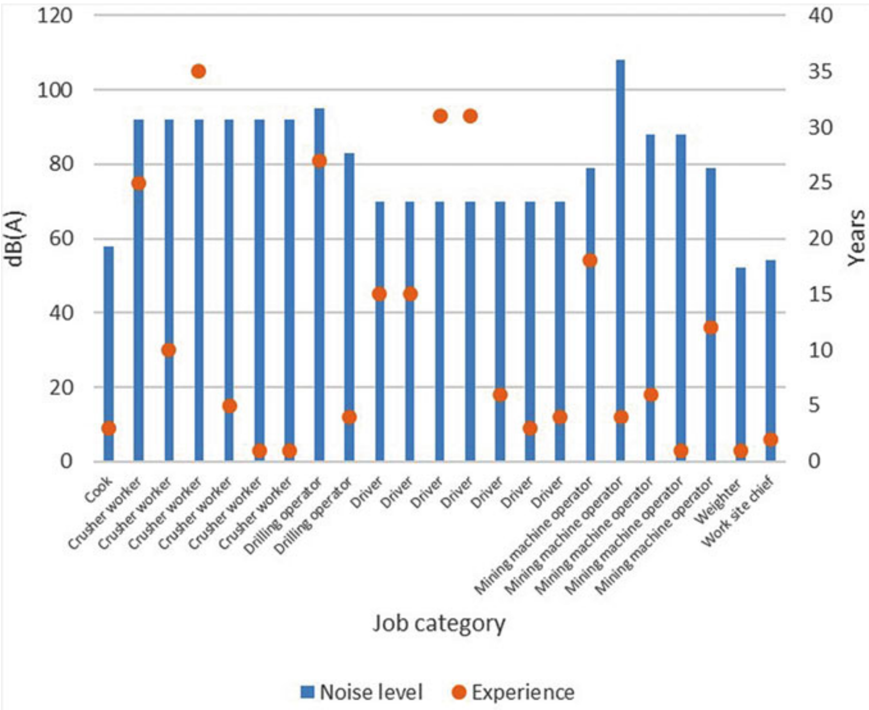

Fig. 2 Noise level related to job category (Onder et al. 2012)

and administration, polish workers (two) were exposed to 100.0 dB(A) and cutter workers to 106.7 dB(A). Three administration workers were exposed to 87.9 dB(A). No further information regarding equipment or other setting was provided. In the study of Onder et al. (2012), it was measured the personal exposure to noise of 23 workers: one cook, six crusher workers, two drilling operators, seven drivers, five mining machine operators, one weighter, and one work site chief. Their working experience was recorded and varied between 1 and 35 years. Figure 2 shows the noise level for each of the workers. No further information regarding equipment or operating condition was provided; therefore, no explanation regarding differences in measurements can be placed, and it cannot be inferred if these measurements were representative. However, it can be pointed out that the weighter was the job category where the noise level was lower, 52 dB(A), followed by the work site chief, 54 dB(A), and cook, 58 dB(A). For the drivers, all the measurements were 70 dB(A), for crusher worker 92 dB(A), the mining machine operator varied between 79–108 dB(A), and the drilling operator had two measurements (83 and 95 dB(A)).

Two studies analysed the working area with respect to noise level (Kerketta et al. 2012; Lokhande et al. 2017). Kerketta et al. (2012) divided their study into five areas: industrial, commercial, working zone, residential area and silence zone. The work zone comprised small (drilling machines), medium (dozers, dumpers, and trucks) and large (payloaders, JCB, shovel with rock breaker, poclain, and giant excavators) heavy earth moving machinery (HEMM), haul road, processing plant and blasting area. The average equivalent continuous sound level, Fig. 3, is presented by area.

The results showed that the HEMM present at the exploitation were major noise sources compared to the other zones. However, further detail is not specified regarding combined utilisation of machines, performed task, and equipment age, among other factors.

Lokhande et al. (2017) divided their study into industrial (nine points), commercial (seven points) and mining zones (15 points) and took measurements during the day (6 am–10 pm) and at night time (10 pm–6 am), period when the measurement results were lower (and the mines had no activity), and then, compare it with the Indian Central Pollution Control Board (CPCB) from 2010. The authors concluded that the noise levels both in residential and sensitive zones exceeded the limits set by CPCB to which contributed the forecast models built from the field data. Moreover, the noise level during the day at different locations varied as such: 64.2–73.4 dB(A) in the industrial zone, 62.2–72.7 dB(A) for commercial zone and 91.1–117.0 dB(A) for mining areas.

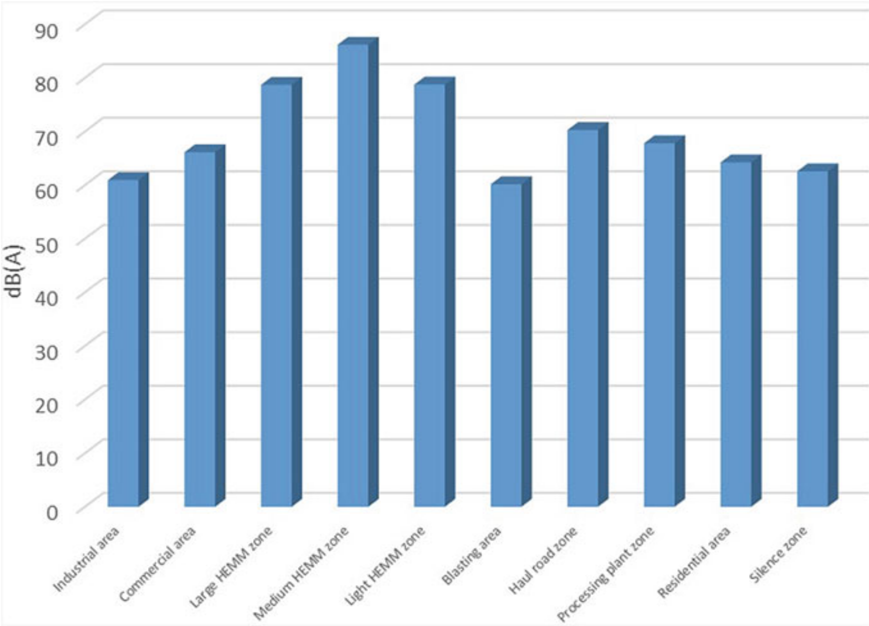

Fig. 3 Equivalent continuous sound level (average) in each zone (Kerketta et al. 2012)

4 Conclusions

Noise cannot be undissociated from industrial practice. Therefore, it is important to analyse it, understand its context, and mitigate it to control its nefarious effects in the long term but especially in the short time. The extractive industry and earthworks receive special attention in this work due to their particular characteristics, associated with the fact that, when not controlled, mining processes and tasks endanger the exposed workers and the surrounding populations. This short review aimed to identify, in the literature, the context of occupational exposure to noise within the extractive industry and earthworks. Of the fifteen selected papers, fourteen are in relation to the mining industry and one to the construction field. The results were divided into four categories: activity, equipment, job category and working area. Despite the plethora of mining tasks that potentially perform as noise sources (Wichers et al. 2018), the only one analysed in literature was blasting (Kosała & Stępień 2016; Srivastava et al. 2010). Furthermore, although diverse equipment was identified with relation to noise, important details were left out of the studies, making it impossible to assess their results properly.

Nonetheless, most of the machinery presented high noise levels (of 80 dB(A) and above). Interestingly, one of the studies first selected the equipment with noise levels above 100 dB(A) and intervened (repair actions). Overall, the results showed that the noise levels lowered between 4.9 and 12.9 dB, thus showing the importance of these types of possessing and this kind of knowledge (Cinar, I., & Sensogut 2013). Job category was studied in two papers (Melo Neto et al. 2012; Onder et al. 2012). Again, no particular focus was paid to operating conditions and other determinants that might help planning and better design the operations in the extractive industry. Polisher worker, cutter worker, administrative worker, crusher worker, drilling operator, driver, mining machine operator, worksite chief and weighter were the jobs brought by these authors. The last category, working area, only remarked commercial and industrial zones, mines, and haulage road (Kerketta et al. 2012; Lokhande et al. 2017), which corresponded to general noise measurements that, once again, did not investigate the particular settings. Regardless of the results, this preliminary study was essential to analyse occupational exposure to noise regarding extractive industry processes design.

References

Alfaro Degan, G., Coltrinari, G., Lippiello, D., Nataletti, P., Annesi, D.: Protection by noise in quarrying activities: test methods comparison of the hearing protection devices efficiency. E3S Web Conf. **128**, 08005 (2019). https://doi.org/10.1051/e3sconf/201912808005

Asady, H., Fuente, A., Pourabdian, S., Forouharmajd, F., Shokrolahi, I.: Acoustical role of ear canal in exposure to the typical occupational noise levels Hadi. Med. J. Islamic Repub. Iran **5**(May), 35–58 (2021). https://doi.org/doi.org/10.47176/mjiri.35.58

Bolm-Audorff, U., Hegewald, J., Pretzsch, A., Freiberg, A., Nienhaus, A., Seidler, A.: Occupational noise and hypertension risk: a systematic review and meta-analysis. Int. J. Environ. Res. Publ. Health **17**, (17) 1–24 (2020). https://doi.org/10.3390/ijerph17176281

Chen, K. H., Su, S. Bin, Chen, K.T.: An overview of occupational noise-induced hearing loss among workers: epidemiology, pathogenesis, and preventive measures. Environ. Health Prev. Med. **25**(1), 1–10 (2020). https://doi.org/10.1186/s12199-020-00906-0

Cinar, I., Sensogut, C.: Evaluation of noise measurements performed in mining sites for environmental aspects. Int. J. Environ. Res. **7**(2), 383–386 (2013). https://doi.org/10.22059/ijer.2013.616

Çınar, I., Şensöğt, C.: Mapping of noise propagation in quarries for environmental perspective. Int. J. Econ. Environ. Geol. **10**(1), 1–4 (2019). https://doi.org/10.46660/ojs.v10i1.210

Duarte, J., Castelo Branco, J., Santos Baptista, J.: Occupational exposure to noise in the extractive industry and earthworks—a systematic review protocol. Int. J. Occup. Environ. Saf. **4**(2), 89–94 (2020). https://doi.org/10.24840/2184-0954_004.002_0007

Dzhambov, A., Dimitrova, D.: Occupational noise exposure and the risk for work-related injury: A systematic review and meta-analysis. Ann. Work Exposures Health **61**(9), 1037–1053 (2017). https://doi.org/10.1093/annweh/wxx078

Directive 2003/10/EC, 38 (2003)

Golmohammadi, R., Darvishi, E.: The combined effects of occupational exposure to noise and other risk factors-a systematic review. Noise Health **21**(101), 125–141 (2020). https://doi.org/10.4103/nah.NAH_4_18

Gupta, P., Roy, S., Rajan, A.B.: Study on noise levels generated due to Jack Hammer Drills in Granite Quarries. Front. Sci. **2**(3), 47–52 (2012). https://doi.org/10.5923/j.fs.20120203.06

Gyamfi, C.K.R., Amankwaa, I., Owusu Sekyere, F., Boateng, D.: Noise exposure and hearing capabilities of quarry workers in Ghana: a cross-sectional study. J. Environ. Pub. Health **2016**, 1–7 (2016). https://doi.org/10.1155/2016/7054276

Hon, C.Y., Tchernikov, I., Fairclough, C., Behar, A.: Case study in a working environment highlighting the divergence between noise intensity and workers' perception towards noise. Int. J. Environ. Res. Publ. Health **17**(17), 1–11 (2020). https://doi.org/10.3390/ijerph17176122

Kerketta, S., Gartia, R., Bagh, S.: Hearing threshold, loss, noise levels and worker's profiles of an open cast chromite mines in Odisha, India. Malays. J. Med. Sci. **19**(4), 64–72 (2012). PMCID: PMC3629681

Kosała, K., & Stępień, B.: Analysis of noise pollution in an andesite quarry with the use of simulation studies and evaluation indices. Int. J. Occup. Saf. Ergon. **22**(1), 92–101 (2016). https://doi.org/10.1080/10803548.2015.1106702

Lee, S.C., Kim, J.H., Hong, J.Y.: Characterizing perceived aspects of adverse impact of noise on construction managers on construction sites. Build. Environ. **152**(Feb), 17–27 (2019). https://doi.org/10.1016/j.buildenv.2019.02.005

Li, X., Dong, Q., Wang, B., Song, H., Wang, S., Zhu, B.: The influence of occupational noise exposure on cardiovascular and hearing conditions among industrial workers. Sci. Rep. **9**(1), 1–7 (2019). https://doi.org/10.1038/s41598-019-47901-2

Lilic, N., Cvjetic, A., Knezevic, D., Milisavljevic, V., Pantelic, U.: Dust and noise environmental impact assessment and control in Serbian mining practice. Minerals **8**(2), 34 (2018). https://doi.org/10.3390/min8020034

Lokhande, S.K., Dhawale, S.A., Pathak, S.S., Gautam, R., Jain, M.C., Bodhe, G.L.: Appraisal of noise level dissemination surrounding mining and industrial areas of Keonjhar, Odisha: a comprehensive approach using noise mapping. Arch. Acoust. **42**(3), 423–432 (2017). https://doi.org/10.1515/aoa-2017-0044

Melo Neto, R. P., Kohlman Rabbani, E.R., Barkokébas Junior, B., Lago, E.M.G., Jonathas, J.B.: Quantitative noise analysis at two marble finishing plants in Olinda, Pernambuco, Brazil. Work **41**(SUPPL.1), 5850–5852 (2012). https://doi.org/10.3233/WOR-2012-0972-5850

Mihut, N.-M.: Noise pollution in the course of the steps of preparing the mining field for the operation of the open cast mine Pinoasa. Fiability Durab. **1**(1), 232–236 (2019)

Ntlhakana, L., Nelson, G., & Khoza-Shangase, K.: Estimating miners at risk for occupational noise-induced hearing loss: A review of data from a South African platinum mine. South African J. Commun. Disord. **67**(2), 1–8 (2020). https://doi.org/10.4102/sajcd.v67i2.677

Onder, M., Onder, S., Mutlu, A.: Determination of noise induced hearing loss in mining: an application of hierarchical loglinear modelling. Environ. Monit. Assess. **184**(4), 2443–2451 (2012). https://doi.org/10.1007/s10661-011-2129-0

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., ... Moher, D.: The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. PLOS Med. **18**(3), e1003583 (2021). https://doi.org/10.1371/journal.pmed.1003583

Simion, S., Kovacs, M., Toth, L., Ilie, C., Gireadă, A.: Workers exposure to noise in surface extractive industry. Environ. Eng. Manag. J. **16**, (6).017 (2017)

Sliwinska-Kowalska, M.: New trends in the prevention of occupational noise-induced hearing loss. Int. J. Occup. Med. Environ. Health **33**(6), 841–848 (2020). https://doi.org/10.13075/ijomeh.1896.01600

Srivastava, R.K., Gupta, N.C., Srivastava, R., Kaur, A.: Noise levels in lignite mining area of Kutch (Gujrat) and mitigation measures. J. Ind. Pollut. Control **26**(1), 79–81 (2010)

Wichers, M., Iramina, W. S., de Eston, S. M., Ayres da Silva, A.L.M.: Using a noise monitoring station in a small quarry located in an urban area. Environ. Monit. Assess. 190(1) (2018). https://doi.org/10.1007/s10661-017-6404-6

Xiao, J., Li, X., Zhang, Z.: DALY-Based health risk assessment of construction noise in Beijing, China. Int. J. Environ. Res. Pub. Health **13**(11) (2016). https://doi.org/10.3390/ijerph13111045

Zhao, S., He, D., Zhang, H., Hou, T., Yang, C., Ding, W., He, P.: Health study of 11,800 workers under occupational noise in Xinjiang. BMC Pub. Health **21**(1), 1–7 (2021). https://doi.org/10.1186/s12889-021-10496-3

Zhou, J., Shi, Z., Zhou, L., Hu, Y., Zhang, M.: Occupational noise-induced hearing loss in China: A systematic review and meta-analysis. BMJ Open **10**(9) (2020). https://doi.org/10.1136/bmjopen-2020-039576

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Fernanda Rodrigues RISCO, ANQIP, University of Aveiro, Portugal, Ph.D. (2008).

J. Santos Baptista Associated Laboratory for Energy, Transports and Aeronautics—LAETA (PROA), Faculty of Engineering, University of Porto, Portugal, Ph.D. (1998).

Occupational Exposure to Bioburden in Portuguese Ambulances

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Abstract Objective: The aim of this study is to characterize the occupational exposure to bioburden of ambulance workers and to suggest control procedures to prevent microbial contamination. Background: Ambulances are of critical importance for health services. Thus effective cleaning protocols are essential. Method: This study was held during winter months (November and December) of 2019 in two Firefighters Headquarters (FF). A total of 12 ambulances were sampled (4 from FF1 and 8 from FF2). The sample consisted of twelve settled dust samples from driver's and medical cabins of the 12 ambulances, 5 mop samples (2 from FF1 and 3 from FF2) used for the cleaning procedures of all the headquarters' ambulances, and also 2 cleaning cloths samples from 2 individual ambulances from FF2. Results: Gram negative bacteria presented the highest prevalence in both matrixes from FF1 (54.7% settled Dust; 56.41% mop and cleaning cloths); in FF2, Total Bacteria (TSA) presented the highest prevalence in settled dust (54.96%). Regarding the fungal contamination, in FF1 the highest prevalence was in MEA in both matrixes (61.2% settled dust; 60.7% mop and cleaning cloths); in FF2, DG18 presented the highest prevalence in settled dust samples (53.3%). Conclusion: The results reinforce the importance to use passive sampling methods combined with active methods and that a wider pool of culture media allow more complete results. Application: This study will support the paramedic sector's mission while ensuring ther working conditions.

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Keywords Multi-approach sampling protocol · Bioburden · Ambulances · Occupational exposure

1 Introduction

Bioburden is commonly defined as an airborne mixture of viable and non-viable microorganisms their metabolites and solid particles of vegetable and animal origin (Oppliger 2014). Exposure to certain fungi is known to produce a wide number of human illnesses due to generation of a harmful immune response, direct infection by the fungal organism or toxic-irritant effects due to mycotoxins exposure (Bush et al. 2006; Viegas et al. 2021). Moreover, it is important to consider the frequent co-occurrence of mycotoxins (Alassane-Kpembi et al. 2013) as the most common situation in several scenarios, including in health care facilities, as already reported in Portugal (Viegas et al. 2019a, 2019b). The consequence of exposure to combined mycotoxins can be different, quantitatively or qualitatively, than would be expected when only one isolated mycotoxin is considered (Klarić et al. 2013). These risk factors may be augmented by the presence of Gram-negative bacteria, as they produce endotoxins that have been associated with asthma exacerbations (Douwes et al. 2003) and other respiratory health effects (Miaśkiewicz-Peska 2011).

Ambulance vehicles are of critical importance for the emergency health services and their goal is to help critically ill patients and to prevent the development of life-threatening complications in seriously wounded cases (Wepler et al. 2015; Viegas et al. 2021). These vehicles can respond to several cases per day and after each mission, each one must be cleaned and desinfected to be ready to use in the next mission (Viegas et al. 2021). Effective cleaning protocols are of upmost importance in order to avoid the exposure to pathogenic microorganisms (Viegas et al. 2021). The recent outbreak of the COVID-19 highlight the importance of all ambulance headquarters to control and manage rapidly during public health threats, in order to prevent transmission and save lives (WHO 2015; Viegas et al. 2021). Additionally, there is a gap of information on best practices regarding to cleaning procedures between missions that guarantee the safety of patients and health staff (Wepler et al. 2015). An increased exposure should be expected for ambulance drivers, with regular work shifts of 8 h a day 5 days a week, at least, considering for considerably more time spent insid e the ambulances than the patients and families (Nowakowicz-Dębek et al. 2017; Viegas et al. 2021). Aiming the exposure assessment of this occupational environment, it is important to acquire accurate information on exposure sources inside the ambulances, and also about the variables that can influence exposure (Wouters et al. 2006; Viegas et al. 2021).

So far, there are no studies regarding the exposure of ambulance drivers to microbiologic agents. The aim of an enlarged study was to characterize the exposure of ambulance drivers in Portugal to bioburden and to suggest control procedures to prevent microbial contamination on Portuguese ambulances (Viegas et al. 2021). In this paper we present the results from a screening performed through passive sampling methods (settled dust and mops and cloths applied on the ambulances' cleaning procedures) to allow the selection of the most suitable sampling and analyses protocol in this specific health care environment.

2 Materials and Methods

This study was held during winter months (November and December) of 2019 in two Firefighters Headquarters (FF). A total of 12 ambulances were sampled (4 from FF1 and 8 from FF2). The sample consisted of twelve settled dust samples from driver's and medical cabins of the 12 ambulances, 5 mop samples (2 from FF1 and 3 from FF2) used for the cleaning procedures of all the headquarters' ambulances, and also 2 cleaning cloths samples from 2 individual ambulances from FF2. All samples were collected before the cleaning procedures in all ambulances. Settled dust (1 g) was collected in all the ambulances' floor and extracted with procedures already reported (Viegas et al. 2021). The obtained extracts were seeded in four different culture media in order to enhance the selectivity for bacterial and fungal growth following procedures of incubation and quantification publish elsewhere (Viegas et al. 2019a, b; Viegas et al. 2021). Mop and cleaning cloths results were consider as a composite sample in this screening study.

3 Results

The prevalence of bacterial contamination was higher in Gram negative bacteria (VRBA) in both matrixes from FF 1 (54.7% settled dust; 56.41% mop and cleaning cloths). In FF2, Total Bacteria (TSA) presented the highest prevalence in settled dust samples (54.96%) and in mop and cleaning cloths the prevalence was 50% in both media (Fig. 1).

Regarding the fungal contamination, in FF1 the highest prevalence was in MEA media in both matrixes (61.2% settled dust; 60.7% mop and cleaning cloths). In FF2, DG18 presented the highest prevalence in settled dust samples (53.3%) and MEA presented the highest prevalence in mop and cleaning cloth samples with a total percentage of 100% (Fig. 2).

4 Discussion

Most of the studies performe in this occupational environment relied only on surface swabs as a standalone method (Nigam and Cutter 2003; El-Mokhtar and Hetta 2018; O'Hara et al. 2017), with some studies using air sampling (Bielawska-Drózd et al. 2017) and some appling, in parallel, air and swabs (Luksamijarulkul and Pipitsangjan

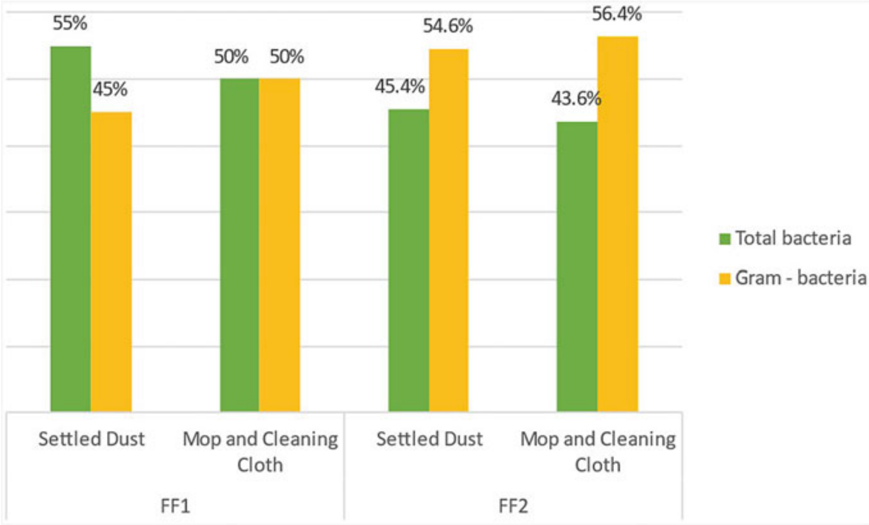

Fig. 1 Bacteria distribution in both environmental samples

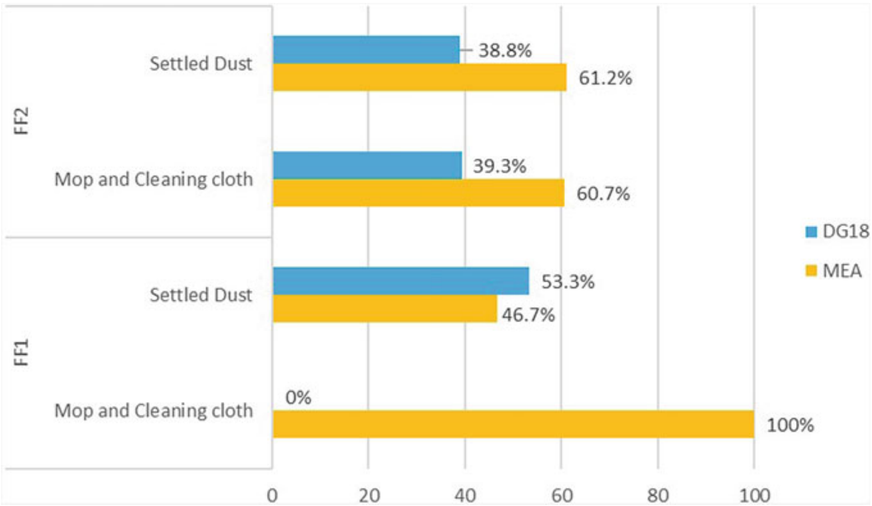

Fig. 2 Fungi distribution in both environmental samples

2015; Bielawska-Drózd et al. 2017). However, results obtained in two studies held in health care facilities suggest a multi-approach sampling protocol to obtain the exposure assessment to microbiologic agents (Viegas et al. 2019a, b). In fact, althought the trend in indoor environments is to use only active sampling (air sampling) in exposure assessment studies, passive methods allow to obtain information from a wider period of time, since air sampling have shorter collection time (minutes), while the passive methods collected in this study (settled dust, mops and cleaning cloths) can retrive information from the last cleaning procedures applied until the sampling moment (Viegas et al. 2019a, b).

Our results permitted corroborating the importance to use passive sampling methods, besides swabs, in sampling protocols that intend to assess occupational exposure to bioburden (Viegas et al. 2019a, b; Viegas et al. 2020a, b). Indeed, bioburden presence was observed in all the sampling methods used and in the different culture media applied. Thus, passive sampling should be used in parallel with active sampling methods (air sampling) to obtained a more detailed risk characterization (Viegas et al. 2019a, b; Viegas et al. 2020a, b).

The culture media allowed to increase bioburden characterization (Total bacteria vs Gram negative bacteria) and to unveil a wider mycobiota characterization since culture media applied (MEA and DG18) presented different species (data not shown), besides different counting. Higher counts in MEA and higher diversity in DG18 has been the trend in different occupational environments where both media were used (Viegas et al. 2019a, b; Viegas et al. 2020a, b).

4.1 Limitations

Further studies will be needed to analyse together the results from active and passive sampling methods obtained from this specific clinical environment and to characterize the potential risk of cross contamination between ambulances (Viegas et al. 2021).

5 Conclusions

Passive methods (settled dust, mops and cleaning cloths) should be used combined with active methods to assess occupational exposure to bioburden in ambulances, since they provide information from a longer period of time (since the last cleaning procedures instead of minutes from air sampling collection). A wider pool of different culture media allows obtaining a more detailed bioburden characterization.

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References

Alassane-Kpembi, I., Kolf-Clauw, M., Gauthier, T., Abrami, R., Abiola, F.A., Oswald, I.P., Puel, O.: New insights into mycotoxin mixtures: the toxicity of low doses of Type B trichothecenes on intestinal epithelial cells is synergistic. Toxicol Appl. Pharma. (2013). https://doi.org/10.1016/j.taap.2013.05.023

Bielawska-Drózd, A., Cieślik, P., Wlizło-Skowronek, B., Winnicka, I., Kubiak, L., Jaroszuk-Ściseł, J., Depczyńska, D., Bohacz, J., Korniłłowicz-Kowalska, T., Skopińska-Różewska, E., Kocik, J.: Identification and characteristics of biological agents in work environment of medical emergency services in selected ambulances. Int. J. Occup. Med. Environ. Health (2017). https://doi.org/10.13075/ijomeh.1896.00816

Bush, R., Portnoy, J., Saxon, A., Terr, A., Wood, R.: The medical effects of mold exposure. J. Allergy Clin. Immunol. (2006). https://doi.org/10.1016/j.jaci.2005.12.001

Douwes, J., Thorne, P., Pearce, N., et al.: Bioaerosol health effects and exposure assessment: progress and prospects. Ann. Occup. Hyg. (2003)

El-Mokhtar, M., Hetta, H.: Ambulance vehicles as a source of multidrug-resistant infections: a multicenter study in Assiut City. Egypt, Infection and Drug Resistance (2018)

Klarić, M., Račić, D., Peraica, M.: Deleterious effects of mycotoxin combinations involving ochratoxin. A. Toxins (2013)

Luksamijarulkul, P., Pipitsangjan, S.: Microbial air quality and bacterial surface contamination in ambulances during patient services. Oman. Med. J. (2015). https://doi.org/10.5001/omj.2015.23

Miaśkiewicz-Peska, E.: Effect of antimicrobial air filter treatment on bacterial survival. Fibres & Textiles in Eastern Europe (2011)

Nigam, Y., Cutter, J.: A preliminary investigation into bacterial contamination of Welsh emergency ambulances. Emerg. Med. J. (2003). https://doi.org/10.1136/emj.20.5.479

Nowakowicz-Dębek, B., Pawlak, H., Wlazło, L., Maksym, P., Kapica, J., Chmielowiec-Korzeniowska, A., Trawińska, B.: Evaluating bioaerosol exposure among bus drivers in the public transport sector. J. Occup. Environ. Hyg. (2017). https://doi.org/10.1080/15459624.2017.1339165

O'Hara, N.B., Reed, H.J., Afshinnekoo, E., Harvin, D., Caplan, N., Rosen, G., Frye, B., Woloszynek, S., Ounit, R., Levy, S., Butler, E., Mason, C.E.: Metagenomic characterization of ambulances across the USA. Microbiome (2017). https://doi.org/10.1186/s40168-017-0339-6

Oppliger, A.: Advancing the science of bioaerosol exposure assessment. Ann. Occup. Hyg. **58**(6), 661–663 (2014)

Snelders, E., Melchers, W., Verweij, P.: Azole resistance in Aspergillus fumigatus: a new challenge in the management of invasive aspergillosis? Fut. Microbiol. (2011)

Viegas, C., Almeida, B., Monteiro, A., Caetano, L.A., Carolino, E., Gomes, A.Q., Twarużek, M., Kosicki, R., Marchand, G., Viegas, S.: Bioburden in healthcare centers: Is the compliance with Portuguese legislation enough to prevent and control infection? Build. Environ. (2019a)

Viegas, C., Almeida, B., Monteiro, A., Paciência, I., Rufo, J., Aguiar, L., Lage, B., Gonçalves, L., Caetano, L., Carolino, E., Quintal Gomes, A., Twarużek, M., Kosicki, R., Grajewski, J., Teixeira, J.P., Viegas, S., Pereira, C.: Exposure assessment in one central Hospital: a multi-approach protocol to achieve an accurate risk characterization. Environ. Res. (2019b). https://doi.org/10.1016/j.envres.2019.108947

Viegas, C., Caetano, L.A., Cox, J., Korkalainen, M., Haines, S., Dannemiller, K., Viegas, S., Reponen, T.: The effects of waste sorting in environmental microbiome, THP-1 cell viability and inflammatory responses. Environ. Res. (2020a)

Viegas, C., Sousa, P., Dias, M., Aranha Caetano, L., Ribeiro, E., Carolino, E., Twarużek, M., Kosicki, R., Viegas, S.: Bioburden contamination and Staphylococcus aureus colonization associated with firefighter's ambulances. Environ. Res. (2021)

Viegas, C., Twarużek, M., Lourenço, R., Dias, M., Almeida, B., Caetano, L.A., Carolino, E., Gomes, A.Q., Kosicki, R., Soszczyńska, E., Viegas, S.: Bioburden assessment by passive methods on a

clinical pathology service in One Central Hospital from Lisbon: what can it tell us regarding patients and staff exposure? Atmosphere (2020b)
Wepler, M., Stahl, W., von Baum, H. Wildermuth, S., Dirks, B., Georgieff, M., Hafner, S.: Prevalence of nosocomialpathogens in German ambulances: the SEKURE study. Emerg. Med. J. (2015)
World Health Organization: 65th session of the WHO Regional Committee for Europe (2015). [Consult. 23 Apr 2020]: http://www.euro.who.int/en/media-centre/events/events/2015/09/65th-session-of-the-who-regional-committee-for-europe
Wouters, I., Spaan, S., Douwes, J., Doekes, G., Heederik, D.: Overview of personal occupational exposure levels to inhalable dust, endotoxin, beta(1–> 3)-glucan and fungal extracellular polysaccharides in the waste management chain. Ann. Occup. Hyg. (2006)

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Occupational and Environmental Health

Long-Term Driving Causes Gait Plantar Pressure Alterations in Subjects Groups

Marko M. Cvetkovic, J. Santos Baptista, and Denise Soares

Abstract Background: The development of driving discomfort caused by prolonged driving is a multifunctional problem. It has been the subject of interest of several articles. After prolonged exposure to driving discomfort, performing gait on different ground levels contributes to a high prevalence of occupational injuries. Objective: This study investigates whether the developed discomfort during prolonged driving might trigger changes in gait plantar pressure. Method: The study includes data based on forty-four subjects aged between 20 and 40 years old. The plantar pressure variable was collected into two periods, before and after steering the driving simulator. Subjects' groups were defined using the Hierarchical clustering method based on walking speed difference performed at post- and pre-steering gait. Results: The results uncover significant changes in the forefoot (central and lateral) area among faster walking participants. The exception was for the hallux. Participants with the fastest walking speed shifted plantar pressure from the hallux to the central forefoot area with a post-steering gait. Conclusions: The time spent driving influenced the plantar pressure distribution among subgroups, suggesting that discomfort occurred at the end of the driving process. Adopting faster walking speed with uneven plantar pressure might explain physiological and psychophysical responses to the driving process.

The original version of this chapter was revised. Sub section "3.2 Plantar Pressure Distribution" has been included. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-89617-1_59.

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Keywords Hierarchical clustering · Gait speed · Driving simulator · Pressure distribution

1 Introduction

Work-related musculoskeletal disorders (WMSD) among professional drivers are developed in the complex interaction between human perception, individual characteristics (both physical and psychological), and exposure time to the harmfulness in the working environment (Messing et al. 2008; Sekkay et al. 2018; Tamrin et al. 2014).

Prolonged driving/sitting increases muscle tension, which could potentially develop the reduction of blood flow with a consequence of the higher perception of discomfort at the loaded area (Tamrin et al. 2014). Moreover, continuous prolonged static driving strategies may trigger various musculoskeletal disorders, such as lower limbs oedema (Belczak et al. 2015; Wrona et al. 2015), local or total body discomfort (Messing et al. 2009), muscles cramps (Wrona et al. 2015), cardiovascular diseases (Thosar et al. 2015), venous disorders (D'Souza et al. 2005; Łastowiecka-Moras 2017), swelling and deformation of the joints (De Looze et al. 2003), among others.

For instance, daily activities of truck drivers can involve additional working effort outside the vehicle (entering/opening/closing the truck trailer, and similar) (Sekkay et al. 2018; Spielholz et al. 2008). These actions require gait performances on the different ground levels, which directly demand additional muscles activities, especially after prolonged driving (Messing et al. 2009; Smith and Williams 2014; Spielholz et al. 2008).

WMSD have the highest rate of injury prevalence among professional truck drivers (Smith and Williams 2014). It was pointed out that work-related injuries and illnesses among professional truck drivers have one of the highest rates in the United States of America (Smith and Williams 2014). This conclusion could bring a discussion regarding the amount of the consequences that can lead to this health problem and generate a high level of medical costs. Injuries caused by slips, trips, and falls occur immediately after the WMSD—represented by the same study (Smith and Williams 2014).

Falls from high places and WMSD represent the highest medical cost compared to the remaining types of injuries. They were identified as the main reason for work absenteeism (Smith and Williams 2014). Spielholz et al. (2008) referred to the problem of slips, trips, and falls as one of the top two most severe issues in the truck industries and, along with WMSD, represent 54% of the overall damages during an individual's driving career.

Oullier et al. (2009) research pointed out that postural stability was disturbed by prolonged exposure to whole-body vibration among professional drivers. Fatigue caused by prolonged driving discomfort combined with demanding walking ground levels will involve different muscle activities and directly indicate plantar pressure modification (Nagel et al. 2008). Disturbing, complex systems of human postural stability (Chiu and Wang 2007) with the risk factors mentioned above may be one of the reasons for injuries reported among researchers (Sekkay et al. 2018; Spielholz et al. 2008).

Reports regarding the relationship between long-time driving and alterations in plantar pressure among drivers are limited. Thus, this study investigates where the two hours of steering a driving simulator might trigger the changes in the applied plantar pressure.

2 Methodology

2.1 Participants

The present study was approved by the Ethical Committee of the University of Porto, Portugal (PARECER No84/CEUP/2019). A sample of forty-four subjects, 22 of which were male and 22 females, voluntarily agreed to participate in this study. The inclusion criteria were healthy subjects without previous lower limbs injuries, neurological or skeletal disorders, as well as a valid driving license for at least two years. Participants with an inability to perform regular barefoot or shod walk, with inappropriate behaviour while driving, or affected during the driving test by the demanding virtual environment, were excluded from the research. A printed informed consent describing the aim of the study, protocol specifications and possible collateral effects was provided to each participant before the data collection.

2.2 Measurement Procedure

A portable mechanical scale (SECA; Germany) with a maximum capacity of 220 kg (with the graduation of 0.005 kg) and vertical measurements of the stature (maximum 200 cm) was used to assess the participant's weight and body height. The remaining attributes were measured using a meter equipped with plastic needles, allowing precise measures (range up to 217 cm) (Sánchez-García et al. 2007).

The barefoot plantar pressure was recorded using a Walkway Pressure Assessment System (Tekscan®, USA). The pressure mat filled the space between the start line and endpoint and enabled at least two steps before and after contacting the sensing area (Sole et al. 2017). The system comprises a 174.4×36.9 cm sensing area containing 9152 pressure-sensing points and a pressure range of 1–850 kPa. The calibration was performed before the experimental process with each participant's weight. Participants walking pattern was recorded at the sampling rate 100 Hz. The gait was documented before and after the steering driving simulator. Participants were instructed to walk at a self-selected comfortable speed. In case of unusual behaviour, sudden changes of the gait pattern, or step out of the pressure mat, participants were asked to repeat the gait until three valid trials (per walking period) were obtained.

2.3 Driving Simulator

A real vehicle (a 1994 Volvo v440) was modified into the driving simulator for that purpose (Cvetkovic et al. 2020). Specially designed elements such as the clutch, brake and gas pedals, the steering wheel, gearshift, display with driving speed, and kilometres were implemented with sensors in the simulator. Drivers were steering the driving simulator for a total duration of 120 minutes.

2.4 Data Processing

Applied barefoot plantar data were acquired using the Walkway software as well. The obtained raw plantar data were further exported to ASCII file and afterwards imported to custom made MATLAB® R2016b (Mathworks Inc., Natick, MA) analysis routine. The routine enabled the two-dimensional footprint to be divided into the ten regions (hallux (H), other fingers (OF), medial forefoot (MF), central forefoot (CF), lateral forefoot (LF), medial mid-foot (MF), lateral mid-foot (LF), medial rearfoot (MR), central rearfoot (CF), lateral rearfoot (LR)) illustrated in Fig. 1. The data treatment was done considering two footprints of the dominant foot per walking trial, assessing the individual plantar size and shape separately. An average value obtained from the three-gait trials was calculated for the pre-and post-steering gait cycles and then was transferred to a spreadsheet for additional statistical analysis.

Data based on performed walking speed was acquired using the Walkway Pressure Assessment System (Tekscan®, USA). Collected raw data were further exported using Walkway 7.02 (Tekscan®, USA) to Excel 2016 (Microsoft Corporation, USA) spreadsheet for further analysis.

2.5 Statistical Analysis

The acquired data were statistically investigated using the SPSS® statistical software (version 23.0; IBM, USA). The hierarchical clustering method was carried out to divide the study population into subgroups. As the first step, differences between post- and pre-steering gait speed were calculated. The single variable was further implemented into the clustering method to define study groups based on increased/decreased gait speed. Ward's method was implemented to characterize the subgroups. Euclidian's distance was applied to examine the dendrogram visually and to define the subgroups. The Shapiro-Wilk's test was performed to resolve if

Table 1 Participant characteristics (data is the mean ± standard deviation)

Personal characteristics	C1 (N = 26)	C2 (N = 10)	C3 (N = 8)
Age (years)	27.0 ± 4.8	27.0 ± 3.6	29.4 ± 5.6
Body height (cm)	171.1 ± 8.1	168.1 ± 8.6	171.1 ± 9.2
Weight (kg)	70.9 ± 15.4	66.1 ± 14.0	62.9 ± 11.0

the collected data has (not) normal distribution. Finally, the between-subjects mean variations were established using the Kruskal-Wallis H test.

Additionally, to demonstrate between which subgroups the difference existed, the Mann-Whitney U test with the Bonferroni adjustment was considered. Finally, to determine if the two hours of the steering driving simulator had a significant influence on the mean peak plantar pressure, the Wilcoxon's Single Ranked Test was used. The statistical difference was considered at $p < 0.05$.

3 Results

3.1 Sample Characteristics

Hierarchical clustering generated three subgroups based on the alterations in gait speed after steering for two hours. Ward's method recognized two clusters with an increase and one with a reduction in walking speed. The first cluster (C1) included twenty-six participants with a faster average speed of 2.85 $cm.s^{-1}$) comparing to pre-steering gait speed. The second cluster (C2) consisted of ten participants with the highest speed (on average 14.47 $cm.s^{-1}$) after the prolonged driving period. The third cluster (C3) had eight participants with a slower average walking speed (8.51 $cm.s^{-1}$) with a post-steering gait. Even though the subgroups differ in the sample size, the personal attributes did not significantly variate (Table 1).

3.2 Plantar Pressure Distribution

Figure 1 illustrates the mean and standard deviation of mean peak pressure between the pre-and post-steering walking periods for each subgroup. During the post-steering gait, the C1 participants performed different walking patterns compared with the initial walking trial. The mean peak pressure under the hallux (H) area has decreased ($p=0.015$), while the FC area achieved higher values (0.009). The C2 considerable increased mean peak pressure under the FC ($p<0.001$) and FL ($p=0.024$) areas. The chosen walking strategy by C3, after the driving process, affected the planar pressure

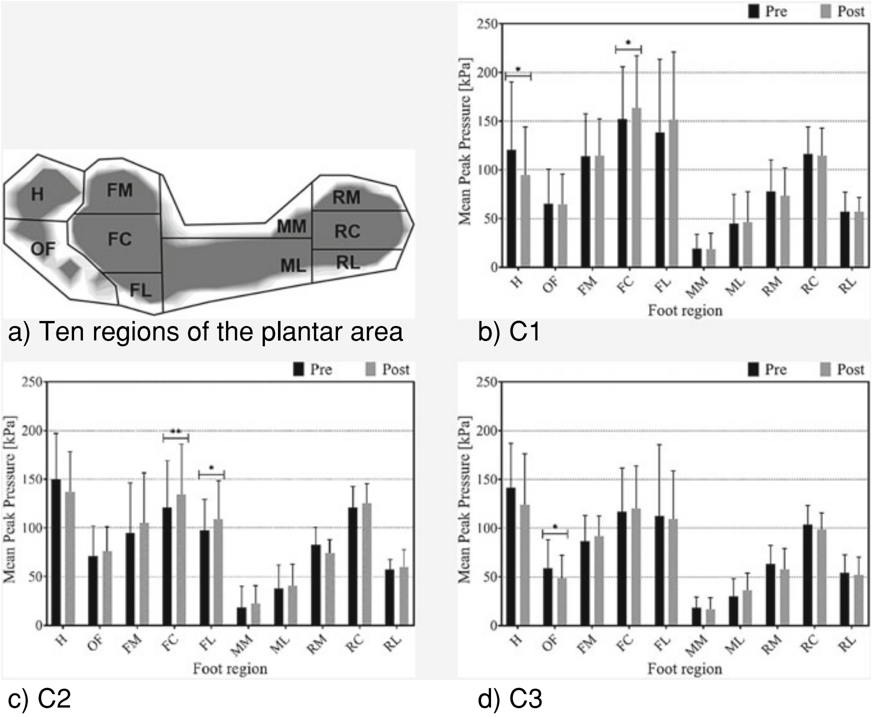

Fig. 1 Mean peak barefoot plantar pressure of the total sample represented in ten-foot regions. The data is illustrated as a mean and standard deviation. Plantar areas: H—Hallux; OF—Other Fingers; FM—Forefoot Medial; FC—Forefoot Central; FL—Forefoot Lateral; MM—Mid-foot Medial; ML—Mid-foot Lateral; RM—Rearfoot Medial; RC—Rearfoot Central; RL—Rearfoot Lateral. **a** C1 = Cluster 1—Increased speed; **b** C2 = Cluster 2—Increased speed; **c** C3 = Cluster 3—Reduced speed. A statistically significant difference between the two walking periods is indicated as * ($p<0.05$) and ** ($p<0.001$)

under the OF area ($p=0.012$), decreasing it. In contrast, the rest areas remained without significant changes.

Mean peak pressure differs between the subgroups only with the gait accomplished after the driving process. Under the H area (Fig. 1), the statistical analysis indicated a considerable difference of applied mean peak pressure between the C1 and C2 participants ($p=0.021$). The C2 applied more substantial pressure in the RC area compared to the C3 sample ($p=0.012$). Statistically, the differences between C1 and C3 subgroups was not established.

4 Discussion

The results indicated the variation of applied barefoot plantar pressure between two walking periods. We suspected that steering the driving simulator in a demanded virtual environment will develop local or total body discomfort (Sammonds et al. 2017; Smith et al. 2015; Varela et al. 2019) affects self-selected comfortable gait pattern. For instance, Smith et al. (2015) explored discomfort in a body part during steering a driving simulator in the total exposure of one hour. A six-level scale has shown that the higher prevalence of discomfort occurred at the right ankle at the end of the driving process. Reported foot or lower limb pain/discomfort might change the comfortable walking rhythm and cause variation in gait (Mickle et al. 2010).

Increasing the walking speed will result in an increase in plantar pressure under a specific surface of the foot (Burnfield et al. 2004; Segal et al. 2004. Burnfield et al. (2004) observed walking performance in healthy adult participants at three different speeds (95 cm.s^{-1}, 133.3 cm.s^{-1} and 116.7 cm.s^{-1}). The analysis of the records has displayed that the mean peak pressure under the rearfoot, FC, FM, H, and OF area increased with faster walking speed. In the current research, participants classified as C1 subgroup experienced higher mean peak pressure under the FC, while the outcome revealed lesser pressure under the H area. Higher speed accounted for the C2 subgroup affected only the FC and FL area, leaving the rest of the foot regions without noticeable change. Furthermore, as a consequence of steering the driving simulator for two hours, the mean peak pressure of the C1 subgroup has shifted from the hallux to the central forefoot area (Fig. 1). Therewith, hallux and other fingers usually are in contact for three-quarters of the stance phase (Liu et al. 2005), while the findings of this study demonstrate that the participants excluded the toes during the push-off phase in the post-driving gait.

It appears that the participants adopted a more cautious initial foot contact and push-off phase and consequently reduced the pressure of the medial heel and hallux area. Dropping of the pressure under the abovementioned foot regions can be associated with the decrease of lesser soleus muscle activity during the gait (Eils et al. 2002). Moreover, higher mean peak pressure under the central forefoot area might be caused by limited joint mobility (Höhne et al. 2009; Van Deursen 2004), causing an imbalance in dorsiflexion of the ankle (Höhne et al. 2009) and the hallux (Nagel et al. 2008; Van Deursen 2004) due to fatigue triggered by the driving process. Nagel et al. (2008) investigated a sample of 200 marathon runners (39.5 ± 8.8 years old, 33 female and 167 male) long-distance runners and changes in peak plantar pressure before and after a marathon race. They observed that post-race peak pressure was higher on the central forefoot and reduced in the hallux area due to local muscle fatigue.

The application of the current result is quite limited since the study population was composed of nonprofessional and young drivers who were steering driving simulator in a controlled condition. Therefore, future investigation needs to consider professional drivers with a wider range of body mass index and age, knowing beforehand that preferred driving postures, applied seat interface pressure, gait pattern, among others, differ between younger and older people and as well as between normal and overweight subjects (Maktouf et al. 2018).

5 Conclusions

The prolonged driving influenced walking speed as a consequence of physiological and psychophysical responses. It is suspected that local fatigue, among C1 and C2 subgroups, immobilized dorsiflexor muscles to perform a basic routine at higher speed and subsequently moved pressure from the hallux to forefoot region. If the process continues in the future, it may overload the metatarsals heads and lead to blisters and other skin problems.

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References

Belczak, C.E.Q., Godoy, J.M.P., Seidel, A.C., Ramos, R.N., Belczak, S.Q., Caffaro, R.A.: Influence of prevalent occupational position during working day on occupational lower limb edema. J. Vasc. Brasileiro **14**(2), 153–160 (2015). https://doi.org/10.1590/1677-5449.0079

Burnfield, J.M., Few, C.D., Mohamed, O.S., Perry, J.: The influence of walking speed and footwear on plantar pressures in older adults. Clin. Biomech. **19**(1), 78–84 (2004). https://doi.org/10.1016/j.clinbiomech.2003.09.007

Chiu, M.-C., Wang, M.-J.: The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking. Gait & Posture **25**(3), 385–392 (2007). https://doi.org/10.1016/j.gaitpost.2006.05.008

Cvetkovic, M., Soares, D., Fonseca, P., Ferreira, S., Baptista, J.S.: Changes in postures of male drivers caused by long-time driving. In: Occupational and Environmental Safety and Health II, pp. 491–498. Springer (2020). https://doi.org/10.1007/978-3-030-41486-3_53

D'Souza, J.C., Franzblau, A., Werner, R.A.: Review of epidemiologic studies on occupational factors and lower extremity musculoskeletal and vascular disorders and symptoms. J. Occup. Rehabil. **15**(2), 129–165 (2005). https://doi.org/10.1007/s10926-005-1215-y

De Looze, M.P., Kuijt-Evers, L.F.M., Van Dieen, J.: Sitting comfort and discomfort and the relationships with objective measures. Ergonomics **46**(10), 985–997 (2003). https://doi.org/10.1080/0014013031000121977

Eils, E., Nolte, S., Tewes, M., Thorwesten, L., Völker, K., Rosenbaum, D.: Modified pressure distribution patterns in walking following reduction of plantar sensation. J. Biomech. **35**(10), 1307–1313 (2002). https://doi.org/10.1016/S0021-9290(02)00168-9

Höhne, A., Stark, C., Brǧgemann, G.-P.: Plantar pressure distribution in gait is not affected by targeted reduced plantar cutaneous sensation. Clin. Biomech. **24**(3), 308–313 (2009). https://doi.org/10.1016/j.clinbiomech.2009.01.001

Łastowiecka-Moras, E.: How posture influences venous blood flow in the lower limbs: results of a study using photoplethysmography. Int. J. Occup. Saf. Ergon. **23**(2), 147–151 (2017). https://doi.org/10.1080/10803548.2016.1256938

Liu, X.C., Thometz, J.G., Tassone, C., Barker, B., Lyon, R.: Dynamic plantar pressure measurement for the normal subject: free-mapping model for the analysis of pediatric foot deformities. J. Pediatr. Orthop. **25**(1), 103–106 (2005)

Maktouf, W., Durand, S., Boyas, S., Pouliquen, C., Beaune, B.: Combined effects of aging and obesity on postural control, muscle activity and maximal voluntary force of muscles mobilizing ankle joint. J. Biomech. **79**, 198–206 (2018). https://doi.org/10.1016/j.jbiomech.2018.08.017

Messing, K., Tissot, F., Stock, S.: Distal lower-extremity pain and work postures in the Quebec population. Am. J. Pub. Health **98**(4), 705–713 (2008). https://doi.org/10.2105/AJPH.2006.099317

Messing, K., Tissot, F., Stock, S.R.: Should studies of risk factors for musculoskeletal disorders be stratified by gender? Lessons from the 1998 Quebec Health and Social Survey. Scand. J. Work Environ. Health 96–112 (2009). https://doi.org/10.5271/sjweh.1310

Mickle, K.J., Munro, B.J., Lord, S.R., Menz, H.B., Steele, J.R.: Foot pain, plantar pressures, and falls in older people: a prospective study. J. Am. Geriatr. Soc. **58**(10), 1936–1940 (2010). https://doi.org/10.1111/j.1532-5415.2010.03061.x

Nagel, A., Fernholz, F., Kibele, C., Rosenbaum, D.: Long distance running increases plantar pressures beneath the metatarsal heads: a barefoot walking investigation of 200 marathon runners. Gait and Posture **27**(1), 152–155 (2008). https://doi.org/10.1016/j.gaitpost.2006.12.012

Oullier, O., Kavounoudias, A., Duclos, C., Albert, F., Roll, J. P., Roll, R.: Countering postural posteffects following prolonged exposure to whole-body vibration: a sensorimotor treatment. Eur. J. Appl. Physiol. **105**(2), 235–245 (2009). https://doi.org/10.1007/s00421-008-0894-4

Sammonds, G.M., Fray, M., Mansfield, N.J.: Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs). Appl. Ergon. **58**, 119–127 (2017). https://doi.org/10.1016/j.apergo.2016.05.009

Sánchez-García, S., García-Peñ, C., Duque-López, M.X., Juárez-Cedillo, T., Cortés-Núñez, A.R., Reyes-Beaman, S.: Anthropometric measures and nutritional status in a healthy elderly population. BMC Pub. Health **7**, 1–9 (2007). https://doi.org/10.1186/1471-2458-7-2

Segal, A., Rohr, E., Orendurff, M., Shofer, J., O'Brien, M., Sangeorzan, B.: The effect of walking speed on peak plantar pressure. Foot Ankle Int. **25**(12), 926–933 (2004). https://doi.org/10.1177/107110070402501215

Sekkay, F., Imbeau, D., Chinniah, Y., Dubé, P.-A., de Marcellis-Warin, N., Beauregard, N., Trépanier, M.: Risk factors associated with self-reported musculoskeletal pain among short and long distance industrial gas delivery truck drivers. Appl. Ergon. **72**, 69–87 (2018). https://doi.org/10.1016/j.apergo.2018.05.005

Smith, C. K., Williams, J.: Work related injuries in Washington State's Trucking Industry, by industry sector and occupation. Accident Anal. Prev. **65**, 63–71 (2014). https://doi.org/10.1016/j.aap.2013.12.012

Smith, J., Mansfield, N., Gyi, D., Pagett, M., Bateman, B.: Driving performance and driver discomfort in an elevated and standard driving position during a driving simulation. Appl. Ergon. **49**, 25–33 (2015). https://doi.org/10.1016/j.apergo.2015.01.003

Sole, G., Pataky, T., Sole, C.C., Hale, L., Milosavljevic, S.: Age-related plantar centre of pressure trajectory changes during barefoot walking. Gait Posture **57**, 188–192 (2017). https://doi.org/10.1016/j.gaitpost.2017.06.016

Spielholz, P., Cullen, J., Smith, C., Howard, N., Silverstein, B., Bonauto, D.: Assessment of perceived injury risks and priorities among truck drivers and trucking companies in Washington State. J. Saf. Res. **39**(6), 569–576 (2008). https://doi.org/10.1016/j.jsr.2008.09.005

Tamrin, S.B.M., Yokoyama, K., Aziz, N., Maeda, S.: Association of risk factors with musculoskeletal disorders among male commercial bus drivers in Malaysia. Hum. Factors Ergon. Manuf. Serv. Ind. **24**(4), 369–385 (2014). https://doi.org/10.1002/hfm.20387

Thosar, S.S., Bielko, S.L., Mather, K.J., Johnston, J.D., Wallace, J.P.: Effect of prolonged sitting and breaks in sitting time on endothelial function. Med. Sci. Sports and Exercise **47**(4), 843–849 (2015). https://doi.org/10.1249/MSS.0000000000000479

Van Deursen, R.: Mechanical loading and off-loading of the plantar surface of the diabetic foot. Clinical Infectious Diseases, **39**(Supplement_2), S87–S91 (2004). https://doi.org/10.1086/383268

Varela, M., Gyi, D., Mansfield, N., Picton, R., Hirao, A., Furuya, T.: Engineering movement into automotive seating: Does the driver feel more comfortable and refreshed? Appl. Ergon. **74**, 214–220 (2019). https://doi.org/10.1016/j.apergo.2018.08.024

Wrona, M., Jöckel, K.-H., Pannier, F., Bock, E., Hoffmann, B., Rabe, E.: Association of venous disorders with leg symptoms: results from the Bonn Vein Study 1. European J. Vasc. Endovasc. Surg. **50**(3), 360–367 (2015). https://doi.org/10.1016/j.ejvs.2015.05.013

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Solutions Aiming a More Reliable Fungal Burden Risk Characterization

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Abstract The aim of this chapter is to present the challenges regarding occupational fungal burden assessment and the solutions to overcome them to allow exposure assessors/occupational hygienists to decide about sampling methods and assays aiming a reliable fungal risk characterization. Fungi occupational exposure can be estimated using a diversity of different sampling methods and assays and each situation is unique and requires very specific and critical decisions. Use passive sampling methods in parallel with active methods and as laboratory routine apply culture based-methods using at least two culture media (MEA and DG18) and target harmful fungal species through molecular tools (qPCR) should be the protocol to follow to assess occupational exposure to fungal burden. To avoid exposure assessments that go beyond the possible conclusions, exposure assessors should be informed about the limitations of sampling methods and assays. Further, if these professionals are also aware of the ways to overcome each limitation the exposure assessment and, consequently, the risk characterization will more reliable.

Keywords Sampling methods · Laboratory assays · Exposure assessment · Fungal · Contamination characterization

1 Introduction

Fungal burden present in occupational environments can cause allergies, infections and intoxications, being the most frequent health effects on workers the respiratory diseases (Dutkiewicz 1997; Schlünssen 2004). Several studies have indicated that

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workers exposure to high fungal load have increased prevalence rates of respiratory diseases and airway inflammation (Heederik et al. 2007; Cox-Ganser et al. 2009). Thus, exposure to fungi can be a serious occupational problem that requires close attention and, because of that, the exposure assessment an utmost important task for every exposure assessor (Viegas 2018).

There are occupational environments more critical regarding fungal burden. Certainly, the presence of high levels of fungal content, is frequently the result of the natural colonization of an organic substrate present in the workstations, but may also be intentionally added as is the case of food industry (Viegas 2018). Workers from some occupational environments, such as health care facilities, animal production, agriculture, waste management, fishery, construction, forestry, mining, and day care are exposed to higher fungal burden due to work characteristics (Viegas et al. 2015, 2017a, b).

Fungi occupational exposure can be estimated using a diversity of different sampling methods and assays and each situation is unique and requires very specific and critical decisions (Viegas 2018; Viegas et al. 2015, 2019) to allow a reliable risk characterization and the identification of the most suitable risk management measures. Additionally, to decide among the different sampling methods and assays to be performed as lab routine, occupational hygienists should be aware about the advantages and limitations of each (Viegas 2018; Viegas et al. 2019).

The aim of this chapter was to present the challenges regarding occupational fungal burden assessment and the solutions to overcome them to allow exposure assessors/occupational hygienists to decide about sampling methods and assays aiming a reliable fungal risk characterization.

2 Sampling Approach

The most recognized guidance for exposure assessors focusing on bio-aerosols occupational exposure assessment rely in air sampling by impaction as a stand-alone method (Health Canada Indoor air quality in office buildings: a technical guide 1993; Mishra et al. 1992; Ministério da Economia e do Emprego, Decreto-Lei n.o 118/2013 2013; Rao et al. 1996; Verhoeff et al. 1992). The method easiness to handle, the cheap cost and possibility to obtain a direct quantitative estimate of the number of culturable are major advantages that motivate exposure assessors for using this method (Viegas et al. 2015). However, this method provides information of a short period of time (load), doesn't allow the employment of other laboratory assays besides the culture-based methods (Viegas 2018) and is more used for environmental and stationary sampling instead of personal fungal exposure assessment, being a relevant drawback when the intention is to perform exposure assessment of workers with high mobility. Therefore, besides using this active method for a screening assessment purpose, we should also use other active methods that allow to perform personal exposure assessments and to use molecular tools (impinger and filtration methods) for a more detailed exposure assessment and to allow to identify intervention priorities (Viegas 2018).

Still, although active (personal or stationary) sampling of fungal burden can be performed to quantify exposure by inhalation, may be widely influenced by environmental variables, such as seasonal variation and ventilation (Flannigan 1997). To overcome this disadvantage passive-collection methods should be used, in parallel, and as a routine in field work to assess occupational exposure to fungi, since allow the collection of contamination over a longer period (days, weeks or several months) (Viegas et al. 2018). Undoubtedly, increasing the number of different sampling methods will allow to collect more data, enabling industrial hygienists to perform a more reliable risk characterization (Viegas 2018).

As a screening passive method and driven by previous experience in three different occupational environments, such as bakeries (Viegas et al. 2018), swine (Viegas et al. 2018) and primary health care centers (Viegas et al. 2019), electrostatic dust collectors (EDC) can be used to prioritize intervention regarding exposure assessment needs, and then other passive methods can be used, depending on the occupational environment under study. Previous studies already reported that EDC can be applied as a screening method for particle-exposure assessment and as a complementary sampling method for assessing bioburden (fungi and bacteria) (Viegas et al. 2018, 2019).

Indeed, passive methods were already described as giving a very important contribution with different fungal species, from the ones obtained by air sampling, being identified. Some of those are: surface swabs (Brenier-Pinchart et al. 2009; Microorganisms and particles in AHU system 2009; Pinheiro et al. 2012; Sabino et al. 2012; Cabo Verde et al. 2015; Ramos et al. 2015; Viegas et al. 2016, 2017), settled dust (Leppänen et al. 2018; Park et al. 2018; Viegas et al. 2019), EDC (Viegas et al. 2018, 2019; Cozen et al. 2008; Normand et al. 2009; Kilburg-Basnyat et al. 2016) and heating, ventilation and air conditioning (HVAC) filters (Viegas et al. 2019; Marchand et al. 2017). Thus, combining both active and sampling methods will cover a more wide number of different fungal species, since in the case of fungal contamination on surfaces, there is the possibility of re-aerosolization during the dispersion of fungal spores, varying with fungal characteristics and environmental variables (Viegas et al. 2017; Roussel et al. 2008; Jürgensen and Madsen 2016). This is of most relevance since the fungal health effects are very much related with the species and not only with the quantity.

3 Laboratory Assays

Previous research work already stated that the number of microorganisms that can be cultured only accounts for $< 5\%$ of the total microbial air load (Eduard and Heederik 1998; Radosevich et al. 2002; Toivola et al. 2002).

Additionally, culture based-methods can overestimate the most tolerant and fast-growing fungal species inhibiting others, with clinical relevance to grow (Pasanen

2001). To overcome this limitation using more than one culture media as a trend on the laboratory routine to assess fungal burden can be the solution. As such, besides the most widely recommended 2% malt extract agar (MEA) with 0.05 g/L chloramphenicol media, dichloran glycerol (DG18) agar-based media should be always used, since restricts the colony size of fast-growing (Bergwall and Stehn 2002), allowing a more diversified species profile from the fungal burden (Viegas et al. 2019). Further, the increasingly emergence of antifungal resistant *Aspergillus* sp., should be considered, also in occupational environments, justifying the use of azoles-supplemented culture media in occupational exposure assessment to fungal burden (Viegas et al. 2019; Aranha Caetano et al. 2017). This approach will allow the determination of the susceptibility pattern of *Aspergillus* section *Fumigati* present in the settings to azoles (Simões et al. 2019) increasing the reliability of the risk characterization.

Additionally, relying exclusively on culture based-methods may not provide an accurate fungal exposure assessment of the occupational environment under study (Viegas et al. 2019; Eduard and Heederik 1998; Radosevich et al. 2002; Toivola et al. 2002). Fungi identification depends on culture and microscopic examination. Although these procedures can be accurate and reliable, they are time-consuming and require well-trained mycologists to interpret the results (Croxatto et al. 2012).

Moreover, culture based-methods results depend exclusively from the various growth conditions of fungi and some are not culturable, whereas the real-time PCR method can replicate the content of all including cultivable and non-cultivable fungi. However, the lack of qPCR detection in complex occupational environments where the target species were identified by culture (Viegas et al. 2018) could be due either to ineffective release of microbial DNA content from cells, or poor DNA recovery after extraction and purification steps (Yang and Rothman 2004), or to the presence of inhibitors, such as particles as formerly reported (McDevitt et al. 2007). The same weaknesses can exist even with more advanced analytical tools, based on next-generation sequencing (NGS) technologies (Degois et al. 2017). Therefore, although the molecular tools relevance as laboratory resource still present drawbacks that need to be surpass for a better reliability in the results. Consequently, probably will never be used as a stand-alone resource and only together with culture based- methods guarantees a suitable assessment.

Overall, fungi culture should be combined with real-time PCR for better evaluation of the occupational environment. This assays approach will permit: by using culture-based methods to acquire information about the infection potential of the fungal burden present (Hung et al. 2005) and comparing quantitative (CFU.m^{-}3) information with available guidelines; by applying molecular tools to target specific fungal species indicators of harmful fungal burden and to overcome some culture-based methods drawbacks (Degois et al. 2017) (Table 1 and Fig. 1).

Table 1 Challenges and best options to accomplish occupational fungal burden exposure assessment

Challenges	Best options (sampling and analysis)
Perform a screening to prioritize workstations needed to be assessed	Apply air sampling by impaction (active methods) and EDC (passive methods)
Obtain data concerning fungal load in the air for guidelines comparison	Apply air sampling by impaction and filtration (personnel exposure)
Characterize the fungal contamination	Use passive sampling methods in parallel with active methods
Obtain the infection potential from the fungal burden	Apply culture based-methods
Avoid results underestimation (quantitatively and qualitatively)	Use at least two culture media (MEA and DG18) and target harmful fungal species through molecular tools (qPCR)
Characterize the susceptibility profile from the fungal burden	Use azoles supplemented media

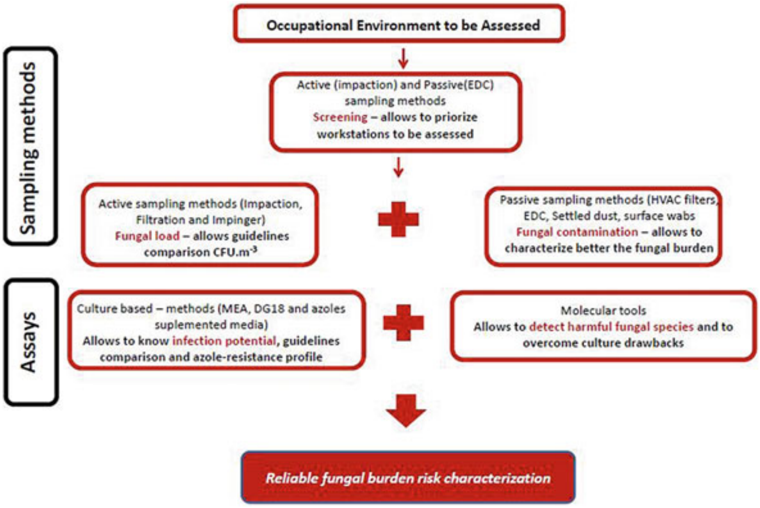

Fig. 1 Protocol for a reliable occupational fungal burden exposure

4 Exposure Assessment Challenges and Solutions

Challenges/limitations of the sampling methods and laboratory assays should be known to be able to tackle them and, at least, to be aware of the results interpretation (Table 1).

The suggested protocol (Fig. 1) covers all the solutions mentioned on the Table 1 and will help the occupational hygienists to define the most suitable sampling strategy, but also the adequate analyses to be performed to allow a reliable risk characterization regarding fungal burden.

5 Conclusions

To avoid exposure assessments that go beyond the possible conclusions, exposure assessors should be informed about the limitations of sampling methods and assays. Further, if these professionals are also aware of the ways to overcome each limitation the exposure assessment and, consequently, the risk characterization will be more reliable. More than one sampling method and a rigorous selection of culture media and fungal targets for molecular detection should be the approach to be considered in protocols from the field to the lab work.

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References

Aranha Caetano, L., Faria, T., Batista, A.C., Viegas, S., Viegas, C.: Assessment of occupational exposure to azole resistant fungi in 10 Portuguese bakeries AIMS microbiology **3**(4), 960–975 (2017). https://doi.org/10.3934/microbiol.2017.4.960

Bergwall, C., Stehn, B.: Comparison of selective mycological agar media for the isolation and enumeration of xerophilic moulds and osmotolerant yeasts in granulated white sugar. Zuckerindustrie **127**, 259–264 (2002)

Brenier-Pinchart, M.P., Lebeau, B., Mallaretm, M.R.: Mobile air-decontamination unit and filamentous fungal load in the hematology ward: how efficient at the low-activity mode? Am. J. Infect. Control **37**, 680–2 (2009). https://doi.org/10.1016/j.ajic.2008.12.006

Cabo Verde, S., Almeida, S.M., Matos, J., Guerreiro, D., Meneses, M., Faria, T., et al.: Microbiological assessment of indoor air quality at different hospital sites. Res. Microbiol. **166**(7), 557–63 (2015). https://doi.org/10.1016/j.resmic.2015.03.004

Cox-Ganser, J.M., Rao, C.Y., Park, J.H., Schumpert, J.C., Kreiss, K.: Asthma and respiratory symptoms in hospital workers related to dampness and biological contaminants. In-door Air **19**, 280–290 (2009)

Cozen, W., Avol, E., Diaz-Sanchez, D., McConnell, R., Gauderman, W.J., Cockburn, M.G., Mack, T.M.: Use of an electrostatic dust cloth for self-administered home allergen collection. Twin Res. Hum. Genet. **11**, 150–155 (2008)

Croxatto, A., Prod'hom, G., Greub, G.: Applications of MALDI-TOF mass spectrometry in clinical diagnostic microbiology. FEMS Microbiol. Rev. **36**(2), 380–407 (2012)

Degois, J., Clerc, F., Simon, X., Bontemps, C., Leblond, P., Duquenne, P.: First Meta-genomic survey of the microbial diversity in bioaerosols emitted in waste sorting plants. Ann. Work Expo. Health 1–11 (2017)

Dutkiewicz, J.: Bacteria and fungi in organic dust as potential health hazard. Ann. Agric. Environ. Med. **4**, 11–17 (1997)

Eduard, W., Heederik, D.: Methods for quantitative assessment of airborne levels of noninfectious microorganisms in highly contaminated work environments. Am. Ind. Hyg. Assoc. J. **59**(2), 113–127 (1998)

Flannigan, B.: Air sampling for fungi in indoor environments. J. Aerosol. Sci. **28**(3), 381–392 (1997). http://linkinghub.elsevier.com/retrieve/pii/S0021850296004417

Health Canada Indoor air quality in office buildings: a technical guide. Vancouver, Health Canada (1993). http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/office_buildingimmeubles_bureaux/93ehd-dhm166-eng.pdf

Heederik, D., Sigsgaard, T., Thorne, P.S., Kline, J.N., Avery, R., Bønløkke, J.H., et al.: Health effects of airborne exposures from concentrated animal feeding operations. Environ. Health Perspect. **115**, 298–302 (2007)

Hung, L.L., Miller, J.D., Dillon, K.H. (eds.): Field guide for the determination of biological contaminants in environmental samples, 2nd edn. AIHA, Fairfax, VA, USA (2005)

Jürgensen, C.W., Madsen, A.M.: Influence of everyday activities and presence of people in common indoor environments on exposure to airborne fungi. AIMS Environ. Sci. **3**(1), 77–95 (2016)

Kilburg-Basnyat, B., Metwali, N., Thorne, P.S.: Performance of electrostatic dust collectors (EDCs) for endotoxin assessment in homes: effect of mailing, placement, heating and electrostatic charge. J. Occup. Environ. Hyg. **13**, 85–93 (2016)

Leppänen, H.K., Täubel, M., Jayaprakash, B., Vepsäläinen, A., Pasanen, P., Hyvärinen, A.: Quantitative assessment of microbes from samples of indoor air and dust. J. Expo. Sci. Environ. Epidemiol. 4 **28**(3), 231–241 (2018). https://doi.org/10.1038/jes.2017.24

Marchand, G., Lacombe, N., Pépin, C.: Évaluation de la Biomasse Mycologique sur les Surfaces des réseaux aérauliques des systèmes de Ventilation, Institut de Recherché Robert-Sauvé en santé et en sécurité du Travail. DesLibris, Rapports Scientifiques (2017)

McDevitt, J.J., Lees, P.S.J., Merz, W.G., Schwab, K.J.: Inhibition of quantitative PCR analysis of fungal conidia associated with indoor air particulate matter. Aerobiologia **23**, 35–45 (2007)

Microorganisms and particles in AHU systems: Lu, Z., Lu. W.Z., Zhang. J.L.: Measurement and analysis. Build Environ. **44**, 694–8 (2009). https://doi.org/10.1016/j.buildenv.2008.05.014

Ministério da Economia e do Emprego, Decreto-Lei n.o 118/2013, Diário da República **159**, 4988–5005 (2013)

Mishra, S.K., Ajello, L., Ahearn, D.G., Burge, H.A., Kurup, V.P., Pierson, D.L., Price, D.L., Samson, R.A., Sandhu, R.S., Shelton, B., Simmons, R.B., Switzer, K.F.: Environmental mycology and its importance to public health. Med. Mycol. **30**(s1), 287–305 (1992)

Normand, A.C., Vacheyrou, M., Sudre, B., Heederik, D.J.J., Piarroux, R.: Assessment of dust sampling methods for the study of cultivable-microorganism exposure in stables. Appl. Environ. Microbiol. **75**, 7617–7623 (2009)

Park, J.-H., Sulyok, M., Lemons, A.R., Green, B.J., Cox-Ganser, J.M.: Characterization of fungi in office dust: comparing results of microbial secondary metabolites, fungal internal transcribed spacer region sequencing, viable culture and other microbial indices. Indoor Air. **28**(5), 708–720 (2018). https://doi.org/10.1111/ina.2018.28.issue-5

Pasanen, A.L.: A review: fungal exposure assessment in indoor environments. Indoor Air **11**, 87–98 (2001)

Pinheiro, C., Viegas, C., Viegas, S., Veríssimo, C., Brandão, J., Macedo, M.: Indoor air quality in Portuguese archives: a snapshot on exposure levels. J. Toxicol. Environ. Health A. **75**, 1359–1370 (2012). https://doi.org/10.1080/15287394.2012.721168

Radosevich, J.L., Wilson, W.J., Shinn, J.H., DeSantis, T.Z., Andersen, G.L.: Development of a high-volume aerosol collection system for the identification of air-borne micro-organisms. Lett Appl Microbiol. **34**(3), 162–7 (2002)

Ramos, C., Viegas, C., Cabo Verde, S., Wolterbeek, H.T., Almeida, S.M.: Characterizing the fungal and bacterial microflora and concentrations in fitness centers. Indoor Built Environ. **0**(0), 1–11 (2015). https://doi.org/10.1177/1420326X15587954

Rao, C.Y., Burge, H.A., Chang, J.C.S.: Review of quantitative standards and guidelines for fungi in indoor air. J. Air Waste Manag. Assoc. **46**(9), 899–908 (1996)

Roussel, S., Reboux, G., Bellanger, A.: Characteristics of dwellings contaminated by moulds. J. Environ. Monit. **10**, 724–729 (2008)

Sabino, R., Faísca, V.M., Carolino, E., Veríssimo, C., Viegas, C.: Occupational exposure to Aspergillus by swine and poultry farm workers in Portugal. J. Toxicol. Environ. Health A. **75**, 1381–91 (2012). https://doi.org/10.1080/15287394.2012.721170

Schlünssen, V.: Indices of asthma among atopic and non-atopic woodworkers. Occup. En-viron. Med. **61**, 504–511 (2004)

Simões, D., Aranha Caetano, L., Veríssimo, C., Viegas, C., Sabino, R.: Aspergillus collected in specific indoor settings: their molecular identification and susceptibility pattern. Int. J. Environ. Health Res. (2019). https://doi.org/10.1080/09603123.2019.1650903

Toivola, M., Alm, S., Reponen, T., Kolari, S., Nevalainen, A.: Personal exposures and microenvironmental concentrations of particles and bioaerosols. J. Environ. Monit. **4**(1), 166–74 (2002)

Verhoeff, A.P., Van Wijnen, J.H., Brunekreef, B.: Presence of viable mould propagules in indoor air in relation to house damp and outdoor air. Allergy **47**(2), 83–91 (1992)

Viegas, C., Almeida, B., Monteiro, A., Aranha Caetano, L., Carolino, E., Quintal-Gomes, A., Twarużekf, M., Kosicki, R., Marchand, G., Viegas, S.: Bioburden in healthcare centers: is the compliance with Portuguese legislation enough to prevent and control infection? Build. Environ. **160**, 106226 (2019)

Viegas, C., Faria, T., Aranha Caetano, L., Carolino, E., Quintal Gomes, A., Viegas, S.: Aspergillus spp: prevalence in different occupational settings. J. Occup. Environ. Hyg. (2017). https://doi.org/10.1080/15459624.2017.1334901

Viegas, C., Faria, T., Aranha Caetano, L., Carolino, E., Quintal Gomes, A., Viegas, S.: Aspergillus spp: prevalence in different occupational settings. J. Occup. Environ. Hyg. (2017). https://doi.org/10.1080/15459624.2017.1334901

Viegas, C., Faria, T., Meneses, M., Carolino, E., Viegas, S., Quintal Gomes, A., Sabino, R.: Analysis of surfaces for characterization of fungal burden—does it matter? Int. J. Occup. Med. Environ. Health **29**(4), 623–632 (2016). https://doi.org/10.13075/ijomeh.1896.00562

Viegas, C., Pinheiro, C., Sabino, R., Viegas, S., Brandão, J., Veríssimo, C. (eds.): Environmental mycology in public health: fungi and mycotoxins risk assessment and management. Academic Press (2015)

Viegas, C., Santos, P., Almeida, B., Monteiro, A., Carolino, E., Quintal Gomes, A., Viegas, S.: Electrostatic dust collector: a passive screening method to assess occupational expo-sure to organic dust in primary health care centers. Air Qual., Atmos. Health (2019). https://doi.org/10.1007/s11869-018-0650-9

Viegas, C.: Sampling methods for an accurate mycobiota occupational exposure assessment—overview of several ongoing projects. In: Arezes et al. (eds.) Occupational Safety and Hygiene VI, CRC Press. Taylor and Francis Group, London, pp. 7–11 (2018). ISBN: 978-1- 138-54203-7

Viegas, C., Viegas, S., Quintal Gomes, A., Taubel, M., Sabino, R.: Exposure to microbiological agents in indoor and occupational environments. Springer Nat. (2017b). https://doi.org/10.1007/978-3-319-61688-9

Viegas, C., Faria, T., Monteiro, A., Aranha Caetano, L., Carolino, E., Quintal Gomes, A., Viegas, S.: A novel multi-approach protocol for the characterization of occupational exposure to organic dust-swine production case study. Toxics **6**, 5 (2018). https://doi.org/10.3390/toxics6010005

Viegas, C., Monteiro, A., Aranha Caetano, L., Faria, T., Carolino, E., Viegas, S.: Electrostatic dust cloth: a passive screening method to assess occupational exposure to organic dust in bakeries. Atmosphere **9**, 64 (2018). https://doi.org/10.3390/atmos9020064

Viegas, C., Almeida, B., Monteiro, A., Paciência, I., Cavaleiro, J.R., Carolino, E., Quintal-Gomes, A., Twarużek, M., Kosicki, R., Marchand, G., Aranha Caetano, L., Viegas, S.: Settled dust assessment in clinical environment: useful for the evaluation of a wider bioburden spectrum. Int. J. Environ. Health Res. (2019). https://doi.org/10.1080/09603123.2019.1634799

Yang, S., Rothman, R.E.: PCR-based diagnostics for infectious diseases: uses, limitations, and future applications in acute-care settings. Lancet. Infect. Dis. 337–348 (2004)

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Differences in Sleep Quality and Sleepiness Between 2017 and 2019 Among Workers from the Water, Sanitation and Waste Sector

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Abstract Objective: To analyse the differences in sleep quantity and quality, and sleepiness among workers from the water, sanitation and waste sector between the years 2017 and 2019. Background: Different shift arrangements, in particular those that include night shifts, have consequences related to health negative effects, insufficient sleep and sleepiness during working times. Insufficient or poor quality of sleep is a determinant of performance modifications and occupational injuries or health disturbances. Method: The study design was longitudinal with two data collection moments, based on questionnaires, intending to characterize the duration and quality of sleep, and the presence of sleepiness during work time. Results: The mean age was 50, 3 years in 2017 and 52, 3 years in 2019. Two main types of shifts were present: fixed and rotating. No differences in age were found between the different types of shifts. Lower duration of sleep after night and early morning fixed shifts, what might be explained by conflicting social and family demands, that turns difficult for these workers to go to bed earlier. Early morning (6–13h) and morning fixed shifts (8–16h) showed a higher percentage of frequent sleepiness when compared with night shift. Further studies are needed in order to analyse the influence of work determinants in sleep patterns.

Keywords Sleep quantity and quality · Sleepiness · Municipal workers · Water · Sanitation and waste sector

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1 Introduction

Different shift schedules are related to various sleep patterns, and, consequently, with the sleepiness perception during work time (Marquié et al. 2012; Parkes 2016). The nature of work of municipal workers belonging to the water, sanitation and waste sector determines different work schedules that include shift work and permanent night shifts. On the other hand, municipal workers are an ageing working population in Portugal (Cotrim et al. 2019). Considering the goals of longer working lives, the impact of work schedules, namely shift work and night shifts, must be assessed in these working populations, mainly because there are also age-related changes in sleep patterns (Bonnefond et al. 2006; Cotrim et al. 2017; Harma et al. 2006). Additionally, this occupational group is characterized for high physical workload and environmental exposure (such as noise, temperature, and dust, for instance), what can be related to an increase of sleep problems as an effect of recovery processes, when concerning the physical workload, as mentioned in the study of Akerstedt et al. (2002), or as a consequence of environmental exposure mainly to noise and heat stress (Mokarami et al. 2020).

It is well-known that different shifts arrangements are diversely associated with negative outcomes, with particular relevance for those that include night shifts (Akerstedt et al. 2014). These consequences may be related to health negative effects but also insufficient sleep and sleepiness during working times (Akerstedt et al. 2014; Parkes 2016). Furthermore, insufficient or poor quality of sleep is a determinant of performance modifications, but also occupational injuries or health disturbances (Marquié et al. 2012).

The present study is longitudinal, included two moments, and focused on a sample of male workers from the water, sanitation and waste sector. The main aim of the study was to characterize the differences in sleep characteristics in sleep quantity and quality and sleepiness between 2017 and 2019, in order to support further studies.

2 Materials and Methods

The study had a longitudinal design and the same workers answered a questionnaire in 2017 and 2019. Data collection was based on a questionnaire applied in the workplaces and preceded by an informed consent form. The study population was made up of male operational workers, from the water, sanitation and waste sector (SMAS), in a total of 484 workers, corresponding to 55, 1% of the total population of workers from SMAS. The inclusion criteria were being a worker at the SMAS for at least six months; participate in a voluntary, informed and responsible manner; belong to the water, sanitation and water sector. The number of respondents consisted of 300 workers in 2017 and the same group of workers was followed in 2019. Six workers that changed shifts from 2017 to 2019 were excluded from the analysis based on the schedules.

The first part of the questionnaire aimed at characterizing the socio-demographic variables, such as, age, sector and occupational group. The second part included variables concerning the type of schedules. And the third part intended to characterize the duration and quality of sleep, and the presence of sleepiness during work time based on the questionnaires of Barton et al. (1995) and Folkard et al. (1995). The questionnaires were administered by means of an interview during the working time.

3 Results and Discussion

The sample of workers had a mean age of 50, 3 years (sd = 9, 9) in 2017 that rose to 52, 3 years (sd = 9, 9) in 2019 (Table 1). The most represented age groups in both periods were the 56–65 years old (36, 3% in 2017 and 39, 3% in 2019), followed by 46–55 years (33, 3% in 2017 and 29% in 2019) (Table 2), what showed an ageing working group, in line with other studies with municipal workers (Cotrim et al. 2019).

The characterization of the schedules was done by work sector. Sector A comprises two fixed shifts, night and early morning, and sector B comprises one fixed day shift and rotating shifts including nights (8 h each shift, with a forward and fast rotation plan). There were no differences in age between the four types of schedules for both years (Table 3).

Regarding the duration of sleep in fixed shifts, in 2017 and 2019, after the day shift (8–16 h) the duration of sleep was higher and the differences between fixed shifts were statistically significant (Table 4). It was found in other studies that the duration

Table 1 Characterization of age in 2017 and 2019

Year	Age			
	Min	Max	Mean	DP
2017	24	68	50, 3	9, 9
2019	26	70	52, 3	9, 9

Table 2 Characterization of age group in 2017 and 2019

		2017		2019	
		N	%	N	%
Age group	<25 years	2	0, 7	2	0, 7
	26–35 years	20	6, 7	21	7, 0
	36–45 years	69	23, 0	69	23, 0
	46–55 years	100	33, 3	87	29, 0
	56–65 years	109	36, 3	118	39, 3
	>65 years	0	0	3	1, 0
	Total	300	100	300	100

Table 3 Characterization of the schedules and age in 2017 and 2019, by work sector

		Sector A (n = 82)		Sector B (n = 212)				
		Fixed 23–06 h (n = 33)	Fixed 06–13 h (n = 51)	Fixed 08–16 h (n = 127)	Rotating (n = 89)	Total (n = 294)	Stat.	p-value
2017	Age (years)	47, 91 (10, 53)	48, 43 (10, 20)	51, 38 (9, 93)	50, 62 (9, 57)	50, 28 (9, 98)	1, 740a	0, 159
2019	Age (years)	49, 47 (11, 85)	51, 07 (9, 49)	52, 79 (9, 31)	53, 57 (10, 21)	52, 45 (9, 96)	1, 487a	0, 218

Mean (SD); a ANOVA

Table 4 Perceived sleep duration after each shift

		Fixed 23–06 h (n = 33)	Fixed 06–13 h (n = 49)	Fixed 08–16 h (n = 126)	Total (n = 208)	Statistics	p-value
Perceived sleep duration after each shift	2017	5 (1)	5 (1)	7 (1)	6 (2)	59, 050a, b	< 0, 001*
	2019	5 (1)	5 (1)	7 (1)	6 (2)	45, 651a, b	< 0, 001*

Median (inter-quartile amplitude); a Kruskal-Wallis test; b The non-parametric test of multiple comparisons Dunn- Bonferroni showed statistically significant differences between the schedules Fixed 23–06 h and Fixed 08–16 h ($p < 0, 001$), and Fixed 06–13 h and Fixed 08–16 h ($p < 0, 001$); * $p < 0, 05$

of sleep before early morning shifts might be lower. One of the explanations for these may be the conflicting social and family demands that turns difficult for these workers to go to bed earlier (Folkard and Barton 1993). On the other side, night shift is expected to be associated with disturbed sleep, including sleep loss (Akerstedt et al. 2002; Bonnefond et al. 2006), what may be due to a second job during daytime. This variable was not controlled in our study, what is recognized as a limitation of the study.

Concerning the rotating shifts, in 2017, the perception of sleepiness was higher in the morning shift, and the differences were statistically significant between the morning shift and the afternoon and night shifts. In 2019, sleepiness was more frequent during the night shift and differences were significant between the three pairs of shifts (Table 9). These results showed that the percentage of sleepiness in rotating shifts is higher than in fixed shifts, and it appears to have increased in the night shift in the two years period.

Concerning the rotating shifts, the pattern of sleep duration was different when comparing 2017 and 2019. In 2017, the duration of sleep after the night shift was higher and the differences were statistically significant. In 2019, the duration of sleep for all shifts was higher then in 2017. There were also differences between the

Table 5 Characterization of the duration of sleep (hours) after the shift in 2017 and 2019, for rotating shifts

		Morning (n = 86)	Afternoon (n = 86)	Night (n = 86)	Statistics	p-value
Perceived sleep duration after each shift	2017	5 (1)	5 (1)	7 (1)	75, 228a, b	< 0, 001*
	2019	6 (1)	7 (1)	6 (1)	90, 778a, c	< 0, 001*

Median (inter-quartile amplitude); a Friedman test; b The non-parametric test of multiple comparisons Dunn-Bonferroni showed statistically significant differences between the schedules Morning and Night ($p < 0, 001$), and Afternoon and Night ($p < 0, 001$); c The non-parametric test of multiple comparisons Dunn-Bonferroni showed statistically significant differences between the schedules Morning and Afternoon ($p < 0, 001$), and Afternoon and Night ($p < 0, 001$); $p < 0, 05$

shifts with higher duration of sleep after the afternoon shift (Table 5). Likewise other studies, the duration of sleep after night shifts may be longer than between morning shifts or before early morning shifts. One of the explanations for these may be the conflicting social and family demands that turns difficult for these workers to go to bed earlier (Folkard and Barton 1993). But other studies showed opposite results, with night shifts related with shorter sleep (Bonnefond et al. 2006).

The perceived quality of sleep showed similar patterns in 2017 and 2019, but varied depending on the type of schedule in both data collection moments. For fixed shifts, the differences between shifts were statistically significant, with the shift of 8–16 h showing a better perception of sleep quality in both years (Table 6).

Table 6 Characterization of the quality of sleep for workers with fixed shifts in 2017 and 2019

			Fixed 23–06 h (n = 33)	Fixed 06–13 h (n = 49)	Fixed 08–16 h (n = 126)	Total (n = 208)	Statistics	p-value
Quality of sleep	2017	Very good/Good	2 (6, 1%)	16 (32, 7%)	46 (36, 5%)	64 (30, 8%)	22, 762a	< 0, 001*
		Moderate	18 (54, 5%)	27 (55, 1%)	67 (53, 2%)	112 (53, 8%)		
		Very Bad/Bad	13 (39, 4%)	6 (12, 2%)	13 (10, 3%)	32 (15, 4%)		
	2019	Very good/Good	2 (5, 6%)	14 (24, 1%)	44 (37, 6%)	60 (28, 4%)	27, 353a	< 0, 001*
		Moderate	18 (50, 0%)	35 (60, 3%)	59 (50, 4%)	112 (53, 1%)		
		Very Bad/Bad	16 (44, 4%)	9 (15, 5%)	14 (12, 0%)	39 (18, 5)		

N (%); a Chi-Squared test; $p < 0,05$

Table 7 Characterization of the quality of sleep for workers with rotating shifts in 2017 and 2019

			Morning (n = 33)	Afternoon (n = 49)	Night (n = 126)	Statistics	p-value
Quality of sleep	2017	Very good/Good	30 (34, 9%)	51 (59, 3%)	11 (12, 8%)	19, 640M, A 23, 533M, N 42, 500A, N	< 0, 001M, A* < 0, 001M, N* < 0, 001A,N*
		Moderate	50 (58, 1%)	31 (36, 0%)	61 (70, 9%)		
		Very Bad / Bad	6 (7, 0%)	4 (4, 7%)	14 (16, 3%)		
	2019	Very good/Good	28 (35.4%)	31 (39.2%)	11 (13.9%)	5, 667M,A 38, 250M, N 10, 333A, N	0, 387M, A* < 0, 001M, N* < 0, 001A,N*
		Moderate	47 (59.5%)	41 (51.9%)	38 (48.1%)		
		Very Bad/Bad	4 (5.1%)	7 (8.9%)	30 (38.0%)		

N (%); a Chi-Squared test; b The McNemar-Bowker test was applied for the comparisons between pairs of variables (M-Morning; A-Afternoon; N-Night) with the correction of Bonferroni; * p<0, 05

About the rotating shifts, the quality of sleep was perceived more positively after the afternoon shift for both years (2017 and 2019). The differences between the three pairs of shifts were statistically significant in 2017. In 2019, the perception of the quality of sleep was clearly worse after the night shift. The differences were statistically significant between the shifts of morning and afternoon when compared with the night shift (Table 7).

For workers with fixed shifts, the perception of sleepiness appears to be mostly moderate in both years and for all types of schedules, despite some differences

Table 8 Characterization of sleepiness for workers with fixed shifts in 2017 and 2019

			Fixed 23–06 h (n = 33)	Fixed 06–13 h (n = 49)	Fixed 08–16 h (n = 126)	Total (n = 208)	Statistics	p-value
Sleepiness	2017	Very frequent / Frequent	2 (6, 1%)	20 (40, 8%)	36 (28, 6%)	58 (27, 9%)	15, 480a	0, 004*
		Sometimes	30 (90, 9%)	24 (49, 0%)	82 (65, 1%)	136 (65, 4%)		
		Seldom/Never	1 (3, 0%)	5 (10, 2%)	8 (6, 3%)	14 (6, 7%)		
	2019	Very frequent/Frequent	9 (25, 0%)	21 (36, 2%)	30 (25, 6%)	60 (28, 4%)	4, 609a	0, 332
		Sometimes	26 (72, 2%)	32 (55, 2%)	81 (69, 2%)	139 (65, 9%)		
		Seldom/ Never	1 (2, 8%)	5 (8, 6%)	6 (5, 1%)	12 (5, 7)		

N (%); a Chi-Squared test; * p < 0, 05

Table 9 Characterization of sleepiness for workers with rotating shifts in 2017 and 2019

			Morning (n = 33)	Afternoon (n = 49)	Night (n = 126)	Statistics	p-value
Sleepiness	2017	Very frequent/Frequent	21 (24.4%)	5 (5.8%)	6 (7.0%)	20, 133M, A 12, 471M, N 2, 867A, N	< 0, 001M, A* 0, 018M, N* 0, 716A, N*
		Sometimes	59 (68.6%)	63 (73.3%)	66 (76.7%)		
		Seldom/Never	6 (7.0%)	18 (20.9%)	14 (16.3%)		
	2019	Very frequent/Frequent	15 (19.0%)	18 (22.8%)	28 (35.4%)	15, 000M, A 24, 267M, N 10, 333A, N	0, 002M, A* 0, 018M, N* 0, 017A, N*
		Sometimes	50 (63.3%)	59 (74.7%)	50 (63.3%)		
		Seldom/Never	14 (17.7%)	2 (2.5%)	1 (1.3%)		

N (%); [a] Chi-Squared test; [b] The McNemar-Bowker test was applied for the comparisons between pairs of variables para (M-Morning; A-Afternoon; N-Night) with the correction of Bonferroni; * p < 0, 05

between shifts. Some studies showed that age is more clearly related to performance decline during night shifts than with the perception of sleepiness (Bonnefond et al. 2006).

Regarding fixed shifts, in 2017 were found differences in the distribution of the perception of sleepiness between shifts. Early morning shifts (6–13 h) and morning shifts (8–16h) showed a higher percentage of frequent sleepiness when compared with night shift (Table 8). This inconsistence was also found in other studies (Bonnefond et al. 2006) that explained this phenomena with the behaviour of older workers more used to work tiredness and sub-estimating their subjective sleepiness. These results may be explained, also, by the selection processes that may occur in shift work (Blok and de Loose 2011).

Concerning the rotating shifts, in 2017, the perception of sleepiness was higher in the morning shift, and the differences were statistically significant between the morning shift and the afternoon and night shifts. In 2019, sleepiness was more frequent during the night shift and differences were significant between the three pairs of shifts (Table 9). These results showed that the percentage of sleepiness in rotating shifts is higher than in fixed shifts, and it appears to have increased in the night shift in the two years period.

4 Conclusions

The relevance of characterizing the schedules of workers with high physical demands and the sleep patterns, particularly if it includes night work or early morning shifts, is based on the fact that shift work is expected to determine some disturbance in sleep (Akerstedt 2002) and is related to an increase in fatigue, decreased performance, and higher risk of accidents (Bonnefond et al. 2006) and disturbance of social and family life and health negative effects (Block and de Looze 2011; Demerouti et al. 2004). Additionally, in this study the sample of workers showed a high average age, and it is expected that elderly workers face more difficulties of adjustment to night work (Bonnefond et al. 2006; Cotrim et al. 2017) with impact in their health. Furthermore, these workers have high physically and environmental demanding tasks, what may influence the onset of sleeping disturbances (Mokarami et al. 2020). Greater work overload may be associated with sleep-related problems (Knudsen et al. 2007). Further studies must analyse the influence of socio-demographic and occupational variables.

References

Akerstedt, T., Fredlund, P., Gillberg, M., Jansson, B.: Work load and work hours in relation to disturbed sleep and fatigue in a larger representative sample. J. Psychosom. Res. **53**, 585–588 (2002)

Åkerstedt, T., Anund, A., Axelsson, J., Kecklund, G.: Subjective sleepiness is a sensitive indicator of insufficient sleep and impaired waking function. J. Sleep Res. **23**(3), 240–252 (2014)

Barton, J., Costa, G., Smith, L., Spelten, E., Folkard, S.: The Standard shift work index: a battery of questionnaires for assessing shift work-related problems. Work Stress. **9**, 3–30 (1995). https://doi.org/10.1080/02678379508251582

Blok, M.M., de Looze, M.P.: What is the evidence for less shift work tolerance in older workers? Ergonomics **54**(3), 221–232 (2011). https://doi.org/10.1080/00140139.2010.548876

Bonnefond, A., Härmä, M., Hakola, T., Sallinen, M., Kandolin, I., Virkkala, J.: Interaction of age with shift-related sleep-wakefulness, sleepiness, performance, and social life. Exp. Aging Res.: Int. J. Devoted Sci. Study Aging Process. **32**(2), 185–208 (2006). https://doi.org/10.1080/03610730600553968

Cotrim, T., Carvalhais, J., Neto, C., Teles, J., Noriega, P., Rebelo, F.: Determinants of sleepiness at work among railway control workers. Appl. Ergon. **58**, 293–300 (2017)

Cotrim, T.P., Ribeiro, C., Teles, J., Reis, V., Guerreiro, M.J., Janicas, A.S., Candeias, S., Costa, M.: Monitoring work ability index during a two-year period among portuguese municipality workers. Int. J. Environ. Res. Public Health **16**, 3674 (2019). https://doi.org/10.3390/ijerph16193674

Demerouti, E., Geurts, S.A., Bakker, A.B., Euwema, M.: The impact of shiftwork on work-home conflict, job attitudes and health. Ergonomics **47**(9), 987–1002 (2004)

Folkard, S., Barton, J.: Does the "forbidden zone" for sleep onset influence morning shift sleep duration? Ergonomics **36**(1–3), 85–91 (1993)

Harma, M., Hakola, T., Sallinen, M., Kandolin, I., Virkkala, R.: Interaction of age with shift-related sleep-wakefulness, sleepiness, performance and social life. Exp. Aging Res. **32**, 185–208 (2006)

Knudsen, H.K., Ducharme, L.J., Roman, P.M.: Job stress and poor sleep quality: data from an American sample of full-time workers. Exp. Aging Res. **64**, 1997–2007 (2007)

Marquié, J.C., Folkard, S., Ansiau, D., Tucker, P.: Effects of age, gender, and retirement on perceived sleep problems: results from de VISAT combined longitudinal and cross-sectional study. Sleep **35**, 1115–1121 (2012)

Mokarami, H., Gharibi, V., Kalteh, H.O., Kujerdi, M.F., Kazemi, R.: Multiple environmental and psychosocial work risk factors and sleep disturbances. Int. Arch. Occup. Environ. Health (2020). https://doi.org/10.1007/s00420-020-01515-8

Parkes, K.R.: Age and work environment characteristics in relation to sleep: additive, interactive and curvilinear effects. Appl. Ergon. **54**, 41–50 (2016)

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Prevalence of Musculoskeletal Symptoms Among Portuguese Call Center Operators: Associations with Gender, Body Mass Index and Hours of Work

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Abstract Objective: To investigate the 12-month prevalence of musculoskeletal symptoms among Portuguese call center operators and their associations with gender, body mass index (BMI) and hours of work. Background: According to previous studies, the prevalence of musculoskeletal symptoms among call center operators is high. However, although this is a developing occupation in Portugal, there is a lack of studies assessing this issue as well as its associations with different risk factors. Method: The study was conducted in a call center company in Portugal. One-hundred and forty-eight workers agreed to participate, and filled out questionnaires to evaluate sociodemographic, anthropometric and occupational variables, as well as the Nordic Musculoskeletal Questionnaire (NMQ) to assess musculoskeletal symptoms in the last 12 months of nine body regions. Results: NMQ revealed that the 3 most

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affected body regions were the neck (56.1%), the low back (54.7%) and the shoulders (43.9%). Significant associations were found between gender and reporting symptoms in the wrist/hands ($p = 0.033$) and the knees ($p = 0.031$), with females reporting significantly more symptoms than males; and between BMI and reporting symptoms in the thighs/hips, with overweight operators reporting more symptoms ($p = 0.010$). No significant associations were found for the hours of work factor. Conclusion: The prevalence of symptoms in call center workers is high, especially in the neck, low back and shoulders, which evidence the need of workplace interventions, such as physical activity programs, among other approaches to decrease musculoskeletal complaints in these workers.

Keywords Musculoskeletal symptoms · Call center · Gender · BMI · Workers

1 Introduction

Call centers are one of the fastest growing sectors of the labor market and are responsible for the employment of a large number of workers (Odebiyi et al. 2016).

Call centers consist of a type of occupation whose main activity is carried out by the simultaneous use of the computer and telephone, with its activity growing substantially (Bagnara and Marti 2001; d'Errico et al. 2010; Odebiyi et al. 2016). The work performed by call center operators presents a limited variety of tasks, since they have to follow scripts that limit their autonomy (d'Errico et al. 2010; Norman et al. 2004). This occupation also presents characteristics that are both occupational and psychosocial risk factors for the development of musculoskeletal disorders, namely: repetitive movements and prolonged static postures (Lacaze et al., 2010); limited/insufficient breaks (Rocha et al. 2005); and the need to solve complex situations, where communication skills and efficiency are expected from them, who are often under time pressure and monitoring of their performance, and are therefore exposed to high levels of stress and anxiety (Bhuyar et al. 2008; d'Errico et al. 2010; Rocha et al. 2005).

In a previous investigation with 374 call center operators, it was reported that 65.2% of them experienced musculoskeletal symptoms during the previous year, with the four most prevalent body regions in the male operators being the neck, the lumbar region, the upper back and the shoulders. The same order of complaints was found for the female participants, however, higher prevalences were reported when compared to the male operators (Odebiyi et al. 2016).

The prevalence of musculoskeletal symptoms in call center operators has been widely studied in different countries, namely in Sweden (Norman et al. 2004), in Brazil (Rocha et al. 2005), Italy (d'Errico et al. 2010) and Nigeria (Odebiyi et al. 2016). However, although this is a developing occupation in Portugal, there is a lack of studies investigating this topic, as well as its association with different sociodemographic, anthropometric and occupational risk factors.

Therefore, the aim of this study is to investigate the prevalence of musculoskeletal symptoms among call center operators and their associations with gender, BMI and the hours of work.

2 Materials and Methods

2.1 Study Design and Sample

The study was approved by the ethical committee of Fernando Pessoa University. The study was conducted in a Portuguese call center company. Both male and female workers were selected to the study, aged between 18 and 65 years old, and that have been working for at least 6 months as part-time or full-time operators. Excluded were workers with health problems prior to their employment in the company that could cause musculoskeletal symptoms, as well as those who started their activity at the company less than 6 months ago. 148 call center operators (68 male and 80 female) gave their written consent to participate.

2.2 Instruments and Procedures

In order to assess sociodemographic (age, gender), anthropometric (weight, height and BMI) and occupational variables (number of hours of work per day, work position), a sample characterization questionnaire was used.

The Standardized Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al. 1987), validated to the Portuguese population (Mesquita et al. 2010), was also filled out in order to assess musculoskeletal symptoms in the last 12 months of nine body regions (neck, shoulders, elbows, wrists/hands, dorsal region, low back region, hips/thighs, knees and ankles/feet).

2.3 Statistical Procedures

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS v.26.0) software for Windows. Descriptive characteristics of the participants (age and BMI) is presented as mean ± standard deviation. The 12-month prevalence of musculoskeletal disorders in each body region was described in percentage (%). The Chi-Square test was used to assess the association between the prevalence of musculoskeletal symptoms and gender (male or female), BMI (normal or overweight) and number of work hours (full-time or part-time). A p value under 0.05 was considered as significant. In Tables 1, 2 and 3, the presented values represent the

Table 1 Association between musculoskeletal symptoms and gender

Body regions	Female (n = 80)	Male (n = 68)	Chi-square test
Neck (n = 83)	46 (57.5)	37 (54.4)	$\chi^2(1) = 0.142$; p = 0.706
Shoulders (n = 65)	40 (50.0)	25 (36.8)	$\chi^2(1) = 2.614$; p = 0.106
Elbows (n = 16)	9 (11.3)	7 (10.3)	$\chi^2(1)) = 0.035$; p = 0.852
Wrists/Hands (n = 48)	32 (40.0)	16 (23.5)	$\chi^2(1) = 4.550$; **p = 0.033***
Thighs/Hips (n = 33)	22 (27.5)	11 (16.2)	$\chi^2(1) = 2.720$; p = 0.099
Knees (n = 41)	28 (35.0)	13 (19.1)	$\chi^2(1) = 4.629$; **p = 0.031***
Ankles/Feet (n = 29)	17 (21.3)	12 (17.6)	$\chi^2(1) = 0.303$; p = 0.582
Dorsal Region (n = 21)	15 (18.8)	6 (8.8)	$\chi^2(1) = 2.975$; p = 0.085
Low Back (n = 81)	48 (60.0)	33 (48.5)	$\chi^2(1) = 1.952$; p = 0.162

Table 2 Association between musculoskeletal symptoms and BMI

Body regions	Normal (n = 87)	Overweight (n = 61)	Chi-square test
Neck (n = 83)	50 (57.5)	33 (54.1)	$\chi^2(1) = 0.166$; p = 0.684
Shoulders (n = 65)	35 (40.2)	30 (49.2)	$\chi^2(1) = 1.166$; p = 0.280
Elbows (n = 16)	7 (8.0)	9 (14.8)	$\chi^2(1) = 1.673$; p = 0.196
Wrists/Hands (n = 48)	24 (27.6)	24 (39.3)	$\chi^2(1) = 2.262$; p = 0.133
Thighs/Hips (n = 33)	13 (14.9)	20 (32.8)	$\chi^2(1) = 6.590$; **p = 0.010***
Knees (n = 41)	19 (21.8)	22 (36.1)	$\chi^2(1) = 3.624$; p = 0.057
Ankles/Feet (n = 29)	13 (14.9)	16 (26.2)	$\chi^2(1) = 2.899$; p = 0.089
Dorsal Region (n = 21)	14 (16.1)	7 (11.5)	$\chi^2(1) = 0.628$; p = 0.428
Low Back (n = 81)	47 (54.0)	34 (55.7)	$\chi^2(1) = 0.043$; p = 0.837

Table 3 Association between musculoskeletal symptoms and work hours

Body regions	Full-time (n = 81)	Part-time (n = 67)	Chi-square test
Neck (n = 83)	48 (59.3)	35 (52.2)	$\chi^2(1) = 0.734$; p = 0.392
Shoulders (n = 65)	35 (43.2)	30 (44.8)	$\chi^2(1) = 0.037$; p = 0.848
Elbows (n = 16)	9 (11.1)	7 (10.4)	$\chi^2(1) = 0.017$; p = 0.897
Wrists/Hands (n = 48)	29 (35.8)	19 (28.4)	$\chi^2(1) = 0.927$; p = 0.336
Thighs/Hips (n = 33)	21 (25.9)	12 (17.9)	$\chi^2(1) = 1.360$; p = 0.244
Knees (n = 41)	23 (28.4)	18 (26.9)	$\chi^2(1) = 0.043$; p = 0.836
Ankles/Feet (n = 29)	15 (18.5)	14 (20.9)	$\chi^2(1) = 0.132$; p = 0.717
Dorsal Region (n = 21)	10 (12.3)	11 (16.4)	$\chi^2(1) = 0.499$; p = 0.480
Low Back (n = 81)	46 (56.8)	35 (52.2)	$\chi^2(1) = 0.307$; p = 0.580

proportion of participants reporting pain in each body region and the corresponding percentage between parenthesis, divided by category (columns).

3 Results

The sample presented a mean ± standard deviation of 34.3 ± 8.6 years and a BMI of 24.9 ± 4.9 kg/m^2.

Regarding the 12-month prevalence of musculoskeletal symptoms by body region, the most affected one was the neck (56.1%), followed by the low back (54.7%), the shoulders (43.9%), the wrist/hands (32.4%), the knees (27.7%), the thighs/hip (22.7%), the ankles/feet (19.6%), the dorsal region (14.2%) and finally, the elbows (10.8%).

The association analysis between the presence of musculoskeletal symptoms and gender, BMI and work hours is presented in Tables 1, 2 and 3, respectively.

Regarding gender, although in all body regions the number of women reporting pain is higher than men, only for the regions of the wrists/hands (p = 0.033) and knees (p = 0.031) there is a significant association.

Regarding BMI, only the thighs/hips region revealed a significant association (p = 0.010), with overweight participants reporting significantly more musculoskeletal symptoms in this body region than those with normal BMI.

Regarding the hours of work, no significant associations were found between the prevalence of musculoskeletal symptoms and working full-time or part-time, even though in general, the number of call center operators working full-time and that report symptoms is higher than those who work in part-time.

4 Discussion

This study aimed to investigate the 12-month prevalence of musculoskeletal symptoms among call center operators and their associations with gender, BMI and the hours of work. The nature of a call center worker has been shown to increase repetitive strain, thus predisposing them to a higher risk of musculoskeletal disorders (Toomingas et al. 2003). Nonetheless, the simultaneous use of a computer and telephone, while under pressure to have an effective communication with their clients, may also contribute to the higher recurrence of these disorders in this group (Subbarayalu 2013).

Results of the present study revealed that the three most affected body regions were the neck (56.1%), followed by the low back (54.7%) and the shoulders (43.9%). These findings are in line with previous investigations, where it seems to have a consensus regarding at least the 2 most affected body regions (d'Errico et al. 2010; Odebiyi et al. 2016). In the study of Odebiyi et al. (2016) conducted in call center workers in Nigeria, it was also reported that the most affected body regions in the previous year were the neck, shoulders, upper back and lower back (Odebiyi et al., 2016). Also, in the study of d'Errico et al. (2010) in Italy, it was demonstrated that the higher complaints came from the neck (39%), shoulders (22%) and wrist/hands (10%). However, it should be noted that in the present investigation, the percentages of reported complaints are in general higher than those reported by the two previous authors.

Regarding the association between musculoskeletal symptoms and gender, our findings revealed that in general, women complained more than men, however, significant associations were only denoted in the wrists/hands and knees. These results are also in accordance with previous investigations who also conclude that a higher prevalence of musculoskeletal disorders is reported by women (d'Errico et al. 2010; Odebiyi et al. 2016; Rocha et al. 2005).

The association between musculoskeletal symptoms and BMI revealed that overweight participants reported significantly more musculoskeletal symptoms than those with normal BMI only in the thighs/hips region. To our knowledge, there are no previous investigations studying the influence of BMI in the musculoskeletal symptoms of these particular workers. However, in a study conducted on a large working population sample, it was demonstrated that having a higher BMI (overweight or obese) was associated with an increased prevalence of musculo-skeletal symptoms (Viester et al. 2013). The results of this investigation also found no significant associations between musculoskeletal symptoms and working full-time or part-time, even though in general the number of call center operators working full-time reported higher prevalences than those who worked in part-time, which can be explained by the fact that full-time workers (8 h daily) are exposed more hours to the repetitive nature of tasks, prolonged static postures and also to more hours of stress and anxiety levels naturally involved in the call center occupation (Bhuyar et al. 2008; d'Errico et al. 2010; Lacaze et al. 2010; Rocha et al. 2005). Likewise, a previous investigation in computer-using office workers reported that musculoskeletal disorders increase with daily working hours (Ardahan and Simsek 2016).

Some limitations should be recognized. First, the sample size could be more representative. Second, it was not collected data related to the assessment of occupational injury risk, so it is not possible to be sure that the reported symptoms were work-related, or if there were some other underlying health conditions outside of the workplace.

5 Conclusions

The prevalence of musculoskeletal symptoms among call center workers is high, with the 3 most affected body regions being the neck, the low back and the shoulders. Significant associations were found between gender and reporting symptoms in the wrist/hands and the knees, with females reporting significantly more symptoms than males; and between BMI and reporting symptoms in the thighs/hips, with overweight operators reporting more symptoms. No significant associations were found regarding the hours of work. Workplace interventions are therefore needed, such as improving workers' daily physical activity through physical activity programs at the workplace and weight loss programs in the sense of decreasing the prevalence of musculoskeletal complaints among call center workers.

References

Ardahan, M., Simsek, H.: Analyzing musculoskeletal system discomforts and risk factors in computer-using office workers. Pak. J. Med. Sci. **32**(6), 1425–1429 (2016). https://doi.org/10.12669/pjms.326.11436

Bagnara, S., Marti, P.: Human work in call centres: a challenge for cognitive ergonomics. Theor. Issues Ergon. Sci. **2**(3), 223–237 (2001)

Bhuyar, P., Banerjee, A., Pandve, H., Padmnabhan, P., Patil, A., Duggirala, S., Rajan, S., Chaudhury, S.: Mental, physical and social health problems of call centre workers. Ind. Psychiatry J. **17**(1), 21–25 (2008)

d'Errico, A., Caputo, P., Falcone, U., Fubini, L., Gilardi, L., Mamo, C., Migliardi, A., Quarta, D., Coffano, E.: Risk factors for upper extremity musculoskeletal symptoms among call center employees. J. Occup. Health **52**(2), 115–124 (2010). https://doi.org/10.1539/joh.L9117

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K.: Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl. Ergon. **18**(3), 233–237 (1987)

Lacaze, D.H.D.C., Sacco, I.D.C., Rocha, L.E., Pereira, C A.D.B., Casarotto, R.A.: Stretching and joint mobilization exercises reduce call-center operators' musculoskeletal discomfort and fatigue. Clinics **65**(7), 657–662 (2010)

Mesquita, C.C., Ribeiro, J.C., Moreira, P.: Portuguese version of the standardized Nordic musculoskeletal questionnaire: cross cultural and reliability. J. Public Health **18**(5), 461–466 (2010)

Norman, K., Nilsson, T., Hagberg, M., Tornqvist, E.W., Toomingas, A.: Working conditions and health among female and male employees at a call center in Sweden. Am. J. Ind. Med. **46**(1), 55–62 (2004)

Odebiyi, D., Akanle, O., Akinbo, S., Balogun, S.: Prevalence and impact of work-related musculoskeletal disorders on job performance of call center operators in Nigeria. Int. J. Occup. Environ. Med. **7**(2), 98–106 (2016)

Rocha, L.E., Glina, D.M.R., de Fatimá Marinho, M., Nakasato, D.: Risk factors for musculoskeletal symptoms among call center operators of a bank in Sao Paulo. Brazil. Ind. Health **43**(4), 637–646 (2005)

Subbarayalu, A.V.: Occupational health problems of call center workers in India: a cross sectional study focusing on gender differences. J. Manag. Sci. Pract. **1**(2), 63–70 (2013)

Toomingas, A., Nilsson, T., Hagberg, M., Hagman, M., Wigaeus Tornqvist, E.: Symptoms and clinical findings from the musculoskeletal system among operators at a call centre in Sweden–a 10-month follow-up study. Int. J. Occup. Saf. Ergon. **9**(4), 405–418 (2003)

Viester, L., Verhagen, E.A., Hengel, K.M.O., Koppes, L.L., van der Beek, A.J., Bongers, P.M.: The relation between body mass index and musculoskeletal symptoms in the working population. BMC Musculoskelet. Disord. **14**(1), 1–9 (2013)

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Musculoskeletal Injuries and Associated Pain in Portuguese Ju Jitsu Athletes: Prevalence and Associated Factors

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Abstract Objective: To study the prevalence of injuries in Ju Jitsu and its association with athletes' experience and state of progression in the modality. Background: Data specifically on the prevalence of injuries in Ju Jitsu is scarce, and absent at national level. Methods: Seventy athletes with more than 6 months of practice and competitive experience answered a sociodemographic and injury characterization questionnaire and the Nordic Musculoskeletal Questionnaire. Results: The total prevalence of injuries in the previous year was 44.3%. It was higher in men, representing 83.9% of the injured subjects. The results suggest a higher prevalence in more experienced athletes. Sprains were the most frequent injuries (29%), followed by tendinopathy (22.6%) and lower back/neck pain (16.1%). The most affected regions were the knee and lumbar spine, both with 19.35%, followed by the ankle/foot (16.13%) and the

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shoulder (12.9%). The injuries occurred mainly during training (87.1%) due to blows delivered by the opponents (80.6%). Conclusion: The study suggests a high prevalence of injuries caused, mostly, by contact and training, higher in more experienced athletes. Application: There is a clear demand for adequate prevention, treatment, and recovery programs in Ju Jitsu athletes.

Keywords Musculoskeletal injuries · Musculoskeletal pain · Ju Jitsu · Injury prevalence

1 Introduction

Ju Jitsu (Ju Jutsu or Jiu Jitsu) is a Japanese martial art, currently practiced worldwide, particularly in Brazil (Guimarães 2005). It's a combat sport, whose objective is to dominate the opponent allowing contacts between athletes that include six main techniques: projections, keys, twists, clamps, strangulations and immobilizations, (Borges 2011; Padilha and Ide 2005). With the exception of immobilizations, which aim to hold/submit the opponent by preventing him in his offensive actions, the other techniques can cause severe trauma when applied with high levels of intensity (Padilha and Ide 2005). This results in high impact forces, which are responsible for the injuries in practitioners of Ju Jitsu.

In modalities such as Ju Jitsu, although injuries are frequent, the literature body on the prevalence of injuries in Ju Jitsu is scarce (Kreiswirth et al. 2014; Reis et al. 2015; Souza et al. 2011). The prevention of these injuries by implementing specific programs for the most affected anatomical structures is vital. To implement an adequate musculoskeletal injury prevention program, it is required to identify the injury epidemiology of the sport. Though, we have failed to identify national data on the prevalence of musculoskeletal injuries in athletes of this modality.

Consequently, the present study aimed to analyse the prevalence of injuries in Ju Jitsu athletes and to verify its association with the practice and progression in this sport.

2 Materials and Methods

2.1 Study Design and Sample

A cross-sectional and descriptive study was carried out on athletes from two Ju Jitsu schools in the northern region of Portugal. The choice of schools was made from convenience, considering the proximity to the author's residence.

The sample consisted of 70 Ju Jitsu competition athletes aged between 18 and 55 years. Inclusion criteria were defined as being Ju Jitsu practitioners for more than 6 months and having participated in certified competitions.

2.2 *Instruments and Procedures*

A sociodemographic and musculoskeletal injuries characterization questionnaire and the Portuguese version of the Nordic Musculoskeletal Questionnaire (NMQ) were used. The sociodemographic and injury characterization questionnaire included quick-response questions, such as age, gender, workplace, implications of pain at work, nature, cause, and sport specific activities that trigger the injury. The NMQ, originally by Kuorinka et al. (1987) was adapted for the Portuguese language by Mesquita et al. (2010). The NMQ assesses the presence of pain in the last 12 months in 9 anatomical areas and, if so, whether it occurred in the last 7 days. It also assesses whether in the previous year the respondent has been prevented from carrying out his activity. All anatomical areas are associated with a pain intensity scale, which must be filled in if the pain was present in the last 7 days. The data collection was preceded by an informal contact with the person in charge of the Ju Jitsu schools, intending to make the study known and to obtain consent for its implementation. After approval, the athletes were given the two questionnaires described above. Their delivery was preceded by informed consent using the model provided by the Ethical Committee of the local University.

2.3 *Data Analysis*

The software Statistical Package for the Social Sciences (SPSS version 25) was used to analyse the data. Descriptive and inferential statistics were used to analyse the responses to the questionnaires. Additionally, we used the Kolmogorov-Smirnov test to assess the distribution of variables and, considering its result, a non-parametric approach was used. The Mann-Whitney test was used to compare the variables, age, weight, height, years of practice, days of training per week and hours of training per day between groups of more experienced and less experienced athletes. The chi-square test was used to test the association between the occurrence of injuries and the athletes' experience. When the expected frequencies were below 5, Fisher's exact test was used to test this association. A significance level of 0.05 was adopted.

3 Results

3.1 Sociodemographic and Injury Characterization Questionnaire

The sample consisted of 70 Portuguese Ju Jitsu athletes, of whom, 90% (n = 63) were male and 10% (n = 7) were female.

In Ju Jitsu, as in many other martial arts, the progression in the sport, merit and experience of the athletes is defined by the colour of their belt.

Based on the colour progression of the belt in Ju Jitsu and to express the sport expertise, the athletes were divided into two independent groups. The athletes with orange, green and blue belts constituted the group classified as “less experienced” (70%). The rest (30%), with colour belts corresponding to the most advanced level, formed the “most experienced” group.

Table 1 shows the results of the sociodemographic questionnaire and the characterization of injuries according to the groups previously formed.

It should also be noted that the age of the youngest and oldest athlete was 18 and 55 years old, respectively. As for the years of practice, the minimum value registered was 1 year, occurring in 10% of the sample and the maximum was 26 years, registered for one athlete.

The results of the inferential analysis suggest the existence of statistically significant differences between the two groups in age ($p < 0.001$) and years of practice ($p < 0.001$), with more experienced athletes being older and with more years of practice.

Table 1 Results of the sociodemographic questionnaire

		Less experience (n = 49)	More experience (n = 21)	Total n = 70
Age (years)	Median	25.0	29.0*	25
	IQR	2,0	7.0	3
Weight (kg)	Median	70.0	71.0	70.0
	IQR	7.5	10.0	8.0
Stature (cm)	Median	177.0	179.0	177.5
	IQR	7.0	7.0	6
Years of practice	Median	2.0	10.0*	3.0
	IQR	2.0	7.0	6.0
Weekly training days	Median	2.0	2.0	2.0
	IQR	0	0	0
Daily training hours	Median	2.0	2.0	2.0
	IQR	0	0	0

Legend: *$p<0.05$; IQR: Interquartile Range

Table 2 Absolute and relative frequency (%) for the part of the body affected by the injury

	Frequency	Relative frequency for the total sample (n = 70)	Relative frequency for the total injured (n = 31)
Head	2	2.9	6.45
Neck	2	2.9	6.45
Shoulder	4	5.7	12.90
Elbow	2	2.9	6.45
Wrist/Hand	2	2.9	6.45
Lower back	6	8.6	19.35
Hip/Thigh	2	2.9	6.45
Knee	6	8.6	19.35
Ankle/Foot	5	7.1	16.13
Total	31	≅ 44.3	≅ 100

Asked about the occurrence of injuries related to the practice of Ju Jitsu, 44.3% of the athletes (n = 31) stated that they had suffered injuries in the last year. Of these, 83.9% (n = 26; 41.3% of total number of male participants) are male and 16.1% were female (n = 5; 71.4% of total number of female participants).

The chi-square test allowed to confirm an association (p = 0.019) between the occurrence of injuries and the athletes' experience. The results suggest, in relative terms, that experienced athletes have more injuries (66.7% = 14/21 * 100) than less experienced athletes (34.7% = 17/49 * 100). However, considering only the total number of injured, the percentage of injuries is higher in the group of athletes with less experience (54.8% = 17/31 * 100). Sprains were the most prevalent injury type (12.9% total sample [n = 70]; 29% of total injured [n = 31]), followed by tendinopathies (10% total sample; 22.6% of total injured), neck/low back pain (7.1% total sample; 16.1% of total injured), dislocations and contractures/distensions (5.7% total sample; 12.9% of total injured for each type) and tears (2.9% total sample; 6.5% of total injured).

Table 2 shows results for the part of the body affected by the injury. The injuries occurred mostly in training (87.1%). In addition, 80.6% of these injuries occurred due to a blow delivered by the opponent.

Regarding the treatment adopted, 80.6% of the injured claim to have resorted to physiotherapy and/or medication treatment, while 19.4% have not resorted to any treatment. Nevertheless, the presence of pain in training and/or competition was confirmed by all injured athletes.

3.2 Results of the Nordic Musculoskeletal Questionnaire

Pain in the last 12 months was most prevalent in the lower back and knee (8.6%) and ankle/foot (7.1%), followed by the shoulder (5.7%), and the neck, elbow wrist/hand, hip/thigh (2.9%). The area where pain in the last 12 months was least prevalent was the thoracic spine, with no athletes reporting pain in this region. In the previous 7 days, only 1 athlete reported pain in the lower back.

Another aim of the present study was to assess whether there was an association between the occurrence of musculoskeletal injuries by region in the last 12 months and the athletes' sport expertise. The results suggest a significant association ($p = 0.026$) only between the occurrence of musculoskeletal injuries in the ankles/feet and the athletes' experience as only 1 athlete (2% of the group) in the less experience group had ankle injuries and 4 (19% of the group) in the more experience group reported ankle injuries.

4 Discussion

The analysed sample consisted of 70 Portuguese Ju Jitsu athletes. The number of athletes analysed in other studies ranged from 41 (Souza et al. 2011) to 951 (Kreiswirth et al. 2014).

Dividing the sample into two groups according to experience (belt colour) allowed us to confirm that, as expected, more experienced athletes are significantly older (+6 years) and have more years of practice (+9 years) than the less experienced. However, all participants reported to train 2 days a week and 2 h a day, explained by the fact that both schools have the same master coordinator and, consequently, similar training schedules and practices.

The prevalence of musculoskeletal injuries recorded in the previous year was 44.3% for this sample. The results obtained are inferior to those found in other studies, whose relative frequency varied between 52.0% in a group of athletes in which 54% had practiced the modality for less than a year (Júnior and Silva 2014), and 97.5% in a group of athletes with an average of 3.7 years of practice (Souza et al. 2011). The lower prevalence observed in the present study when compared to the study of Souza et al. (2011) may be associated with the established time limit, given that the questionnaire in the present study referred to the previous year of practice and in the study of Souza et a. (2011) the period of analysis is not reported and may possible have been the whole period of sports practice. Nonetheless, in an equal period of 12 months, Machado et al. (2012) reported an injury prevalence of 75.09%, although in athletes with more than twice the training per week.

To the best of our knowledge, none of the previously published studies compared the prevalence of injuries according to gender. In the present case, the prevalence of injuries was higher in females (71.4% of all female participants). Although 83.9% of the total injured participants—41.3% of the total number of male participants—were males the proportion of injured female participants was higher. However, given the small number of female participants, these findings must be considered with caution and future studies should analyse the effect of gender on the prevalence of injuries in Ju Jitsu. The higher prevalence in females may be explained by physical and biomechanical factors related to muscular and ligamentar characteristics. However, this association requires further study.

Regarding the type of injury, the results suggest that sprains were the most frequent injuries (29%), followed by tendinopathy (22.6%) and low back/neck pain (16.1%). In the study by Barreto (2017), sprains were also the most frequent, although with higher relative frequencies (61.5%) compared to the present study. In this study, the blue belt athletes had the highest prevalence of injuries (30.8%). The same trend was observed in the present study representing 35.5% of injured athletes. It should be noted, however, that black belt athletes and, consequently, those with more years of practice and higher category were the second group with the most injuries (16.1%). These results confirm, to a certain extent, the association found between the occurrence of injuries and the athletes' experience.

An injury reported as common in Ju Jitsu and other combat sports is ear trauma/hematoma (Roy and Smith 2010). It is estimated that it can affect about 40% of combat sports practitioners (Padilha & Ide 2005; Safran et al. 2002). This injury was not reported in the present study. Two athletes reported an injury in the head region, however both described as "dislocation" and not as ear trauma/hematoma.

Considering the other injured regions, this study reveals that the most affected were the knee and lower back, both with 19.35%, followed by the ankle/foot (16.13%) and shoulder (12.9%). The knee region was also the most affected in the studies by Júnior and Silva (2014) (24%), Souza et al. (2011) (16.3%) and Machado et al. (2012) (28.4%). The shoulder joint is also one of the most affected. In the study by Barreto (2017), the shoulder injury prevailed (21.7%) when comparing to the knee (20.5%). In the studies by Souza et al. (2011) and Machado et al. (2012) the prevalence of shoulder injuries was 14.4% and 15.6%, respectively.

In the present study, injuries occurred mostly in training (87.1%), a value higher than that observed by Barreto (2017) (67.40%). In addition, 80.6% of these injuries occurred due to a blow delivered by the opponent, a value lower than that reported by Machado et al. (2012) (42.8%).

The severity of the injury can be partially assessed by the treatment adopted. In the present study, 19.4% of the athletes did not resort to any type of treatment, suggesting that they were mild injuries, and 80.6% resorted to physiotherapy and/or medication. Contrary to previous data, the study by Machado et al. (2012) reveals that 72% of the injured people interrupted the practice of the sport. The authors add that in 34% of the cases the injury was severe, corresponding to a 2-to-4-week break from practice. In the study by Barreto (2017), an average of 21.32 ± 14.5 physiotherapy sessions were reported, although the study is unclear as to its temporal delimitation. The amount of time away from practice was not assessed in the present study.

With regard to the results of the NMQ, it is important to note that its application must be questioned in the context of combat sports, given that one of the most affected areas in these sports is the head (Roy and Smith 2010) and, as already mentioned, this anatomical region is not included in the NMQ. The NMQ also does not specifically refer to the problem of the injury, asking only about problems associated with pain, discomfort, or numbness. In fact, this questionnaire applies mainly to workers and in the context of the ergonomic assessment of a job. Furthermore, in this study, the results obtained in the NMQ confirmed the results already obtained in the injury characterization questionnaire, strengthening its findings. When comparing pain reported in the last 12 months and in the last 7 days, it is important to note that only 1.4% of the respondents reported pain in the last 7 days. The most likely reason for this occurrence is related to the moment when the questionnaire was applied, after a vacation period.

It is important to note that, as reported, research suggests a high prevalence of pain and injuries in combat sports, where contact between opponents is, generally, violent. Contact injuries are very difficult to avoid, when compared to other types of injuries, such as those caused by fatigue or overtraining. Therefore, the use of protective equipment in the most affected areas by the blows can be a strong contribution to reducing the prevalence of injuries and pain in combat sports.

4.1 Limitations

This study presents some limitations. The sample, although larger than in previous studies is not large enough to allow generalizations. Moreover, the fact that the sample was a convenience sample from schools with the same master coordinator, strengthen this limitation.

In the present study, athletes were asked to report the prevalence of injuries in the previous 12 months but the amount of time away from sports practice was not assessed, which limits the analysis of the injury severity. Another limitation is that injuries were reported by athletes, without confirmation from medical records, which demands caution when interpreting the present results.

5 Conclusions

The main objective of the present study was to study the prevalence of injuries and pain in Portuguese Ju Jitsu athletes and to verify whether an association between the experience/progression in sport and injury prevalence exists. The obtained results suggest a high prevalence, affecting 44% of study participants, although lower than the prevalence reported in previous studies. The most frequent injuries include sprains (29%), tendinopathy (23%) and low back / neck pain (16%) with higher prevalence in the knee and lumbar area (19%), ankle/foot (16%) and shoulder (13%). An association between the occurrence of injuries in general and the experience of athletes was confirmed.

The results of this study highlight the importance of adequate prevention, treatment, and recovery programs in these modalities, even in less severe injuries.

References

Barreto, A.P.: Perfil das lesões ortopédicas no brazilian jiu-jitsu. Mestrado, Universidade Federal de Sergipe (2017). https://ri.ufs.br/handle/riufs/8665. [Assessed in Jan 2021]

Borges, O.A.: Ju-jutsu, Ju-jitsu ou Jiu-jitsu: origens e evolução. EFDesportes **16**(156) (2011)

Guimarães, F.M.: Jiu-Jitsu Brasileiro. In: DaCosta, L. (ed.) Atlas do Esporte no Brasil, pp. 381–384. Shape (2005)

Júnior, N.S.R., Silva, N.C.R.: A ocorrência de lesões na prática de Jiu-Jitsu em academias de Floriano-PI. J. Health Sci. **16**(1), 25–28 (2014)

Kreiswirth, E.M., Myer, G.D., Rauh, M.J.: Incidence of injury among male Brazilian jiujitsu fighters at the World Jiu-Jitsu No-Gi Championship 2009. J. Athl. Train. **49**(1), 89–94 (2014)

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K.: Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl. Ergon. **18**(3), 233–237 (1987)

Machado, A.P., Machado, G.P., De Marchi, T.: A prevalência de lesões no Jiu-Jitsu de acordo com relatos dos atletas participantes dos campeonatos mundiais em 2006. ConScientiae Saúde **11**(1), 85–93 (2012)

Mesquita, C.C., Ribeiro, J.C., Moreira, P.: Portuguese version of the standardized Nordic musculoskeletal questionnaire: cross cultural and reliability. J. Public Health **18**(5), 461–466 (2010)

Padilha, D.A., Ide, B.N.: Possíveis lesões decorrentes da aplicação das técnicas do jiu-jitsu desportivo. Lecturas: Educación física y deportes **20**(83) (2005)

Reis, F.J., Dias, M.D., Newlands, F., Meziat-Filho, N., Macedo, A.R.: Chronic low back pain and disability in Brazilian Ju-Jitsu athletes. Phys. Ther. Sport. **16**(4), 340–343 (2015)

Roy, S., Smith, L.P.: A novel technique for treating auricular hematomas in mixed martial artists (ultimate fighters). Am. J. Otolaryngol. **31**(1), 21–24 (2010)

Safran, M.R., McKeag, D.B., Van Camp, S.P., do Nascimento, F.G., de Paula Gonçalves, J.: Manual de medicina esportiva. Manole, São Paulo (2002)

Souza, J.M.C.D., Faim, F.T., Nakashima, I.Y., Altruda, C.R., Medeiros, W.M., Silva, L.R.D.: Lesions in Shotokan Karate and Jiu-Jitsu: direct trauma versus indirect. Revista Brasileira de Medicina do Esporte **17**(2), 107–110 (2011)

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An Overview of the Development and Implementation of the Radon Action Plans in European Countries

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Abstract The European Directive 2013/59/Euratom sets the basic safety standards for protection against hazards resulting from exposure to ionising radiation. The document intends to provide recommendations and tools for better protection of people in workplaces and dwellings. Exposure to radon gas is introduced for the first time into the radiological protection system. It establishes not only references levels but also the need to develop and implement national radon plans. Radon is the largest natural source of exposure to ionising radiation by the population in general and the second leading cause of lung cancer in smokers. Radon policies have been very heterogeneous throughout Europe: while some countries have already a national radon action plan implemented, other countries are just starting the process or it is currently ongoing. With the transposition of the Euratom directive into national law, in December 2018, Portugal initiated the process to implement the radon action plan, which is currently under development. This work intends to give an overview of the development and implementation of the radon action plans in EU countries and verify compliance with the European Directive 2013/59/Euratom. A survey was undertaken for selected key basic safety standards requirements from the Directive, emphasising the radon action plan. The survey findings indicate that approximately 65% of the Member States have already implemented the national radon plan, and 89% has produced a radon map, which is one of the requirements of the national radon action plans. In Portugal, it is expected to have the process concluded and implemented by 2022.

Keywords Radon Plan · Occupational exposure · Indoor radon · Lung cancer · Risk

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1 Introduction

Exposure to indoor radon represents an important part of the overall exposure to ionising radiation by members of the public and workers, in particular, in specific geographical areas and workplaces (Silva et al. 2016; IAEA 2015; USEPA 2005, 2007, 2021; WHO 1993). Several scientific studies have demonstrated that there is a statistically significant increase in the risk of lung cancer associated with radon activity concentrations above 100 Bq/m3 (ICRP 2010; WHO 2007, 2008, 2009; UNSCEAR 2008; Darby et al. 2005; USEPA 2003; Faísca et al. 1992; IARC 1988). The relative risk of lung cancer increases by approximately 16% per 100 Bq/m^3 (Ferlay et al. 2007; WHO 2006). Radon is the second leading cause of lung cancer in smokers and the leading cause of lung cancer in non-smokers (WHO 2006).

The European Directive 2013/59/Euratom—the Basic Safety Standards Directive (BSSD)—has introduced binding legal requirements to ensure appropriate protection of individuals from the dangers arising from exposure to radon across the European Union (Silva et al. 2020). The importance of occupational radiation protection, and the protection of the health of workers against dangers arising from ionising radiation, is explicitly recognised in Articles 2 and 30 of the Euratom Treaty.

Previous Euratom directives already provided a very high level of occupational radiation protection, mainly focussing on workers involved in planned exposure situations (previously called practices—e.g., nuclear, medical or industrial sector, as well as in research and education), and included general requirements on the identification of work activities where workers could be exposed to thoron or radon, explicitly mentioning spas, caves, mines, underground workplaces and aboveground workplaces in identified areas. The European Directive 2013/59/Euratom extends the scope to cover the protection of workers in workplaces with enhanced natural radiation, e.g., workers exposed to radon in workplaces, workers in industries processing naturally-occurring radioactive materials (NORM), as well as aircrew and space crew. In what concerns in particular the radon exposure, Member States are required to develop and implement national radon action plans addressing long-term risks from radon exposure in dwellings, buildings with public access and workplaces from any source of indoor radon. The national plan should be revised periodically. In addition, Member States are required to establish national reference levels for indoor radon concentration, which should not exceed 300 Bq/m^3. The European Directive 2013/59/Euratom was transposed into national law (Portuguese) by the publication of the Decree-Law N. º 108/2018.

The national radon action plan should present the general, and specific objectives outlined in the Euratom Directive, including scientific knowledge about radon and its health effects and address long-term goals (reducing the risk of lung cancer attributable to exposure to radon).

For the preparation of the national radon action plan, several aspects must be delineated in detail:

(i) a basic strategy to protect the public and workers from radon exposure, including measures to be implemented, details of the planned implementation schedule and actors involved;

(ii) methods for communicating basic information on radon to the public;

(iii) approach for identifying areas for which there is an increased probability that the reference level may be exceeded;

(iv) analysis and assessment of the effectiveness of measures after implementation.

The implementation of the radon action plan represents a challenge at several levels, starting with collecting data or harmonising data from the different existent studies or measurement equipment; the application of a radiation protection system, in case indoor radon concentrations remain above the reference level, the application of remedial actions, or the financial implications of these issues are some of the pertinent concerns.

This work intends to give an overview of the development and implementation of the radon action plans in EU countries and verify compliance with the European Directive 2013/59/Euratom.

2 Materials and Methods

A survey was undertaken through the World Health Organization (WHO) and the Portuguese Environment Agency (APA) databases and published documents, covering selected key aspects of radiation protection as defined within the BSSD: (i) national radon map, (ii) national radon action plan; (iii) reference level for dwellings; (iv) reference level for buildings with high public occupancy; (v) reference level for workplaces; (vi) existence of national radon risk communication strategy; (vii) inclusion of radon measurements in property transactions; (viii) cancer control strategy; (ix) lung cancer reporting/screening strategy; (x) tobacco control strategy; (xi) indoor air quality strategy, and (xii) energy conservation strategy.

A systematic review was also carried out in several databases with the Metalib tool. The search was done using a combination of a pair of keywords: “radon plan” and “occupational exposure” refined with “risk” or “lung cancer” in the search field in question, between 2016 and 2021. The research was carried out in official documents from International organizations (WHO, APA, IARC, IAEA, EPA, USEPA) scientific articles and book chapters, in Portuguese and English, related to European Union countries.

Eight articles were selected for review in the following databases: Science Direct (3), Scopus (2) and Web of Science (3) and fifteen consulted: APA (1); EPA (1), IAEA (1), IARC (1), USEPA (4) and WHO (7).

3 Results

3.1 National Radon Action Plan in the European Union Countries

The national radon action plan has been implemented by 65% (17/26) of the EU countries (Table 1, Fig. 1 1). Nevertheless, although there is no national radon plan in several European countries, most of them (89%) produced a radon map.

The selected key aspects of radiation protection, as defined within the BSSD, are summarized in Table 2.

In what concerns the reference value for the concentration of radon in buildings and dwellings, the value varies between 100 Bq/m^3 and 300 Bq/m^3 among the differ-

Table 1 Radon action plan (WHO 2021)

Country	National radon map	National radon action plan	National radon action plan (years covered)
Austria (AT)	Yes	No	Not applicable
Belgium (BE)	Yes	Yes	2019–2020
Bulgaria (BG)	No	Yes	2018–2022
Cyprus (CY)	Yes	Yes	2019–2025
Czech Republic (CZ)	Yes	Yes	2019–2025
Denmark (DK)	Yes	Yes	2016–2019
Estonia (EE)	Yes	Yes	2018–2027
Finland (FI)	Yes	Yes	2020–2025
France (FR)	Yes	Yes	2016–2019
Germany (DE)	Yes	Yes	2019–2028
Greece (EL)	Yes	No	Not applicable
Hungary (HU)	Yes	Yes	2018–2023
Ireland (IE)	Yes	Yes	2019–2024
Italy (IT)	Yes	Yes	2002–2020
Latvia (LV)	Yes	No	Not applicable
Lithuania (LT)	Yes	Yes	2017–2023
Luxembourg (LU)	Yes	Yes	2017–2020
Malta (MT)	Yes	No	Not applicable
Netherlands (NL)	Yes	No	Not applied
Poland (PL)	Yes	No	Not applicable
Portugal (PT)	Yes	No	Not applicable
Slovenia (SI)	Yes	Yes	2018–2022
Spain (ES)	Yes	Yes	2019
Sweden (SE)	Yes	Yes	2018–2022

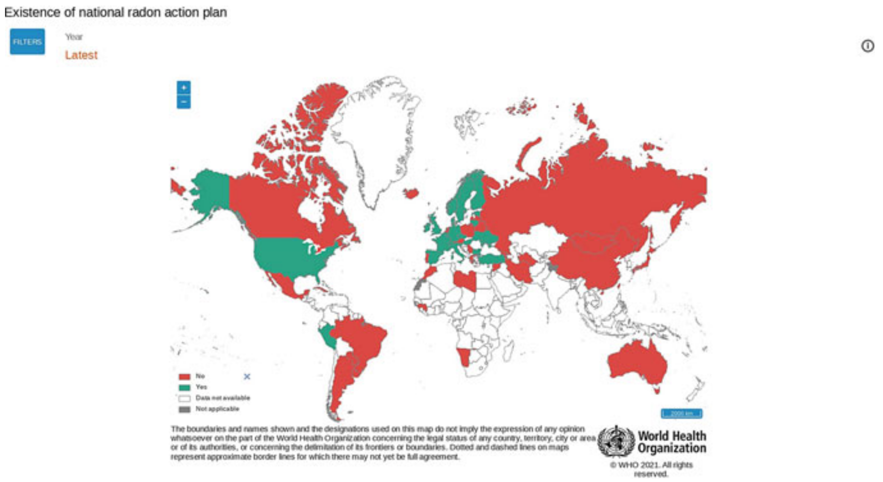

Fig. 1 Existence of National Radon Action Plan (WHO 2021)

ent Member States. In terms of occupational exposure, all Member States decided to set the reference level at 300 Bq/m^3, with the exception of Denmark, which fixed this value in 100 Bq/m^3.

Regarding the risk communication strategy, only 46% (11/24) of the Member States have a defined strategy, and 38% (9/24) have a lung cancer control strategy (WHO 2007, 2008). The implementation of a lung cancer control strategy is not a single and easy task, rather it implies multiphased research. The identification of lung cancer risks and causes and the reduction of the exposure, are the first two phases of the strategy. In what concerns the reduction of exposure, well-tested, durable and cost-efficient methods exist for preventing radon entering in new buildings and reducing radon levels in existing dwellings.

According to the BSSD, each country must have a national risk communication strategy, including clear and attainable objectives, communicating the risk assessment, risk perception, and risk management developed for each target audience (WHO 2021). The elaboration of a radon risk communication program should be a cooperative effort involving both technical specialists (e.g., radiation scientists, epidemiologists) and specialists in the field of communication (e.g., social scientists, psychologists, journalists) (WHO 2002) since the risk to an individual requires a description of the probability, or probability of damage, and the severity of the damage.

Table 2 Key aspects for radiation protection concerning radon exposure (WHO 2021)

Country	Inclusion of radon in different national strategies									
	1	2	3	4	5	6	7	8	9	10
AT	300	300	300	Yes	No	No	No	No	Yes	No
BE	300	300	300	Yes	No	Yes	No	No	Yes	No
BG	300	300	300	Yes	No	No	No	No	No	No
CY	300	300	300	No	No	Yes	Yes	No	No	No
CZ	300	300	300	–	No	No	No	No	No	No
DK	100	100	100	Yes	No	Yes	No	No	No	Yes
EE	300	300	300	Yes	No	No	No	No	No	No
FI	300	300	300	No	No	No	No	No	No	No
FR	300	300	300	Yes	No	Yes	Yes	No	Yes	No
DE	300	No	300	No	No	No	No	No	Yes	No
EL	300	300	300	Yes	No	No	No	No	No	No
HU	300	300	300	No	No	No	No	No	No	No
IE	200	No	300	Yes	No	Yes	No	No	No	No
IT	200	300	300	No	No	Yes	No	No	Yes	No
LV	200	No	400	No	No	No	No	No	No	No
LT	300	300	300	Yes	No	No	No	No	No	No
LU	300	300	300	Yes	No	No	No	No	Yes	No
MT	300	No	300	No	No	Yes	No	No	No	No
NL	100	100	100	No	No	No	No	No	No	No
PL	300	300	300	No	No	Yes	No	No	No	No
PT	300	300	300	No	No	No	No	No	No	No
SI	300	300	300	No	No	No	No	No	Yes	No
ES	300	300	300	Yes	No	Yes	Yes	Yes	Yes	No
SE	200	No	200	No	No	No	No	No	No	No

(1) Reference level for dwellings (Bq/m^3). (2) Reference level for buildings with high public occupancy (Bq/m^3). (3) Reference level for workplaces (Bq/m^3). (4) Existence of national radon risk communication strategy. (5) Inclusion of radon measurements in property transactions. (6) Cancer control strategy. (7) Lung cancer reporting/screening strategy. (8) Tobacco control strategy. (9) Indoor air quality strategy. (10) Energy conservation strategy

3.2 National Radon Action Plan in Portugal

The Portuguese Environment Agency (APA) is the competent authority for the regulation of radiological protection, with the responsibility of: (i) exercising, independently, the regulatory functions provided in European rules; (ii) ensuring that there is a high level of radiation protection and nuclear safety; and, (iii) granting registration and licensing of practices (APA 2021). Therefore, the APA is the competent authority responsible for developing and implementing the national radon action plan.

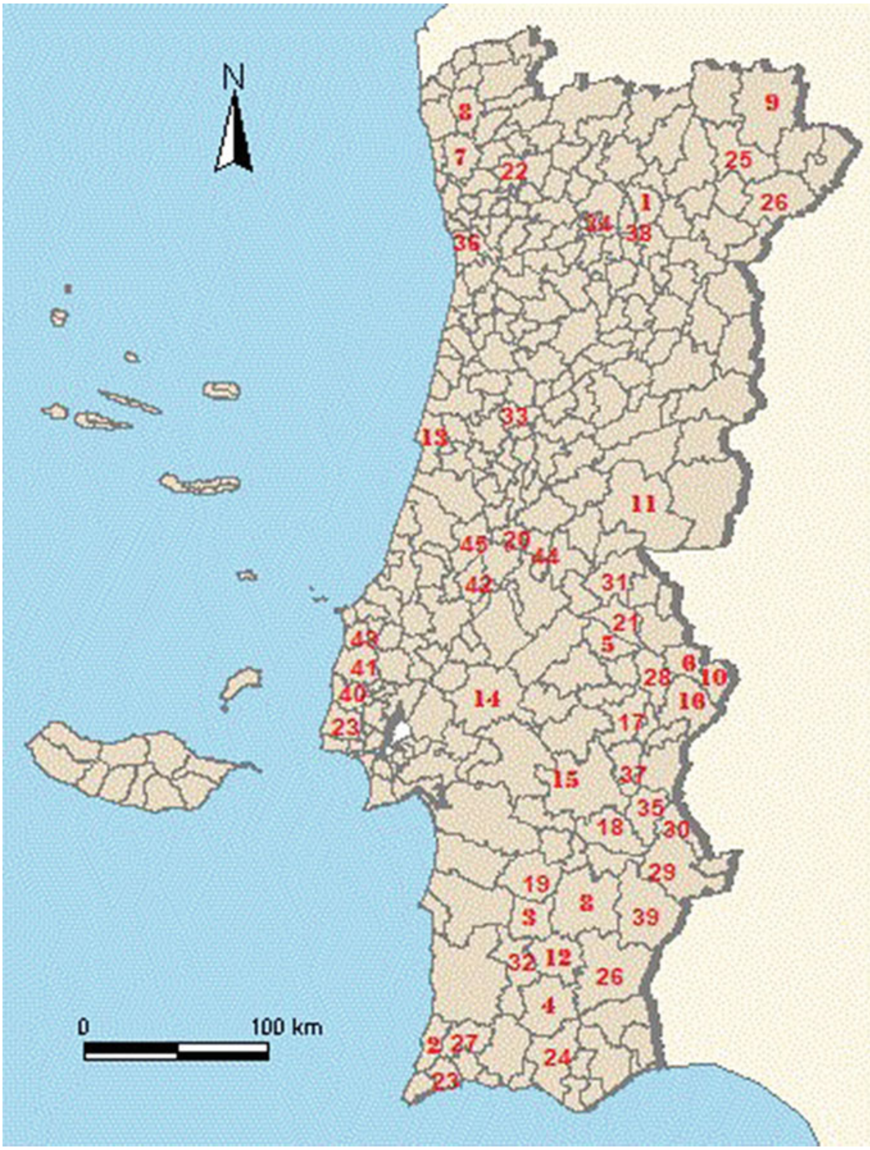

Fig. 2 Municipalities selected for indoor radon survey. (1) Alijó, (2) Aljezur, (3) Aljustrel, (4) Almodovar, (5) Alter do Chão, (6) Arronches, (7) Barcelos, (8) Beja, (9) Braga, (10) Bragança, (11) Campo Maior, (12) Castelo Branco, (13) Castro Verde, (14) Coimbra, (15) Coruche, (16) Cuba, (17) Elvas, (18) Estremoz, (19) Évora, (20) Ferreira do Alentejo, (21) Ferreira do Zêzerre, (22) Fronteira, (23) Guimarães, (22) Lagos, (23) Lisboa, (24) Loulé, (25) Macedo de Cavaleiros, (26) Mértola, (27) Mogadouro, (28) Monchique, (29) Monforte, (30) Moura, (31) Mourão, (32) Nisa, (33) Ourique, (34) Penacova, (35) Peso da Régua, (36) Portalegre, (37) Porto, (38) Reguengos de Monsaraz, (39) Sabrosa, (40) Serpa, (41) Sertã, (42) Sintra, (43) Terras Vedras, (41) Torres Vedras, (42) Viana do Alentejo, (43) Vila Nova de Ourém

The General Inspection of Agriculture, Sea, Environment and Spatial Planning (IGAMAOT) becomes the authority that inspects the compliance with this legal regime of radiological protection, with the competence of (i) inspecting the practices covered by the D.L. Nº 118/2018; (ii) institute and instruct the administrative offence processes; (iii) apply infractions in case of non-compliance; (iv) verify that corrective actions are taken.

The APA is currently developing an indoor radon survey focussing on dwellings from 47 municipalities (Fig. 2). The goals of this survey are primarily to provide inputs to the national radon action plan, allowing to (i) prepare an indoor radon exposure risk map and, therefore, to determine the geographical distribution of indoor radon levels and identify radon priority areas; (ii) to assess the effective dose, and (iv) to determine national average concentration.

The selection of the locations to be sampled was made based on zones with geological formations without or with poor characterization regarding data on radon concentration. The ultimate goal was to identify potential dwellings with radon concentrations exceeding the reference level. Measurement procedures, such as detector deployment and retrieval, were undertaken on a volunteer basis in dwellings from the selected municipalities. Passive detectors CR-39 were used for an average exposure period of three months.

Quality standards for radon detectors and analytical procedures are being followed according to previous protocols developed under the collaboration between the APA and Coimbra University through the Natural Radioactivity Laboratory, an accredited laboratory for radon measurements in the indoor air (ISO 11665-4:2012). The elaboration of the national radon action plan should be concluded by 2022.

4 Discussion

The implementation of the European Directive 2013/59/Euratom is expected to have a relevant and positive impact on European radiological protection. Each European Member States needs to accomplish the Directive requirements through their national legislation. The process should give recommendations and tools for a harmonised implementation and performance of national radon action plans of EU Member States according to the EU-BSS requirements.

As previously mentioned, developing and implementing a national radon action plan is mandated within the BSSD as a long-term strategy to reduce lung cancer risk associated with radon exposure. The national radon action plan addresses the long-term risks of exposure to radon in homes, buildings with public access and workplaces for any source of radon penetration.

This survey throughout the European countries, in what concerns the development and implementation of the radon action plan, has revealed a lack of compliance with some of the BSSD radiation protection requirements. Only 65% of the covered countries have effectively prepared and implemented the national radon action plan. These will now undergo through a review and evaluation focusing on the compliance of the practical implementation of radon action plans with the requirements of the BSSD. For those countries without a national radon action plan, this task should be accomplished within the three years after the transposition of the BSSD. Portugal should complete the national radon action plan by the end of 2022. The results also show that 89% of the EU countries have already prepared the radon map, including Portugal, which means that at least 24% of these countries produced a map out of the scope of the national action plan. As a consequence, a large diversity within sampling strategies may be subjacent in the existing radon surveys.

Regarding the reference levels for the concentration of radon in buildings, public buildings and workplaces, the values are different depending on the country: 100 Bq/m^3 in Denmark and Netherlands; 200 Bq/m^3 in Sweden; between 200 and 300 Bq/m^3 in Italy; between 200 and 400 Bq/m^3 in Latvia, and 300 Bq/m^3 in the remaining countries. There are specific guidelines for each country since the type of soil varies both per country and within each region. Other particular reasons, such as blue concrete used as construction material in Sweden (material containing various levels of uranium-rich alum shale), may have influenced the set value according to the assessed health risk.

Regarding the cancer control strategy, only nine countries (BE, CY, DK, FR, EL, IE, LT, LU and ES) have a defined plan, and only three (CY, FR and ES) are linked to lung cancer strategy. Only Spain has a strategic plan linked to tobacco control. Based on solid evidence, indoor exposure to radon increases lung cancer incidence and mortality, particularly among smokers (Darby 2005; Al Zoughool et al. 2009; EPA 2013; Erdogan et al. 2013; Silva and Dinis 2016; Silva et al. 2016). In homes with high radon concentrations, taking steps to prevent radon from entering homes by the available means would be expected to result in a corresponding decrease in the risk of lung cancer.

As for the indoor air quality strategy, only nine countries have this strategy (AT, BE, FR, DE, IT, LU, SI, ES). In this case, radon is the main cause of indoor air quality problems in homes, and inadequate ventilation can increase levels of radon concentration in indoor air.

As far as the energy conservation strategy is concerned, only Denmark defined a strategy for energy renovation within buildings in May 2014, including an initiative to strengthen energy renovation and energy efficiency in the construction sector. The initiative draws attention to the connection between energy renovation and solutions to improve indoor climate and health, including the radon risk factor.

After three years of the deadline for the transposition of Directive 2013/59/Euratom, it appears that the safety rules regarding the protection of the dangers resulting from exposure to ionising radiation are still not being met by all Member States. The BSSD places a responsibility on the governments to: "provide information on levels of radon indoors and the associated health risks and, if appropriate, establish and implement an action plan for controlling public exposure due to radon indoors". International organizations such as the International Atomic Energy Agency (IAEA) have been providing support to its Member States in implementing all aspects of the Safety Standards through the organization of national and regional workshops and other training events under the technical cooperation program.

5 Conclusions

Radon is a public health issue and therefore it is upmost importance to protect people in workplaces and dwellings from the dangers resulting from the exposure to ionizing radiation. The European Directive 2013/59/Euratom requires the establishment of a national radon action plan as a set of measures to address the long-term risks from radon in buildings and workplaces for any source of radon ingress, whether from soil, building materials or water. The long-term goal of the radon action plan is to sustainably reduce the number of lung cancer cases caused by exposure to radon and its short-lived decay products.

At this stage, the progress in the implementation of the radon action plan among EU Member States is quite variable depending on actions mainly related with national health protection strategies, stakeholder's engagement and building partners, in an attempt to align priorities with national and international obligations. For the challenges on the implementation of the radon action plan, a wide collaboration is needed from different sectors and authorities at national, regional and local levels. Moreover, partnerships (public, private, and academia) may be a way of accelerating the progress in achieving the common goal of reducing radon exposure.

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References

Al Zoughool, M., Krewski, D.: Health effects of radon: a review of the literature. Int. J. Radiat Biol. **85**(1), 57–69 (2009). https://doi.org/10.1080/09553000802635054

APA: Portal da Agência Portuguesa do Ambiente (2021). https://apambiente.pt/index.php?ref=17&subref=1544. Accessed 29 April 2021

Darby, S., Hill, D., Auvinen, A., Barros-Dios, J.M., Baysson, H., Bochicchio, F., Deo, H., Falk, R., Forastiere, F., Hakama, M., Heid, I., Kreinbrock, L., Kreuzer, M., Lagarde, F., Mäkeläinen, I., Muirhead, C., Oberaigner, W., Pershagen, G., Ruano-Ravina, A., Ruosteenoja, E., Rosario, A.S., Tirmarche, M., Tomásek, L., Whitley, E., Wichmann, H.E., Doll, R.: Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. BMJ **330**(7845), 223–227 (2005)

Decreto Lei nº 118/2018 de 27 de dezembro do Ministério do Trabalho, Solidariedade e Segurança Social. Diário da República: I série, N.º 118 (2018), Acedido em 26 de abril. 2020. Disponível em www.dre.pt

Diretiva 2013/59/EURATOM de 5 de dezembro do Conselho da União Europeia. Jornal Oficial da União Europeia: L 13/1 (2014)

EPA: United States Environmental Protection Agency. Consumer's Guide to Radon Reduction, How to fix your home (2013). http://www.epa.gov/radon, EPA 402/K-10/005 | March 2013

Erdogan, M., Ozdemir, F., Eren, N.: Measurements of radon concentration levels in thermal waters in the region of Konya, Turkey. Isot. Environ. Health Studies **49**(4), 567–574 (2013). https://doi.org/10.1080/10256016.2013.815182

Faísca, M.C., Teixeira, M.M.G.R., Bettencour, A.O.: Indoor radon concentrations in Portugal - a national survey. Radiat. prot. Dosim. **45**, 465–467 (1992). https://doi.org/10.1093/rpd/45.1-4.465

Ferlay, J., Autier, P., Boniol, M., Heanue, M., Combet, M., Boyle, P.: Estimates of the cancer incidence and mortality in Europe in 2006. Ann Oncol. **2007**(18), 581–592 (2007)

IAEA: Safety Standards for protecting people and the environment. Protection of Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation, No. SSG-32, International Atomic Energy Agency, Vienna (2015)

International Agency for Research on Cancer: Man-made mineral fibres and radon. IARC Monographs on the evaluation of carcinogenic risks to humans, vol. 43. IARC (1988)

International Commission on Radiological Protection: Lung cancer risk from radon and progeny and statement on radon. ICRP Publication 115, Ann. ICRP **40**(1) (2010)

Silva, A.S., Dinis, M.L., Pereira, A.J.S.C.: Assessment of indoor radon levels in Portuguese thermal spas. Radioprotection 249–254 (2016). https://doi.org/10.1051/radiopro/2016077

Silva, A.S., Dinis, M.L.: Indoor radon levels in thermal spas and the compliance with the European bss directive: a portuguese case study. In: Arezes, P., Baptista, J.S., Barroso, M., Carneiro, P., Cordeiro, P., Costa, N., Melo, R., Miguel, A.S., Perestrelo, G. (eds.) Occupational Safety and Environmental Safety and Health II, pp. 163–171 (2020). https://doi.org/10.1007/978-3-030-41486-3

Silva, A.S., Dinis, M.L.: Measurements of indoor radon and total gamma dose rate in Portuguese thermal spas. In: Arezes, P., Baptista, J.S., Barroso, M., Carneiro, P., Cordeiro, P., Costa, N., Melo, R., Miguel, A.S., Perestrelo, G. (eds.) Occupational Safety and Hygiene IV, pp. 485–489. Taylor & Francis, London (2016)

United Nations Scientific Committee on the Effects of Atomic Radiation: Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly with Scientific Annexes. (Vol 1, Annex B: Exposures of The Public and Workers from Various Sources of Radiation, p. 404. New York, 2010) (2008)

United States Department of Health and Human Services: Surgeon General Releases National Advisory on Radon (2005). http://www.surgeongeneral.gov

United States Environmental Protection Agency: Communicating Radiation Risks. USEPA Publication, 402-F-07-008, USEPA Office of Radiation and Indoor Air (2007)

United States Environmental Protection Agency: Find Information About Local Radon Zones and State Contact Information. Indoor Environments Division, Office of Radiation and Indoor Air, Office of Air and Radiation, USEPA. Last updated on January 14 (2021). www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information

United States Environmental Protection Agency: Radon report 2003. USEPA Publication, 402-R-03-003 (2003) http://www.epa.gov/radon

World Health Organization: EUR/ICP/CEH. Indoor Air Quality: A Risk-based Approach to Health Criteria for Radon Indoors, S. Vol. 108. WHO Regional Office for Europe (1993)

World Health Organization Health: Radon and Health. Information Sheet (2002)

World Health Organization Health: Hazards and Public Debate: Lessons for risk communication from the BSE/CJD saga, Regional Office for Europe (2006)

World Health Organization: Effective Media Communication during Public Health Emergencies (2007)

World Health Organization: Report on the Global Tobacco Epidemic-The MPOWER package (2008)

World Health Organization: WHO Handbook on Indoor Radon (2009)

World Health Organization Health (2021). https://www.who.int/data/gho/indicator-metadata-registry/imr-details/5611

Cortisol as a Biomarker of Work-Related Stress in Firefighters: A Systematic Review

Tatiana Teixeira, Joana Santos, D. Bustos, and J. C. Guedes

Abstract Introduction: Work-related stress results from exposure to factors such as high workloads and lack of control over one's work. This exposure stimulates the hypothalamic-pituitary-adrenal axis to increase the secretion of stress-related glucocorticoid hormones, including cortisol. The main objective of this study was to investigate the production of cortisol (or cortisol levels) of firefighters in response to work-related stress. Methodology: For the systematic literature review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement was used. The research was developed in the databases SCOPUS, Web Of Science, and Pubmed. Results: Eleven articles were included in the present study, with hormonal and physiological assessments verifying the psychophysiological response to stress. Discussion: The nervous system and the endocrine system trigger the production of hormones called corticosteroids in response to stress. The primary corticosteroid is cortisol, produced in the adrenal gland. Exposure to extreme environments and involvement in intense physical activities impact hormone production and all stress biomarkers. Conclusion: Further studies are needed to confirm cortisol

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as a biomarker of occupational stress, particularly in occupations with high physical and mental demands such as firefighters.

Keywords Psychophysiological response · Stress hormones · Occupational exposure

1 Introduction

Stress is defined by an internal or external environment that threatens the individual's psychophysiological integrity (Shahsavarani et al. 2015). Fatigue is one of the stress-inducing factors due to its association with tensions caused by work and depression (Rose et al. 2017). Work can be the most significant stressor in humans due to high-pressure work environments, lack of appreciation by hierarchical superiors, teamwork with a psychosocial impact and increased human-machine interaction (The National Institute for Occupational Safety and Health (NIOSH) 2013). On the other hand, work environments with exposure to extreme environments are also stress inducers. In addition, harsh environments are the cause of occupational illnesses and injuries (CDC 2018). Mentally demanding tasks are affected when they are performed under extreme temperatures, particularly in hot environments (Wyon et al. 1981). Thus, it is possible to indicate that harsh environments can induce fatigue in the individual, affecting cognitive performance and physiological response to stress caused by a specific task (Nunneley et al. 1978).

Alterations are seen in the different systems of the human body in response to stress, namely the nervous, cardiovascular, endocrine and immune systems. Acute or chronic exposure to stressful events, depending on their intensity, severity, and feeling of control of the individual under the stressful event, determine physiological responses. These changes can cause serious diseases such as hypertension and vascular hypertrophy (Schneiderman et al. 2005). Stress can be identified through post-traumatic stress disorder (PTSD) and prolonged grieving disorder (Maercker et al. 2013).

The stress response triggers psychophysiological responses during the activation of the autonomic nervous system through the hypothalamic-pituitary-adrenal axis to significantly increase the levels of adrenaline in the metabolism for the reaction to real or perceived stress (Ahrens et al. 2008; Iob and Steptoe 2019) (Ahrens et al. 2008; Iob and Steptoe 2019; Smith and Vale 2006). The end product of the response to stressful events is cortisol.

Cortisol is a hormone produced to participate in the metabolism of the most varied energetic nutrients and its anti-inflammatory function. Cortisol, for being a hormone associated with stress and significant physiological impacts on individuals, particularly cardiovascular diseases, has been a focus of study through measurements of body fluids such as blood, saliva and urine (Harrewijn et al. 2020; Iob and Steptoe 2019).

Acute exposure to stress causes some adverse effects on metabolism, such as metabolic syndrome, obesity, cancer, mental health disorders, cardiovascular diseases and increased susceptibility to infections (Iob and Steptoe 2019; Russell and Lightman 2019; Thau et al. 2021). According to a study by Pineles et al. (2013), the sample under analysis shows cortisol levels upon waking concerning anxiety symptoms. Actually, the physiological alterations have associated with post-traumatic stress disorder (PTSD) and anxiety symptoms presented in individuals.

Firefighters' activity is characterized by a demanding work path physically and mentally. They operate during emergencies and have a high number of working hours, combined with exposure to heat, dust, carbon monoxide (CO), and many others (Fabrizio Perroni et al. 2014). Among all the tasks performed by them, wildland firefighting is still the most worrying. When fighting forest fires, firefighters are put into strenuous physical activity for long periods. Consequently, work performance depends on the firefighter's ability to perform physically demanding tasks in extreme environments. As a result, the main objective of this study was to investigate the production of cortisol (or cortisol levels) of firefighters in response to work-related stress.

2 Materials and Methods

For the systematic literature review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement was used (Moher et al. 2009). The research results from a scoping review, about to assess psychophysiological variables during regular firefighters' occupational activities. In this scoping review talk about Assessment of cognitive function, Assessment of psychological status and Physiological and hormonal Assessment. In Physiological and hormonal assessment where the authors detected the importance of studying cortisol and its impact on the health of firefighters during the execution of their activities. With this, the present article presentation the short results about relation in between firefighters' activities and cortisol production.

The research was developed in the databases SCOPUS, Web Of Science, and Pubmed. The keywords used were: Firefighters, anxiety, hormonal responses, mental demand, cortisol, cognitive performance, memory, cognitive function, psychological responses, psychophysiological responses, selective attention, cognitive responses, mindfulness and burnout.

Date restrictions on the selection of the articles were not applied and research published articles and articles in press were included. Theoretical articles were not considered, such as literature reviews and conference articles. All the articles considered field and laboratory investigations to study cortisol levels of firefighters in various activities. The research was focused on samples of firefighters and there were no gender and age restrictions. Field and laboratory investigations were included with a focus on psychophysiological response in the various tasks performed during the activity of firefighters. The review consists of articles written in English only.

3 Results

Seventy-five articles were selected from the databases. However, only eleven were used in the present review because they are related to the physiological response to stress. The reports included mentioned variables such as stress hormones (cortisol and catecholamines), heart rate (HR) and fatigue. In Table 1, it is possible to check the articles included.

There is an excellent association between the measurement of fatigue and the response to stress on individuals since when they are in a state of exhaustion, they tend to stress more significantly. Other physiological parameters mentioned in the different studies are indicators of stress, as is the example of HR.

4 Discussion

In the articles included, it was observed that the areas with the most significant focus of study on stress and the psychophysiological response were public health and ergonomics, with three and two studies, respectively. The remaining areas included occupational and environmental hygiene, clinical practice and epidemiology in mental health, neuroendocrinology, among many other areas.

The relationship between the different stressors and the individuals psychological and physiological response in the occupational context proves to be a critical point in assessing occupational risk. In firefighters' cases, the tasks performed have high physical and psychological demands, increasing the workers' risk exposure. Thus, it is considered extremely important to understand the psychophysiological changes and the possible causes of these changes so that it is possible to assess the different work situations that influence these responses.

4.1 Hormonal Production in Response to Stress

Hormone production is the responsibility of the hypothalamus and the pituitary gland. The hypothalamus, among other functions such as regulating body temperature, thirst and appetite, produces hormones that stimulate or suppress the release of hormones by the pituitary gland. In turn, the pituitary gland produces hormones to control the segregation of other endocrine glands, such as the adrenal glands. The cephalorachidian fluid surrounds the brain and spinal cord, circulating between two meningeal layers (pia matter and arachnoid) and have a protection function (Fox 2011; Powers and Howley 2004; Raff and Levitzky 2011).

The adrenal glands are located in the upper part of the kidneys. It is in the adrenal gland cortex, a layer of tissue formed by epithelial cells, that steroids or, also known as, corticosteroids are produced. These hormones are made from cholesterol when

Table 1 Overview of qualitative data analysis of the results

References	Objective	Cortisol levels	Main results
Lim et al. (2020)	Assess changes in cortisol levels and spinal cycle after night shifts	Serum cortisol after night sleep after day work: 2.44 ± 0.37 µg/dL Serum cortisol after night work / serum cortisol after 24 h work: 2.71 ± 0.31 µg/dL Urinary cortisol during night sleep after day work: 1.39 ± 0.89 µg/dL Urinary cortisol during night sleep in the next day after night work: 1.13 ± 1.11 µg/dL	The serum cortisol level increased significantly after night or 24-h shifts
Kim et al. (2018)	Assess vital signs and biomarkers of heart disease	No direct results*	Increased levels of cortisol and lactic acid just 1 min after the fire simulation. In this same period, HR and body temperature skyrocket
Rosalky et al. (2017)	Evaluate the influence of exercise on cortisol production, anxiety and fear response to a firefighting scenario	Mean concentration of 40.93 ± 11.41 nmol/L in a group with two simulated fire suppression to 25.07 ± 9.88 nmol/L at the end of the protocol In the group with three simulated fire suppression, the mean concentration was 42.89 ± 11.83 nmol/L before the first burn and 25.07 ± 8.82 nmol/L at protocol finish	No difference in cortisol production was found between working times
Wolkow et al. (2016a)	Evaluate the effect of work and sleep restriction on cortisol and HR	No direct results*	However, after the shortened sleep period, participants in the sleep restriction condition demonstrated higher levels of cortisol in the afternoon and evening
Wolkow et al. (2016a)	Determine the relationship between sleep restriction, physical work, psychological responses and increased cytokine and cortisol	No direct results*	Several significant relationships between psychological Stress factors and cytokine and cortisol responses among firefighters

(continued)

Table 1 (continued)

References	Objective	Cortisol levels	Main results
Wolkow et al. (2015)	Determine the relationship between daytime and nighttime cytosine production and total cortisol production	No direct results*	An 8-h sleep opportunity between firefighting shifts mitigates subsequent increases in nighttime cortisol, providing a protective buffer against adverse health effects
Susoliakova et al. (2014)	Assess salivary cortisol levels among teachers and firefighters	No direct results*	Cortisol levels decrease from morning to work day and are lower at night
Pineles et al. (2013)	Evaluate physiological and psychological measures after exposure to a stressful environment	No direct results*	The level of cortisol upon waking has divergent relationships with psychometric measures of mood and symptoms of anxiety versus physiological reactivity to high tones, aversive conditioning
Perroni et al. (2009)	Evaluate firefighting simulation in the levels of salivary alpha-amylase, free cortisol, anxiety and profile of mood states	Concentrations in the morning 16.7±2.2 nmol/l. Concentrations in afternoon is 2.7 +0.4 nmol/l. The morning of the experimental session is 11.3 ± 1.9 nmol/l	There were no significant changes in cortisol levels
Heinrichs et al. (2005)	Assess subjective and neuroendocrine characteristics	No direct results*	There were no significant changes in the levels of salivary cortisol and urinary catecholamines
Smith et al. (2005)	Evaluate the effects of strenuous firefighting exercises with real fire and a 90-minute recovery period on hormonal, immunological and psychological variables	No direct results*	HR and rectal temperature indicated that repeated attempts to fight fires resulted in considerable cardiovascular and thermal stress

*The authors represented the results in statistical analysis and graphs without the possibility of extracting the data the hypothalamus releases corticotropin up to the pituitary gland, where there is the release of adrenocorticotropin into the bloodstream, allowing glucocorticoids. This cycle is daily due to the well-known spinal cycle. However, the highest production is observed in the periods of wakefulness and sleep, and in the morning there are notorious higher concentrations (Drake 2005; Fox 2011; Jonathan et al. 2009; Kemeny 2003; Powers and Howley 2004; Raff and Levitzky 2011). According to a study by Lim et al. (2020), in a group of firefighters, the serum cortisol level increased significantly after night or 24-h shifts compared to the level measured after day shifts. This study contradicts another one carried out by Wolkow et al. (2016b), where cortisol levels are highest in the afternoon.

This cycle of cortisol production is characterized by being self-limited; that is, even if there is an increase in production, the concentration values will always remain within certain levels (Drake 2005; Fox 2011; Jonathan et al. 2009; Kemeny 2003; Powers and Howley 2004; Raff and Levitzky 2011; Rosalky et al. 2017). Perroni et al. (2009) found that 30 min after fighting structural fires, the HR showed significantly higher values than the baseline values, although the cortisol values did not show significant changes. Despite this, firefighters considered the task difficult, according to the Borg scale. This study is in line with another carried out by Susoliakova et al. (2014), in a sample of firefighters and teachers, in which cortisol values decreased from morning to night. Thus, it is possible to indicate an increase in the cardiovascular tension of firefighters when they are in hot environments such as in front of a fire (Smith et al. 1997).

Among many of the groups of hormones produced, glucocorticoids are the main ones that regulate lipids, carbohydrates, and proteins. Of this group of hormones, the most important is cortisol. The adrenal medulla, belonging to the autonomic nervous system, specializes in producing catecholamines, such as adrenaline and norepinephrine, to prepare the physiological responses for stressful situations. With the production of these hormones, we verify some physiological changes caused by the induction of stress in the individual. Some of these changes include increased HR, increased blood pressure and increased blood flow in the muscles (Khan et al. 2019; Rodrigues et al. 2018). According to Smith et al. (2005), there is an activation of the hypothalamic-pituitary-adrenal axis characterized by elevations in cortisol in response to firefighting stress.

4.2 *Physical Activity, Exposure to Hot Environments and Cortisol Production*

The execution of intense physical activities and exposure to extreme environments, as is the case of firefighters, can influence the physiological response to individuals' stress (Huang et al. 2010). Kim et al. (2018) indicate that during a simulation exercise to combat structural fires, one minute after its beginning, an increase in cortisol and lactic acid levels was observed, as well as HR and body temperature.

Lactic acid and cortisol seem to be related since cortisol trigger an increase in glucose for energy supply, and lactic acid is a by-product of bioenergy production through the glucose molecule (Christison et al. 2021; Kemeny 2003). Thus, it is considered lactic acid measurement of extreme importance, becoming a biomarker of performance and resistance (Fabrizio Perroni et al. 2014).

On the other hand, in a study by Wolkow et al. (2017), it is verified that firefighters demonstrate an increase in cortisol when exposed to hot environments. In fighting forest fires, several significant relationships between psychological stress factors and the response of cytokine and cortisol are verified (Wolkow et al. 2016a). With this, it is recommended, according to the study by Wolkow et al. (2015), an 8-h sleep rest between forest firefighting shifts to mitigate subsequent increases in nighttime cortisol, providing a protective buffer against adverse health effects.

4.3 Cortisol Measurement Methods

Blood samples can give values of circulating cortisol levels at a given time. On the other hand, urine samples allow assessing the total cortisol concentration at the time of sampling. Thus, to carry out a detailed analysis of the evolution of cortisol levels during the execution of an activity, it is necessary to collect several samples, blood or urine, throughout the experimental protocol. However, it is not guaranteed that cortisol levels correspond to the stress induced by the activity since it refers to the assessment of body fluids and that they vary depending on individual susceptibility (Greff et al. 2019; Iob and Steptoe 2019).

As seen in a study of Heinrichs et al. (2005), where there were no significant changes in the levels of salivary cortisol and urinary catecholamines. Alternatively, the use of hair has been suggested for the measurement of psychosocial exposures since the hair can provide information on cortisol levels by accumulation over time, demonstrating better reliability (Greff et al. 2019; Iob and Steptoe 2019).

5 Conclusions

Stress is a factor present in daily life activities and physiological responses to stress are dependent on individual susceptibility. Exposure to stress can represent a serious health problem, with physiological and psychological changes in the long term. Examples of these changes are the increase in HR and the onset of psychiatric illnesses such as PTSD. Cortisol is the primary hormone produced in response to stress.

During the production of cortisol, changes are seen in other systems that may influence when the individual is exposed to different conditions such as intense physical activity in extreme environments. Strenuous activities increase the production of cortisol by the stress caused and by products such as lactic acid. There is a chance that these two products are related.

Occupational stress is prevalent in the most demanding professions, as is the example of firefighters. Further studies are needed for establishing the relationship between occupational exposure of firefighters and increased cortisol levels. However, as our results showed, cortisol should not be assessed individually but in conjunction with different occupational exposure biomarkers.

References

Ahrens, T., Deuschle, M., Krumm, B., van der Pompe, G., den Boer, J.A., Lederbogen, F.: Pituitary-adrenal and sympathetic nervous system responses to stress in women remitted from recurrent major depression. Psychosom. Med. **70**(4), 461–467 (2008). https://doi.org/10.1097/PSY.0b013e31816b1aaa

CDC: Heat Stress - Heat Related Illness (2018). https://www.cdc.gov/niosh/topics/heatstress/heatrelillness.html

Christison, K.S., Gurney, S.C., Sol, J.A., Williamson-Reisdorph, C.M., Quindry, T.S., Quindry, J.C., Dumke, C.L.: Muscle damage and overreaching during wildland firefighter critical training. J. Occup. Environ. Med. **63**(4), 350–356 (2021). https://doi.org/10.1097/JOM.0000000000002149

Drake, R.L., A.W.V., A.W.M.M.: Gray's - Anatonomia para Estudantes, 2nd edn. Elsevier, Amsterdam (2005)

Fox, S.I.: Human Physiology, 12th edn. (2011)

Greff, M.J.E., Levine, J.M., Abuzgaia, A.M., Elzagallaai, A.A., Rieder, M.J., van Uum, S.H.M.: Hair cortisol analysis: an update on methodological considerations and clinical applications. Clin. Biochem. **63**, 1–9 (2019). https://doi.org/10.1016/j.clinbiochem.2018.09.010

Harrewijn, A., Vidal-Ribas, P., Clore-Gronenborn, K., Jackson, S.M., Pisano, S., Pine, D.S., Stringaris, A.: Associations between brain activity and endogenous and exogenous cortisol – A systematic review. Psychoneuroendocrinology **120**, 104775 (2020). https://doi.org/10.1016/j.psyneuen.2020.104775

Heinrichs, M., Wagner, D., Schoch, W., Soravia, L.M., Hellhammer, D.H., Ehlert, U.: Predicting post-traumatic stress symptoms from pretraumatic risk factors: a 2-year prospective follow-up study in firefighters. Am. J. Psychiatry **162**(12), 2276–2286 (2005). https://doi.org/10.1176/appi.ajp.162.12.2276

Huang, C.-J., Webb, H.E., Evans, R.K., McCleod, K.A., Tangsilsat, S.E., Kamimori, G.H., Acevedo, E.O.: Psychological stress during exercise: immunoendocrine and oxidative responses. Exp. Biol. Med. (Maywood, N.J.) **235**(12), 1498–1504 (2010). https://doi.org/10.1258/ebm.2010.010176

Iob, E., Steptoe, A.: Cardiovascular disease and hair cortisol: a novel biomarker of chronic stress. Curr. Cardiol. Rep. **21**(10), 116 (2019). https://doi.org/10.1007/s11886-019-1208-7

Jonathan, D., Kibble, P., Halsey, C.R.: Medical Physiology, 1st edn. McGraw-Hill Education/Medical, New York (2009)

Kemeny, M.E.: The psychobiology of stress. Curr. Dir. Psychol. Sci. **12**(4), 124–129 (2003). https://doi.org/10.1111/1467-8721.01246

Khan, A.A., Lip, G.Y.H., Shantsila, A.: Heart rate variability in atrial fibrillation: the balance between sympathetic and parasympathetic nervous system. Eur. J. Clin. Inve. **49**(11), e13174 (2019). https://doi.org/10.1111/eci.13174

Kim, S.-C., Lee, H.-J., Shin, D.-M., Ku, B.-S., Oh, J.-H., Cho, B.-J., In, H., Ma, J.-Y.: Cardiovascular risk in fire academy instructors during live-fire simulation activity. Ann. Burns Fire Disasters **31**(4), 313–321 (2018)

Lim, G.-Y., Jang, T.-W., Sim, C.-S., Ahn, Y.S., Jeong, K.S.: Comparison of cortisol level by shift cycle in Korean firefighters. Int. J. Env. Res. Public Health **17**(13) (2020). https://doi.org/10.3390/ijerph17134760

Maercker, A., Brewin, C.R., Bryant, R.A., Cloitre, M., van Ommeren, M., Jones, L.M., Humayan, A., Kagee, A., Llosa, A.E., Rousseau, C., Somasundaram, D.J., Souza, R., Suzuki, Y., Weissbecker, I., Wessely, S.C., First, M.B., Reed, G.M.: Diagnosis and classification of disorders specifically associated with stress: proposals for ICD-11. World Psychiatry: Official J. World Psychiatric Ass. (WPA) **12**(3), 198–206 (2013). https://doi.org/10.1002/wps.20057

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Group, T.P: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLOS Med. **6**(7), e1000097 (2009)

Nunneley, S., Dowd, P., Myhre, L., Stribley, R.: Physiological and psychological effects of heat stress simulating cockpit conditions. Aviat. Space Environ. Med. **49**, 763–767 (1978)

Perroni, F., Tessitore, A., Cibelli, G., Lupo, C., D'Artibale, E., Cortis, C., Cignitti, L., De Rosas, M., Capranica, L.: Effects of simulated firefighting on the responses of salivary cortisol, alpha-amylase and psychological variables. Ergonomics **52**(4), 484–491 (2009). https://doi.org/10.1080/00140130802707873

Perroni, Fabrizio, Guidetti, L., Cignitti, L., Baldari, C.: Psychophysiological responses of firefighters to emergencies: a review. Open Sports Sci. J. **7**(1), 8–15 (2014). https://doi.org/10.2174/1875399X01407010008

Pineles, S.L., Rasmusson, A.M., Yehuda, R., Lasko, N.B., Macklin, M.L., Pitman, R.K., Orr, S.P.: Predicting emotional responses to potentially traumatic events from pre-exposure waking cortisol levels: a longitudinal study of police and firefighters. Anxiety Stress Coping **26**(3), 241–253 (2013). https://doi.org/10.1080/10615806.2012.672976

Powers, S.K., Howley, E.T.: Fisiologia do Exercício (E. Manole (ed.); 5a) (2004)

Raff, H., Levitzky, M.: Medical Physiological - A systems Approach. McGraw-Hill, New York (2011)

Rodrigues, S., Paiva, J.S., Dias, D., Pimentel, G., Kaiseler, M., Cunha, J.P.S.: Wearable biomonitoring platform for the assessment of stress and its impact on cognitive performance of firefighters: an experimental study. Clin. Prac. Epidemiol. Mental Health: CP & EMH **14**, 250–262 (2018). https://doi.org/10.2174/1745017901814010250

Rosalky, D.S., Hostler, D., Webb, H.E.: Work duration does not affect cortisol output in experienced firefighters performing live burn drills. Appl. Ergon. **58**, 583–591 (2017). https://doi.org/10.1016/j.apergo.2016.04.008

Rose, D.M., Seidler, A., Nübling, M., Latza, U., Brähler, E., Klein, E.M., Wiltink, J., Michal, M., Nickels, S., Wild, P.S., König, J., Claus, M., Letzel, S., Beutel, M.E.: Associations of fatigue to work-related stress, mental and physical health in an employed community sample. BMC Psychiatry **17**(1), 167 (2017). https://doi.org/10.1186/s12888-017-1237-y

Russell, G., Lightman, S.: The human stress response. Nat. Rev. Endocrinol. **15**(9), 525–534 (2019). https://doi.org/10.1038/s41574-019-0228-0

Schneiderman, N., Ironson, G., Siegel, S.D.: Stress and health: psychological, behavioral, and biological determinants. Annu. Rev. Clin. Psychol. **1**, 607–628 (2005). https://doi.org/10.1146/annurev.clinpsy.1.102803.144141

Shahsavarani, A. M., Azad Marz Abadi, E., Hakimi Kalkhoran, M.: Stress: facts and theories through literature review. Int. J. Med. Rev. **2**(2), 230–241 (2015). http://www.ijmedrev.com/article_68654.html

Smith, S.M., Vale, W.W.: The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. Dial. Clin. Neurosci. **8**(4), 383–395 (2006). https://doi.org/10.31887/DCNS.2006.8.4/ssmith

Smith, D.L., Petruzzello, S.J., Kramer, J.M., Misner, J.E.: The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill. Ergonomics **40**(4), 500–510 (1997). https://doi.org/10.1080/001401397188125

Smith, D.L., Petruzzello, S.J., Chludzinski, M.A., Reed, J.J., Woods, J.A.: Selected hormonal and immunological responses to strenuous live-fire firefighting drills. Ergonomics **48**(1), 55–65 (2005). https://doi.org/10.1080/00140130412331303911

Susoliakova, O., Smejkalova, J., Bicikova, M., Potuznikova, D., Hodacova, L., Grimby-Ekman, A., Fiala, Z.: Salivary cortisol in two professions: daily cortisol profiles in school teachers and firefighters. Neuro Endocrinol. Lett. **35**(4), 314–321 (2014)

Thau, L., Gandhi, J., Sharma, S.: Physiology, Cortisol (2021)

The National Institute for Occupational Safety and Health (NIOSH): Stress at work (2013). https://www.cdc.gov/niosh/topics/stress/default.html

Wolkow, A., Aisbett, B., Reynolds, J., Ferguson, S.A., Main, L.C.: Relationships between inflammatory cytokine and cortisol responses in firefighters exposed to simulated wildfire suppression work and sleep restriction. Physiol. Rep. **3**(11) (2015). https://doi.org/10.14814/phy2.12604

Wolkow, A., Aisbett, B., Ferguson, S.A., Reynolds, J., Main, L.C.: Psychophysiological relationships between a multi-component self-report measure of mood, stress and behavioural signs and symptoms, and physiological stress responses during a simulated firefighting deployment. Int. J. Psychophysiol.: Official J. Int. Org. Psychophysiol. **110**, 109–118 (2016a). https://doi.org/10.1016/j.ijpsycho.2016.10.015

Wolkow, A., Aisbett, B., Reynolds, J., Ferguson, S.A., Main, L.C.: The impact of sleep restriction while performing simulated physical firefighting work on cortisol and heart rate responses. Int. Arch. Occup. Environ. Health **89**(3), 461–475 (2016b). https://doi.org/10.1007/s00420-015-1085-3

Wolkow, A., Aisbett, B., Jefferies, S., Main, L.C.: Effect of heat exposure and simulated physical firefighting work on acute inflammatory and cortisol responses. Ann. Work Expos. Health **61**(5), 600–603 (2017). https://doi.org/10.1093/annweh/wxx029

Wyon, D.P., Andersen, I., Lundqvist, G.R.: Chapter 16 the Effects of moderate heat stress on mental performance. In: Cena, K., Clark, J.A. (eds.) Bioengineering, Thermal Physiology and Comfort, vol. 10, pp. 251–267. Elsevier, Amsterdam (1981). https://doi.org/10.1016/S0166-1116(08)71093-8

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Medium and Long-Term Assessment of Fatigue Based on Workload and Rest-Activity Cycle

A Systematic Review

E. A. Stradioto Neto, D. Bustos, and J. C. Guedes

Abstract Fatigue is considered an intermediate state between tiredness and exhaustion. This study aims to filter and evaluate a series of articles focused on fatigue associated with activities performed in long working hours, seeking to understand better the causes, equipment, and methods used to assess this condition. For this purpose, a bibliographic review of the literature was performed using the systematic review methodology referenced in PRISMA Statement. From this search, a total of 10789 first articles were obtained and, after the application of exclusion criteria, 16 were finally selected. After that, a brief qualitative analysis was made, comparing the common characteristics and individual highlights among these articles. Methods and equipment used were found to be of great value for enriching future studies about fatigue in workers. As a result, this work can serve as a departure point for future studies addressing fatigue among safety-sensitive occupational groups, such as firefighters or any physically demanding occupation.

Keywords Fatigue detection · Heart rate · Firefighters

1 Introduction

Fatigue can be defined as an unpleasant symptom, which brings sensations that vary from tiredness to exhaustion, interfering with an individual's ability to act and perceive efficiently (Ream and Richardson 1996). According to Enoka and Duchateau (2008), the term "muscle fatigue" can be used to indicate the decreased ability to perform physical activities.

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Symptoms related to heat exposure (dizziness, headache, nausea, cramps muscles, perception, vomiting, fainting) to which an individual is subjected are directly related to the working time he is exposed to this factor (Kim et al. 2019).

During forest fires, firefighters are exposed to several risks that may compromise their safety and performance (Vincent et al. 2016a). These professionals must always be on the alert for any emergencies. Their performance and alertness are directly linked to their sleep time the night before the activity (Mantua et al. 2019).

However, to this date, there are not many studies related to fatigue generated by activities performed under such circumstances (prolonged periods of high effort activity combined with short rest periods), since there are not many professions that are exposed to these situations. Most of the current studies focus on fatigue resulted from short term practices. As a result, the objective of this study is to filter and evaluate a series of articles focused on fatigue associated with activities performed in long working hours, seeking to understand better the causes, equipment and methods used to assess this condition, thus enabling the deepening of knowledge about this topic.

2 Methods

The selection of articles used for this bibliographic review was performed through the systematic review methodology referenced in PRISMA Statement (Moher et al. 2009; Shamseer et al. 2015). The databases chosen for the studies retrieval were Scopus, PubMed and Web of Science.

All databases used required the use of keywords as a means of search. Therefore, their choice was of paramount importance for a good direction of the research.

Keywords were selected according to their potential association with the goals of this review. First, as we intended to assess the various forms of fatigue in occupational settings, the terms "fatigue" and "work cycle" were the most suitable. Furthermore, understanding fatigue as a reversible situation when the sufficient recovery period is reached, the term "work-rest cycle" was also selected to obtain results leading to establish the work-rest relationship to fatigue. In this last regard, one of the most widely used methods to determine work-rest periods is actigraphy. This method allows measuring activity patterns through accelerometer counts. As a result, the term "actigraphy" was also considered along with "fatigue".

Therefore, three sets of keywords were formed: "Fatigue" + "Work Cycle"; "Work Rest Cycle" and "Actigraphy" + "Fatigue".

2.1 Information Sources, Search, and Filters

The search in the three chosen databases was carried out through the selection of documents found directly after inserting the keyword sets previously mentioned. Any other specifications regarding authors, affiliations or any different scope were not considered. Subsequently, a group of five filters was used to restrict the criteria for selecting articles. These filters were applied continuously, that is, applying one on top of the other so that, after each filter, the number of articles decreased. At the end of this step, the number of studies was significantly reduced and were considered the ones of greater relevance for the goals of this review.

The first filter, "Date", consisted of filtering articles based on their year of publication, selecting articles published only over the past five years (2015–2019). Therefore, for the cases in which the database already had articles published in 2020, we used an interval from 2015 to 2020. The second filter introduced, referred to "Document Type", consisted of determining the type of document observed for analysis. For all databases, we opted only for scientific articles.

The third applied filter, called "Source Type", indicated the source from which the scientific articles (filtered in the previous step) were retrieved. For this stage, it was decided to use only articles published in scientific journals. Since only articles were selected in the second stage, the third filter became unnecessary since all papers were published in scientific journals. Therefore, the number of articles was not reduced at this stage.

The fourth applied filter was "Language", and consisted of selecting only scientific articles written in one or more specified languages. In this case, only English-written articles were considered. Finally, the fifth applied filter, called "Other", consisted of applying one or more additional filters made available by each database used. It is of great importance to highlight that, once a filter is applied to a given database, to a set of keywords, it must be applied to the other keywords searched in the same system. In this regard, no other filters were used on the Scopus platform. In the PubMed database, we applied the "Humans" filter, restricting the search for data to articles related to human beings. For the Web of Science database, two categories proposed by the platform: "Ergonomics" and "Physiology" were selected. The choice of these was due to their proximity to the researched topic.

After applying the fifth category of filters, articles were screened according to their potential association with the subject. At this stage, articles were analysed by title, and if it was related to the theme, its abstract was read and evaluated following the aims of this work. In this stage, studies were selected if any of these conditions were met:

- Research was carried out in the field;
- Work activities were of high physical effort;
- Studies were related to firefighters;
- Analyses were made by actigraphy indirectly;
- Studies were related to the rest time needed to exercise.

Finally, after selecting the articles of most significant interest, the number of articles excluded in each database was allocated to the item "Off topic".

3 Results and Discussion

Using these three electronic databases (Scopus, Pubmed and Web of Science), a total of 10,789 articles were obtained, of which 700 were obtained on the Scopus platform, 1,969 on PubMed and 8,120 on the Web of Science.

Table 1 shows the overview of the search, presenting the set of articles found throughout all databases, as well as the total number of files excluded in the process of screening.

As a result, 27 articles were identified through the three databases. Besides them, only one article was selected externally to the search system due to the relationship with the topic addressed. Therefore, a total of 28 scientific articles were listed for analysis. Subsequently, it was found the presence of repeated articles within this group. Eleven articles were removed after this verification, with a total of 17 articles remaining for analysis.

For each of these articles, it was verified whether the experimental protocols had the approval of an ethics committee and if participants provided their informed written consent before the experiences. Only one study showed that it was not within the verified conditions; therefore, we opted for his exclusion. At the end of this analysis, a total of 16 articles were obtained. They were individually assessed, seeking technical references, making comparisons to similar studies, among other analyses. In Fig. 1, it is possible to observe the analysis carried out, separated into the four stages delimited by the PRISMA methodology.

Among the 16 selected articles, objectives and experimental procedures were diverse. However, it was possible to identify three common characteristics. As a result, they were divided into three tables according to these encountered similarities.

Table 2 enlists the four articles in which the primary studied variable is muscle activity (EMG). The articles in Table 3 have as a common objective the study of the workload associated with certain activities performed and the rest time necessary to avoid the work in workers. Finally, Table 4, encompasses the eight articles related to the profession with the highest number of studies: firefighters.

Regarding the samples, as mentioned before, eight of the studies found had as participants members of fire brigades, and in the studies carried out by Kesler et al. (2018a, b), the same sample was used to obtain the results. Only two out of the 16 selected works had a sample whose profile professional was linked. The work of Taylor et al. (2019) brings with it sleep analysis due to the exchange of shifts by police officers, while Thomas et al. (2019) makes a similar analysis, with sailors, with a greater focus on fatigue generated by this craft.

The repetition of the same samples in different studies can also be observed in Tse et al. (2016) and McDonald et al. (2016), whose studies are complementary. Both developed the study referring to only one specific muscle. Therefore, they are not of extreme value for understanding the expected methodology for the present work, but they are important for greater understanding of the concept of muscle fatigue.

Muscle fatigue is also the theme associated with the works of McDonald et al. (2019), which sought the creation of a function to determine shoulder fatigue, and

Table 1 General summary of the research obtained through the databases used

Basis of Data	Summary of articles selected	Records identified by research medium in the database	Records excluded by criteria screening	Summary of the total items rejected by the criteria of screening					
				Date	Document type	Source type	Language	Other	Off topic
Scopus	9	700	691	445	31	0	3	0	212
Pub Med	12	1969	1957	1451	0	0	3	176	327
Web of science	6	8120	8114	5547	484	0	55	1874	154
Total	27	10789	10762	7443	515	0	61	2050	693

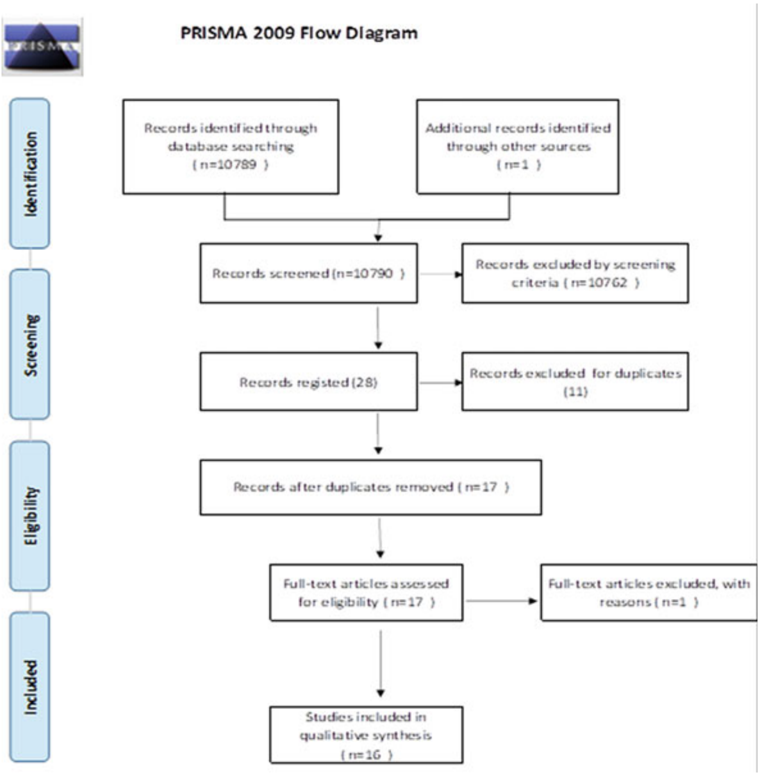

Fig. 1 Flow diagram using the Prisma evaluation method

Pritchard et al. (2019), which analysed the effects of repetitive efforts in the same region of the human body.

Regarding the evaluated parameters, it can be noted that in Horn et al. (2015), Kesler et al. (2018b) and Walker et al. (2015), heart rate and internal temperature were measured in sampled individuals (firefighters). In addition to these factors, each author used other specific parameters in their analysis.

The study presented by Reinberg et al. (2017) also refers to heart rate analysis, in fact, these authors only focus their investigation on the variations in this parameter due to the activities performed by a firefighter.

It is noteworthy the fact that although Horn et al. (2015) did not have as main objective the study of fatigue, they presented an analysis by actigraphy in their research, making it of great interest for the present study, due to the found relationship between physical activity type and intensity and fatigue.

The study by Garcia et al. (2018) evidenced the importance of rest periods during work situations and how different rest periods influence muscle fatigue. Rest periods can be considered a factor of great importance for increasing or reducing fatigue.

Table 2 Muscle Activity (EGM) articles

Reference	Sample	Objective	Variables evaluated	Equipment
McDonald et al. (2019)	20 males (23 ± 4 years)	To develop a function to quantify fatigue in multiple shoulder muscles by generating a single score using relative changes in EMG amplitude and frequency over time	Muscle activity (EMG)	Bipolar surface electrodes (Trigno, Delsys Inc., Natick MA, USA)
Pritchard et al. (2019)	15 males (age 21.9 ± 2.7 years;)	To examine the progressive effects of highly repetitive work on joint kinematics and muscle activity of the trunk and upper extremity	Muscle activity (EMG)	Visual feedback using custom software (LabView, National Instruments, Austin, TX), An electrical switch active work cycle (effort time) for each participant
Tse et al. (2016)	12 males, (age 20–24 years)	To examine adaptation strategies in response to isolated anterior deltoid muscle fatigue while performing simulated repetitive work	Muscle activity	Eleven cameras (Raptor-4, Motion Analysis Corporation, Santa Rosa, CA) sampled 26 reflective markers (100 Hz), Surface electromyography (EMG) using silver-contact wireless bipolar bar electrodes, Borg CR-10 scale throughout the protocol
McDonald et al. (2016)	12 males (20–24 years)	To examine how the response of the shoulder complex changed over one hour of simulated repetitive work	Muscle activity	Eleven cameras (Raptor-4, Motion Analysis Corporation, Santa Rosa, CA) sampled 26 reflective markers (100 Hz), Surface electromyography (EMG) using silver-contact wireless bipolar bar electrodes, Borg CR-10 scale throughout the protocol

Table 3 Work rest Cycle and sleep studies

Reference	Sample	Objective	Variables evaluated	Equipment
Garcia et al. (2018)	15 males, 15 females 30(±12) years and 68 (±13,9)	To evaluate the long-lasting motor, behavioural, physiological, and perceptual effects of prolonged standing work in three work–rest cycle conditions including passive or active rest breaks	Subjective evaluation, MTF, postural stability, dynamic force control, lower-leg muscle oxygenation	Electrodes, Digitimer, pulse generator, volumetric edema gauge, OxyPerm near-infrared spectroscopy surface sensors and adapted Nordic questionnaire
Thomas et al. (2019)	12 males, (age 52.41 ± 9.49 years; range 37–65 years)	To examine the impacts of peak summer demand on operator workload and fatigue in a maritime environment	Sleep/wake patterns, fatigue Level	Activity monitors (Philips Respironics, OR, USA), response time (RT) task. Samn–Perelli Fatigue Checklist
Mantua et al. (2019)	27 adults (age 24.4 ± 5.4 years, 11 female)	To assess the effects of one week of sleep extension on mood, fatigue and subjective sleepiness in normal-sleeping young adults	Fatigue, mood, and sleepiness	Actiwatch 2, Automated Neuropsychological Assessment Metric and Karolinska Sleepiness Scale, nasal cannula, a pulse oximetry probe worn on the index finger, a thorax and abdomen effort belt, and a snore and position monitor
Taylor et al. (2019)	23 police officers and staff aged 31–54 years. 21 males, 2 females	To compare sleep duration, cognitive performance, and vigilance at the start and end of each shift within a three-shift, forward rotating shift pattern	Sleep duration, sleep diary and incident report, cognitive and vigilance tests	Actigraphy iHealth, Cognitive tests

Table 4 Firefighters articles

Reference	Sample	Objective	Variables evaluated	Equipment
Walker et al. (2015)	42 male firefighters	To quantify changes to immune and inflammatory activity in firefighters	Core temperature, Heart rate, Borg's rate of perceived exertion, blood analysis, hydration status	Ingestible thermometer and radio receiver, Borg Scale, haemotology analyser, Siemens Immulite 1000 chemiluminescent solid-phase immunometric assays, portable refractometer
McGillis et al. (2017)	21 Wildland firefighters	To assess the sleep quality, quantity, and fatigue levels	Objective and subjective sleep and fatigue measures	w-ActiSleep-BT watch, log booklet iPod touch [Apple Inc.—Psychomotor Vigilance Test Application], Anker Astro Pro2 20000 mAh Multi-Voltage external battery pack. Physical Component Score and Mental Component Score
Vincent et al. (2016b)	33 firefighters (25 men, 8 women)	To describe firefighters' sleep during planned burn operations and evaluate the impact of the key operational factors	Time in bed, total sleep time, efficiency, latency, sleep quantity, times woken, sleep quality, awake time, bed time, fatigue level	(Actical MiniMitter/Respironics, Bend, OR), software (Actical v3.10), 5-point Likert Scale, current level of fatigue on a 7-point Samn–Perelli fatigue scale
Vincent et al. (2016a)	40 firefighters (31 men, 9 women)	To examine firefighters' sleep quantity and quality throughout multi-day wildfire suppression and assessed the impact of sleep location	Time in bed, Total sleep time, sleep efficiency, sleep latency, Fatigue Level	Actical MiniMitter/Respironics, Bend, OR; Fatigue 7-point Scale
Reinberg et al. (2017)	30 Firefighters (Male)	To assess the levels of systolic and diastolic [SBP and DBP] blood pressure	Systolic and diastolic blood pressures (BP) [SBP and DBP]	Actigraph Model 90207 SpaceLabs Healthcare™ ABPMs (Issaquah, Washington, USA)
Kesler et al. (2018a)	30 firefighters (29 male, 1 female)	To quantify the effects of simulated firefighting activity (work cycle and time main effects) and SCBA configuration	DST, SST, SL, SW and SV; time main effect; spatiotemporal measures	7.9 m gait mat (GAITRite, Platinum, CIR Systems; Sparta, NJ)
Kesler et al. (2018b)	30 firefighters (29 male, 1 female)	To examine the effects of SCBA configuration and work cycle	Heart rate, core temperature, oxygen consumption, work output and self-reported perceptions	Eight-point rating scale (Young 1987), K4b2 (Cosmed s.r.l., Rome, Italy), Equivital (Phillips Respironics, Andover, MD), core temperature pill
Horn et al. (2015)	19 firefighters (18 male, 1 female)	To investigate the effects of different simulated firefighter exercise protocols on maximal	Heart rate, core temperature and accelerometry	Equivital (Phillips Respironics, Andover, MD, USA), Accelerometers (ActiGraph, Pensacola, FL, USA), core temperature pill

The time that a young adult sleeps interferes with the fatigue that he may feel, as confirmed by Mantua et al. (2019).

The works of Vincent et al. (2016a, b) and McGillis et al. (2017) present different investigations regarding the analysis of sleep in firefighters during periods of active duty. These studies also present methods for fatigue analysis through scales of perception, methodologies that can be applied to complement fatigue assessment and management.

As it was observed, and despite the variety of analyses developed by the studies, this review helped to understand the possible associations between muscle activity, heart rate and others physiological parameters and fatigue conditions among workers. The most evaluated variables were muscle Activity (EGM) and heart rate (HR), and the equipment used involved electrodes and cameras to capture signals of movement. Finally, it was observed that the most studied profession was firefighting (8 articles in total). As a result, this work can serve as a departure point for future studies addressing fatigue among safety-sensitive occupational groups, such as firefighters or any physically demanding occupation.

4 Conclusion

The 16 articles obtained through the review methodology are of great value to understand the associations between the variables presented and the fatigue caused in workers who perform higher-risk activities. In this last regard, firefighters were the group of workers who presented a greater number of studies related to fatigue. The greater number of studies focused on this occupational group can be explained due to the stressful characteristics of their tasks, including the long and physically demanding shifts of their work.

Variables such as heart rate and rest time were of paramount importance for understanding the effects and causes of fatigue. This analysis enabled an important expansion of knowledge regarding fatigue and its impact. Methods and equipment identified in the research were found of great value for enriching future studies about fatigue in workers.

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References

Enoka, R.M., Duchateau, J.: Muscle fatigue: what, why and how it influences muscle function. J. Physiol. **586**(1), 11–23 (2008). https://doi.org/10.1113/jphysiol.2007.139477

Garcia, M.G., Läubli, T., Martin, B.J.: Muscular and vascular issues induced by prolonged standing with different work-rest cycles with active or passive breaks. Hum. Factors **60**(6), 806–821 (2018). https://doi.org/10.1177/0018720818769261

Horn, G.P., Kesler, R.M., Motl, R.W., Hsiao-Wecksler, E.T., Klaren, R.E., Ensari, I., Petrucci, M.N., Fernhall, B., Rosengren, K.S.: Physiological responses to simulated firefighter exercise protocols in varying environments. Ergonomics **58**(6), 1012–1021 (2015). https://doi.org/10.1080/00140139.2014.997806

Kesler, R.M., Bradley, F.F., Deetjen, G.S., Angelini, M.J., Petrucci, M.N., Rosengren, K.S., Horn, G.P., Hsiao-Wecksler, E.T.: Impact of SCBA size and fatigue from different firefighting work cycles on firefighter gait. Ergonomics **61**(9), 1208–1215 (2018a). https://doi.org/10.1080/00140139.2018.1450999

Kesler, R.M., Ensari, I., Bollaert, R.E., Motl, R.W., Hsiao-Wecksler, E.T., Rosengren, K.S., Fernhall, B., Smith, D.L., Horn, G.P.: Physiological response to firefighting activities of various work cycles using extended duration and prototype SCBA. Ergonomics **61**(3), 390–403 (2018b). https://doi.org/10.1080/00140139.2017.1360519

Kim, S., Kim, D.H., Lee, H.H., Lee, J.Y.: Frequency of firefighters' heat-related illness and its association with removing personal protective equipment and working hours. Ind. Health **57**(3), 370–380 (2019). https://doi.org/10.2486/indhealth.2018-0063

Mantua, J., Skeiky, L., Prindle, N., Trach, S., Doty, T.J., Balkin, T.J., Brager, A.J., Capaldi, V.F., Simonelli, G.: Sleep extension reduces fatigue in healthy, normally-sleeping young adults. Sleep Sci. **12**(1), 21–27 (2019). https://doi.org/10.5935/1984-0063.20190056

McDonald, A.C., Tse, C.T.F., Keir, P.J.: Adaptations to isolated shoulder fatigue during simulated repetitive work. Part II: recovery. J. Electromyogr. Kinesiol. **29**, 42–49 (2016). https://doi.org/10.1016/j.jelekin.2015.05.005

McDonald, A.C., Mulla, D.M., Keir, P.J.: Using EMG amplitude and frequency to calculate a multimuscle fatigue score and evaluate global shoulder fatigue. Hum. Factors **61**(4), 526–536 (2019). https://doi.org/10.1177/0018720818794604

McGillis, Z., Dorman, S.C., Robertson, A., Larivière, M., Leduc, C., Eger, T., Oddson, B.E., Larivière, C.: Sleep quantity and quality of ontario wildland firefighters across a low-hazard fire season. J. Occup. Environ. Med. **59**(12), 1188–1196 (2017). https://doi.org/10.1097/JOM.0000000000001175

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., ... Tugwell, P.: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. **6**(7) (2009). https://doi.org/10.1371/journal.pmed.1000097

Pritchard, S.E., Tse, C.T.F., McDonald, A.C., Keir, P.J.: Postural and muscular adaptations to repetitive simulated work. Ergonomics **62**(9), 1214–1226 (2019). https://doi.org/10.1080/00140139.2019.1626491

Ream, E., Richardson, A.: Fatigue: a concept analysis. Int. J. Nurs. Stud. **33**(5), 519–529 (1996). https://doi.org/10.1016/0020-7489(96)00004-1

Reinberg, A.E., Smolensky, M.H., Riedel, M., Riedel, C., Brousse, E., Touitou, Y.: Do night and around-the-clock firefighters' shift schedules induce deviation in tau from 24 hours of systolic and diastolic blood pressure circadian rhythms? Chronobiol. Int. **34**(8), 1158–1174 (2017). https://doi.org/10.1080/07420528.2017.1343833

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., Altman, D.G., Booth, A., Chan, A.W., Chang, S., Clifford, T., Dickersin, K., Egger, M., Gøtzsche, P.C., Grimshaw, J.M., Groves, T., Helfand, M., Whitlock, E.: Preferred reporting items

for systematic review and meta-analysis protocols (prisma-p) 2015: elaboration and explanation. BMJ (Online) **349**(January), 1–25 (2015). https://doi.org/10.1136/bmj.g7647
Taylor, Y., Merat, N., Jamson, S.: The effects of fatigue on cognitive performance in police officers and staff during a forward rotating shift pattern. Saf. Health Work **10**(1), 67–74 (2019). https://doi.org/10.1016/j.shaw.2018.08.003
Thomas, M.J.W., Paterson, J.L., Jay, S.M., Matthews, R.W., Ferguson, S.A.: More than hours of work: fatigue management during high-intensity maritime operations. Chronobiol. Int. **36**(1), 143–149 (2019). https://doi.org/10.1080/07420528.2018.1519571
Tse, C.T.F., McDonald, A.C., Keir, P.J.: Adaptations to isolated shoulder fatigue during simulated repetitive work. Part I: fatigue. J. Electromyogr. Kinesiol. **29**, 34–41 (2016). https://doi.org/10.1016/j.jelekin.2015.07.003
Vincent, G.E., Aisbett, B., Hall, S.J., Ferguson, S.A.: Fighting fire and fatigue: sleep quantity and quality during multi-day wildfire suppression. Ergonomics **59**(7), 932–940 (2016a). https://doi.org/10.1080/00140139.2015.1105389
Vincent, G.E., Aisbett, B., Hall, S.J., Ferguson, S.A.: Sleep quantity and quality is not compromised during planned burn shifts of less than 12 h. Chronobiol. Int. **33**(6), 657–666 (2016b). https://doi.org/10.3109/07420528.2016.1167734
Walker, A., Keene, T., Argus, C., Driller, M., Guy, J.H., Rattray, B.: Immune and inflammatory responses of Australian firefighters after repeated exposures to the heat. Ergonomics **58**(12), 2032–2039 (2015). https://doi.org/10.1080/00140139.2015.1051596

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Assessment of Fatigue Based on Workload and Rest Activity Cycles—A Pilot Study

E. A. Stradioto Neto, D. Bustos, and J. C. Guedes

Abstract Fatigue is defined as an unpleasant symptom surrounded by sensations that vary from tiredness to exhaustion. There are several careers that demand much effort from their workers, inducing fatigue and affecting their health and performance. The goal of this paper is to establish a series of alerts to anticipate the level of fatigue an individual exposed to emergency situations may experience. In order to do this, it is intended to make use of non-invasive analysis techniques to monitor physiological parameters (heart rate and internal body temperature). The data used for this work were collected in a laboratory environment from 6 individuals with an average age of 22.67 years. Their physiological responses were analysed and classified using a set of programs created with Visual Basic for Applications software. The obtained data were compared to a fatigue alert system, and results evidenced the internal body temperature as the most consistent parameter. Heart rate and internal body temperature are compatible variables for creating systems capable of indicating and anticipating the conditions resulting from intense physical efforts, which could later lead to fatigue states. The analysis of additional non-invasive parameters is an alternative for refining the system contributing to fatigue prevention and management.

Keywords Fatigue assessment · Alert-based system · Heart rate · Internal temperature

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1 Introduction

Over the years, technology has been developing more and more in order to facilitate much of the work done by man. However, there are still a number of activities that promote fatigue in humans. Fatigue and sleepiness in modern society are personal and occupational risk factors (Caldwell et al. 2019). According to Brown (1994), fatigue can be associated with factors such as inadequate sleep, circadian disorder and excessive task times. Even though there is still no universal definition of fatigue (Trendall 2000), several works try to search for alternatives for the definition of this condition. Olson (2007) presents a historical context and shows how fatigue is associated with conditions such as sleep quality, stamina, cognition, emotional reactions, body processes, and social interactions.

Among workers, there are a number of services and activities that require a high load of effort from them to be carried out. Many of these activities are performed by professionals such as police officers, firefighters, paramedics, military, among others, whose occupation is often directly linked to the lives of other citizens. The work of these professionals is fundamental for the maintenance of society, making it necessary to understand the afflictions or diseases associated with their activities (Han et al. 2018).

Fatigue can manifest itself in various forms. Specifically referring to muscle fatigue, Romer and Polkey (2008) indicate that it can be associated with oxygen levels present in an organism. The change in respiratory mechanics influences the entry of oxygen in the body and, consequently, in the experienced fatigue.

Furthermore, fatigue has a measurable relationship with cardiac functioning (Nelesen et al. 2008). Although heart rate is a parameter widely used to assess health-related issues, authors (Kesler et al. 2018 and Nelesen et al. 2008) also highlight the challenge of relying only on this physiological measure to indicate fatigue, as this indicator varies greatly compared to other variables associated with this condition.

On the other hand, internal body temperature has also been evidenced as an indicator of fatigue-related effects such as heat strain and physical exhaustion. In addition, authors (Castellani et al. 2006) also highlight the importance of analysing this parameter in relation to the energy expenditure.

As a result, understanding the importance of these two physiological variables (heart rate and internal body temperature), the objective of this work is, through non-invasive methods of analysis, to assess the conditions to which individuals may be subject during their working period through a fatigue alert-based system. Based on the expected results, it is intended to establish the level of fatigue an individual is exposed to during his regular working activities and evaluate if he is in good general health conditions to continue with such activities. Within this work, the proposed system is presented and validated with data from maximal exertion tests.

2 Materials and Methods

The data used for developing the system were collected from six physical tests performed in laboratory-controlled conditions between January 2014 and June 2015. Before the tests, all the individuals analysed gave their written consent to use their data and permission to use the results from tests performed. They were also informed of the risks and benefits of the experiences and expected results.

Physiological responses were gathered from two different laboratory experimental protocols. Four participants performed a short maximal physical exertion test on a treadmill (approximate completion duration: 10–15 min). Furthermore, in order to test the system within more extended periods, two other participants developing another physical test (completion time: 30–40 min) in the same controlled laboratory conditions were assessed. The average age of participants was 22.67 years (±1.21 years; age range 21–24 years). According to the records, all individuals presented good physical and mental conditions for accomplishing the tests, showing no signs of cardiorespiratory or allergic diseases, and did not take medications to treat any chronic or high-risk illnesses.

Obtained physiological recordings were processed and assessed with a set of alarms generated from formulas created through the software Visual Basic for Applications (VBA), in parallel with Excel software.

2.1 Equipment

To obtain the data in the laboratory, two measuring equipment were used: the Equivital TM EQ02 LifeMonitor, an integrated physiological monitor, and the Cosmed K4b2 device, for data collection linked to the individuals' oxygen consumption during the tests.

According to the instruction manual of the EquivitalTM EQ02 LifeMonitor device, the system provides the following parameters: heart rate, respiratory rate, skin temperature, body position of the individual, ambulation status, expansion chest temperature, internal body temperature, an indicator of physiological well-being and generation of an electrocardiogram (ECG). For measuring internal body temperature, an associated ingestible thermometer pill can be used along with the Equivital system. In the present study, we opted to use two of these parameters to assess the individual's status: heart rate (HR) and internal body temperature (from the ingestible pill).

2.2 Examined Physiological Variables

2.3 Heart Rate

Heart rate is a variable that is constantly evaluated to indicate several health conditions among the military while performing their regular physical tests (Gómez-Oliva et al. 2019; Lieberman et al. 2016). The increase in heart rate may be associated with factors such as the presence of epinephrine and norepinephrine in the bloodstream (Romero et al. 2008), which can be stimulated due to chronic, acute stress, high physical demands, and caloric deprivation associated with military practices (Lieberman et al. 2016). Increased heart rate is also present in activities such as walking and in pre-exercise carried out by the military (O'Leary et al. 2018).

These heart rate increases are important to identify the stressful and physically demanding conditions soldiers are exposed. However, decreases in values are also fundamental to determine if there was a recovery from those extreme conditions or identify potential health risk indicators when these decreases are not reached. Therefore, a continuous tracking of this variable is essential for a complete overview of the impact of highly demanding activities among the military. The developed system included this variable and based its analysis on the scale proposed by D'Artibale et al. (2008).

2.4 Internal Body Temperature

Along with cardiac responses, literature has also evidenced the importance of core temperature to determine the effects of stressful situations on the individual (Buller et al. 2017; Friedl 2018). For this parameter, the choice of the limit values was made through the standard (ISO 9886 International Standard 1987). According to these normative guidelines, the value for the internal temperature of the human body must not exceed 38 ºC or have a variation of 1 ºC in a period equal to or less than one hour.

The same guidelines (ISO 9886 International Standard 1987) also indicate that when heart rate and internal temperature are continuously monitored, the limit values can be modified to 38.5 ºC or a difference of 1.4 ºC. Therefore, considering the multivariable recordings obtained from the laboratory experiences, these last criteria were used as limit values for the system.

2.5 The Minute by Minute Alarm System

In the first moment, a system was conceived capable of determining the level of exertion under which the studied individual would be according to the heart rate evaluated during testing. To determine the maximum heart rate (HRmax), the Kar-

Table 1 HR alert levels

HR alert level	Percentage multiplied by HRmax (bpm)
Level 0	< (220 – age) * 0.6
Level 1	>= (220 – age) * 0.6
Level 2	>= (220 – age) * 0.7
Level 3	>= (220 – age) * 0.8
Level 4	>= (220 – age) * 0.9
Level 5	>= (220 – age)

vonen formula was used: HRmax = (220 − age) (D'Artibale et al. 2008; Justine et al. 2018; Senthilvel et al. 1987; Kim et al. 2020).

Subsequently, based on the study by D'Artibale et al. (2008), the limit value for categories according to the percentage of effort in relation to the HRmax was determined, having a difference of 10% between each level. The different levels and established criteria can be observed in Table 1.

So that the data could be appropriately catalogued, it was decided to develop a program able to automatically perform the heart rate classification according to the levels from Table 1. For this purpose, the Visual Basic for Applications (VBA) software was used.

The program generated, in addition to classifying the heart rate levels according to the percentage of HRmax, also indicates if there is an increase or decrease in the frequency from the Level 1 alert. This process is performed by comparing the value of the cardiac response of the minute under analysis with the value from the previous minute.

For the internal body temperature, the system also includes the generation of alerts according to a total of 6 categories. The starting value for the level 1 alert was set at 37.3 ºC, and the limit value for the last alert (level 5) was determined for values equal to or greater than 38.5 ºC, with a variation of 0.3 ºC between each new category.

2.6 Applied Improvements

After analysing the heart rate and internal body temperature recordings and the obtained alerts, it was noted that, in addition to the number of alerts generated at a given level, it would be more useful if the system could also monitor and indicate the increasing trend of the values. For this, it was decided to build an equation capable of examining the value measured by the sensor in the previous minute and compare it with the value obtained in the minute under analysis. This alternative consisted of ascertaining the percentage of increase between one minute and the other according to the limit established between one class and another (10% in relation to HRmax out 0, 3 ºC for the temperature).

As a result, the level of alert is increased by the percentage by which the physiological variable increased. It is noteworthy that the system was programmed to ascertain and multiply this percentage only when the data under analysis were under the same classification level and only from level 1 alerts.

After the temperature intervals were established for each level, the program performed the same procedure applied to heart rate, that is, the alert levels were classified according to the temperature value and also indicated the increase and decrease of the parameter evaluated minute by minute.

3 Results and Discussion

The developed system was able to independently analyse heart rate and internal body temperature and obtained accurate results regarding the level of physical exertion and fatigue experienced by participants. Literature has previously reported the relevance of evaluating these variables responses among the military and similar systems to the one proposed have also been presented (Buller et al. 2017; Friedl 2018; Lieberman et al. 2005, 2016). In this work, the minute-by-minute analysis was evidenced as a simple approach to determine the level of alert at a time interval, while the progressive trend examination showed how the evaluated parameter could increase within the same alert level and helped to anticipate the higher levels.

Figures 1, 2, 3 and 4 show the results from the first short protocol, in which individuals reached a maximal exertion within 10–15 min. As it can be observed, there were corresponding variations of alarms for all individuals according to the

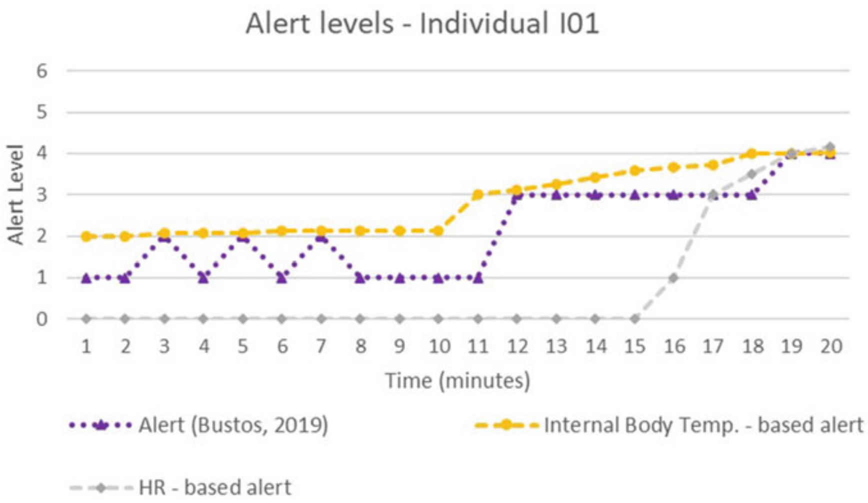

Fig. 1 Alert levels from individual I01

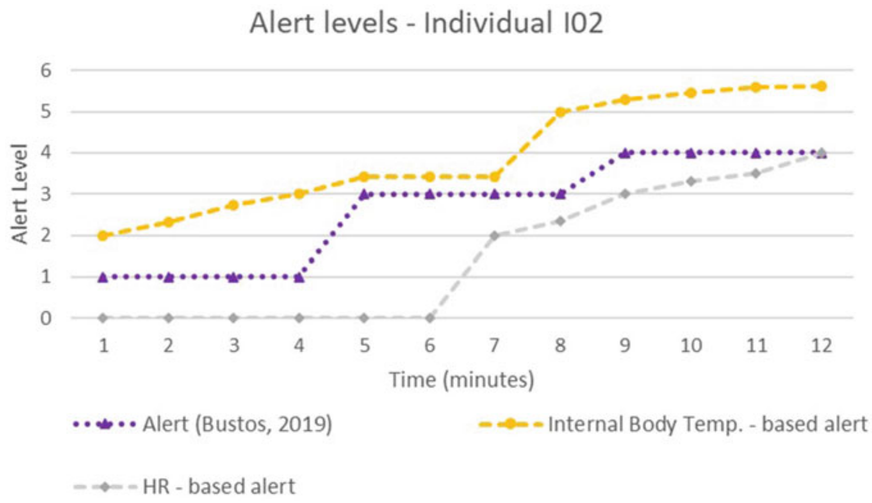

Fig. 2 Alert levels from individual I01

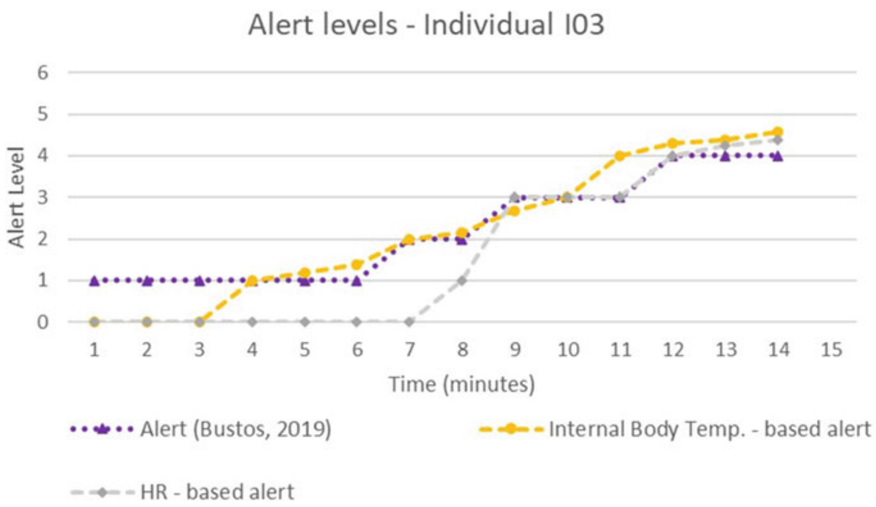

Fig. 3 Alert levels from individual I03

progress of the activities performed during the maximal exertion test. There was an increase in values for cardiac frequency and internal body temperature throughout the tests, and alarms were able to reflect these increases.

Summary of the number of publications coded in each category. Furthermore, in order to validate the accuracy of the system created, results were also compared with the work performed by Bustos et al. (2019) since it has similarities in the objectives and evaluated parameters. The results from that system can also be observed

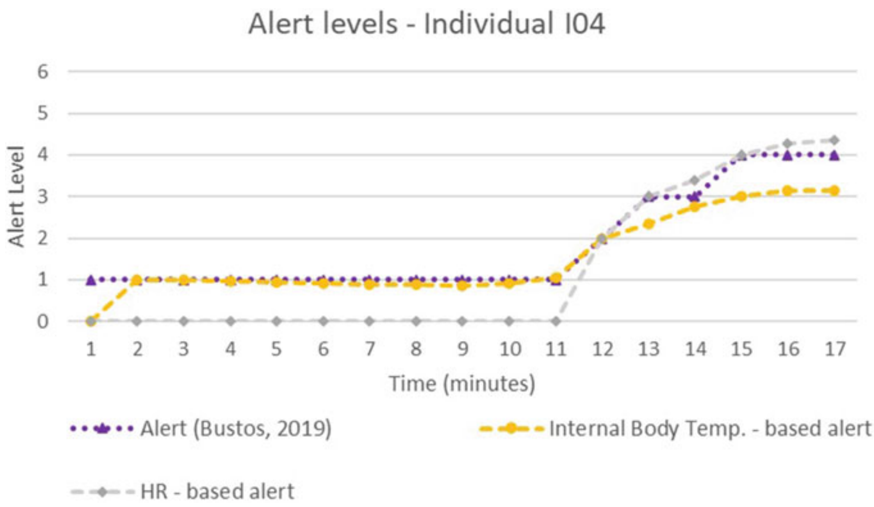

Fig. 4 Alert levels from individual I04

in the figures. Part of the study carried out by Bustos et al. (2019) had as one of its objectives, to develop a method for assessing the state of fatigue based on the physiological monitoring of individuals using parameters such as heart rate, respiratory rate, internal body temperature and movement of individuals to create a fatigue alert.

The system (Bustos et al. 2019) divides the status of its analysed individuals into 10 different categories, of which five were extremely important for the present study: alarms 1, 2, 3, 4 and 5. As indicated by the author, alerts 2–5 indicate different fatigue categories, with level 2 being considered low-intensity fatigue, presenting no risks to the health of the individual, and levels 3 (moderate intensity), 4 (high intensity) and 5 (maximum effort), which preceded a state of compromised health.

The objective of comparing both systems is to verify if the alerts generated through the analysis of heart rate and internal body temperature can anticipate fatigue status alarms generated by Bustos et al. (2019). The data used for the present study were consented by Bustos et al. (2019), since 5 of the 6 individuals (I02 to I06) were also analysed in their work. In contact with the author, the request was made so that their system was applied to individual I01, thus making it possible to compare results from the six participants.

Concerning the results from the two subjects performing the second physical test, Figs. 5 and 6 illustrate the outcomes and respective comparisons with the other system. Since our final aim is to be able to apply this system in occupational settings, the evaluation of both protocols was important to test the system's sensitivity within different scenarios. Future research will include the evaluation of longer in-field military practices.

Analysing the generated graphics, it is possible to perceive the sensitivity of the alerts under each parameter. The internal body temperature was determined as the

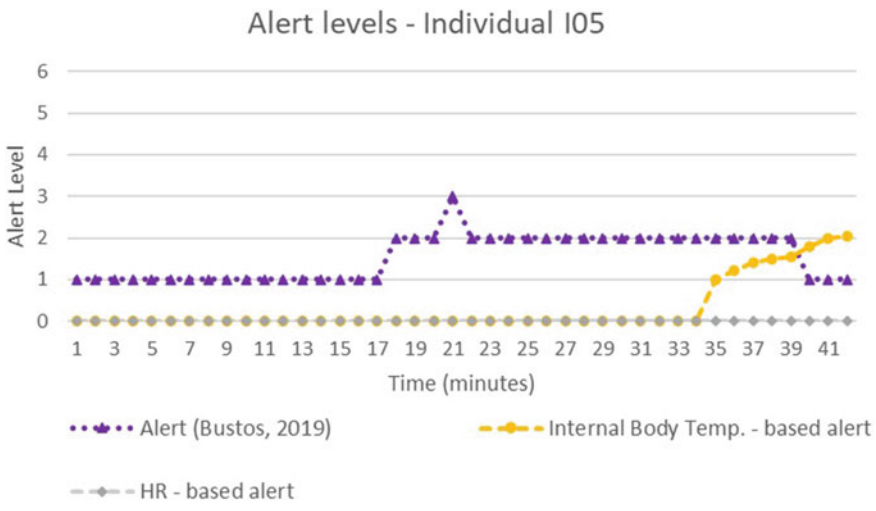

Fig. 5 Alert levels from individual I05

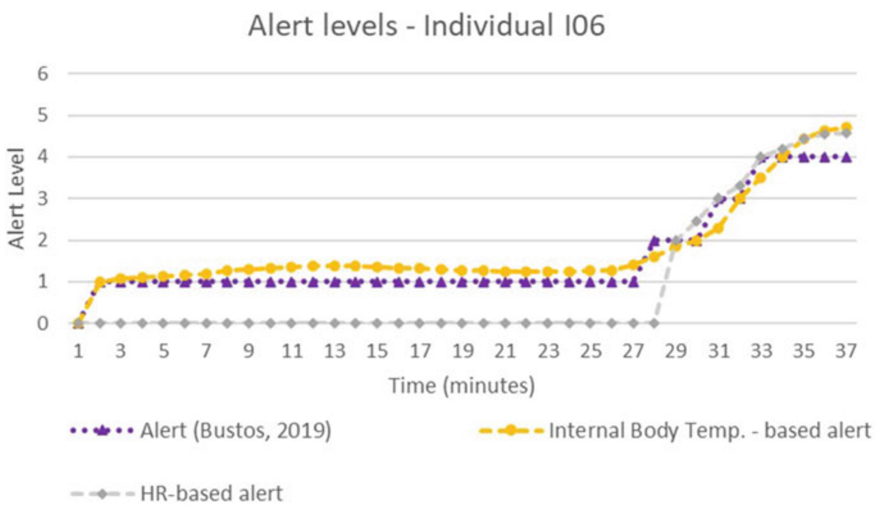

Fig. 6 Alert levels from individual I06

most sensitive parameter. In fact, the relation between this parameter and fatigue condition has previously been reported by several authors (Anwer et al. 2021; Frone and Blais 2019; Techera et al. 2018 and González-Alonso et al. 1999). Figure 1 from individual I01 showed that a small variation within level 2 caused that the alert generated by Bustos et al. (2019), varied between levels 1 and 2 during the first 8 min of the test. Subsequently, it is also possible to note that the developed system anticipated the rise to level 3 of the alert proposed by Bustos et al. (2019) in the 11th minute.

Similar results could be observed from the test performed by individual I02, in which the alert for internal body temperature anticipated the level 3 alert in the fifth minute of the test. It is also possible to notice that in the figures from individuals I06, I03 and I04, the variation between the three alerts is quite similar, indicating a good correlation between both systems.

On the other hand, Fig. 5, which shows the results from individual 5, is the only one where alerts from heart rate were not high enough to activate the level 01 alarm. This outcome may be associated with the type of test performed, in this case, with a lower effort generated in a longer time interval.

Respectively, it was evidenced that the system created for heart rate generally indicates level 0 most of the time, increasing the level only in half or in the last quarter of each test. On the other hand, this last rise may also anticipate and indicate an increase in the alerts from Bustos et al. (2019). We can observe such occurrences during the tests performed by individuals I01, I02 and I03.

In summary, results revealed that Bustos et al. (2019) alerts indicate an individual's current fatigue stage, but our generated system can also show the state before severe fatigue conditions through the two parameters studied. This represents important improvements for alert-based systems able to monitor individuals during a working day, and could lead to the identification of the ideal periods for work-rest cycles.

3.1 Limitations

Throughout the development of this work, some limitations were encountered. First, due to the small sample of participants, it was not possible to obtain generalisable results. As a result, data were individually analysed, and future studies are needed to establish fatigue in the individuals' physiological state accurately. Furthermore, as the study was conducted in a laboratory environment, the system's applicability in a real occupational context could not be tested.

4 Conclusions

This study showed that heart rate and internal body temperature are compatible parameters for creating systems capable of indicating and anticipating the conditions resulting from intense physical activities that could later lead to states of fatigue in individuals. Internal body temperature stood out as a parameter of greater reliability for the present study since the obtained results were found more consistent and allowed to anticipate higher alerts. The evaluation of parameters on an individual basis proved to be effective in predicting the fatigue state proposed by the study of

Bustos et al. (2019), however, the levels and their limit values can be adjusted to present a greater sensitivity and accuracy for determining the alerts.

Finally, the analysis of additional non-invasive variables such as respiratory rate, analysis of body movement, and actigraphs to monitor the activity and rest cycles of individuals are alternatives for future research perspectives to refine the system contributing to fatigue prevention.

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References

Anwer, S., Li, H., Antwi-Afari, M.F., Umer, W., Wong, A.Y.L.: Evaluation of physiological metrics as real-time measurement of physical fatigue in construction workers: state-of-the-art review [Review]. J. Constr. Eng. Manag. **147**(5) (2021). Article 03121001. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002038

Brown, I.D.: Driver fatigue. Hum. Factors.**36**(2), 298–314 (1994). https:/doi.org/10.1177/001872089403600210

Buller, M.J., Welles, A.P., Friedl, K.E.: Wearable physiological monitoring for human thermal-work strain optimisation. J. Appl. Physiol. **124**(2), 432–441 (2017)

Bustos D., Guedes J.C., Alvares M., Baptista J.S., Vaz M., T.C.J.C.: Real time fatigue assessment: identification and continuous tracing of fatigue using a physiological assessment algorithm. Occupational and Environmental Safety and Health. Studies in Systems, Decision and Control, vol. 202 (2019). https://doi.org/10.1007/978-3-030-14730-3_28

Caldwell, J.A., Caldwell, J.L., Thompson, L.A., Lieberman, H.R.: Fatigue and its management in the workplace. Neurosci. Biobehav. Rev. **96**, 272–289 (2019). https://doi.org/10.1016/j.neubiorev.2018.10.024

Castellani, J.W., Delany, J.P., O'Brien, C., Hoyt, R.W., Santee, W.R., Young, A.J.: Energy expenditure in men and women during 54 h of exercise and caloric deprivation. Med. Sci. Sports Exercise **38**(5), 894–900 (2006). https://doi.org/10.1249/01.mss.0000218122.59968.eb

D'Artibale, E., Tessitore, A., Capranica, L.: Heart rate and blood lactate concentration of male road-race motorcyclists. J. Sports Sci. **26**(7), 683–689 (2008). https://doi.org/10.1080/02640410701790779

Friedl, K.E.: Military applications of soldier physiological monitoring. J. Sci. Med. Sport (2018)

Frone, M.R., Blais, A.-R.: Work fatigue in a non-deployed military setting: assessment, prevalence, predictors, and outcomes. Int. J. Env. Res. Public Health **16**(16) (2019). https://doi.org/10.3390/ijerph16162892

Gómez-Oliva, E., Robles-Pérez, J.J., Ruiz-Barquín, R., Hidalgo-Bellota, F., de la Vega, R.: Psychophysiological response to the use of nuclear, biological and chemical equipment with military tasks. Physiol. Behav. **204**(March), 186–190 (2019). https://doi.org/10.1016/j.physbeh.2019.02.019

González-Alonso, J., Teller, C., Andersen, S.L., Jensen, F.B., Hyldig, T., Nielsen, B.: Influence of body temperature on the development of fatigue during prolonged exercise in the heat. J. Appl. Physiol. **86**(3), 1032–1039 (1999). https://doi.org/10.1152/jappl.1999.86.3.1032

Han, M., Park, S., Park, J.H., Hwang, S.S., Kim, I.: Do police officers and firefighters have a higher risk of disease than other public officers? A 13-year nationwide cohort study in South Korea. BMJ Open **8**(1), 1–7 (2018). https://doi.org/10.1136/bmjopen-2017-019987

ISO 9886 International Standard: International Standard - Evaluation of thermal strain by physiological measurements (1987)

Justine, M., Ishak, A., Manaf, H.: Effects of sub-maximal exercise on energy expenditure and heart rate recovery in individuals with normal weight, overweight and obesity. J. Phys. Educ. Sport **18**(3), 1632–1639 (2018). https://doi.org/10.7752/jpes.2018.03239

Kesler, R.M., Ensari, I., Bollaert, R.E., Motl, R.W., Hsiao-Wecksler, E.T., Rosengren, K.S., Fernhall, B., Smith, D.L., Horn, G.P.: Physiological response to firefighting activities of various work cycles using extended duration and prototype SCBA. Ergonomics **61**(3), 390–403 (2018). https://doi.org/10.1080/00140139.2017.1360519

Kim, K.H., Jang, Y.C., Song, M.K., Park, H.K., Choi, I.S., Han, J.Y.: Changes in aerobic capacity over time in elderly patients with acute myocardial infarction during cardiac rehabilitation. Ann. Rehabil. Med. **44**(1), 77–84 (2020). https://doi.org/10.5535/arm.2020.44.1.77

Lieberman, H.R., Bathalon, G.P., Falco, C.M., Kramer, F.M., Morgan, C.A., III., Niro, P.: Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. Biolog. Psychiatry **57**(4), 422–429 (2005)

Lieberman, H.R., Farina, E.K., Caldwell, J., Williams, K.W., Thompson, L.A., Niro, P.J., Grohmann, K.A., McClung, J.P.: Cognitive function, stress hormones, heart rate and nutritional status during simulated captivity in military survival training. Physiol. Behav. **165**, 86–97 (2016). https://doi.org/10.1016/j.physbeh.2016.06.037

Nelesen, R., Dar, Y., Thomas, K., Dimsdale, J.E.: The relationship between fatigue and cardiac functioning. Arch. Intern. Med. **168**(9), 943–949 (2008). https://doi.org/10.1001/archinte.168.9.943

O'Leary, T.J., Saunders, S.C., McGuire, S.J., Izard, R.M.: Sex differences in neuromuscular fatigability in response to load carriage in the field in British Army recruits. J. Sci. Med. Sport **21**(6), 591–595 (2018). https://doi.org/10.1016/j.jsams.2017.10.018

Olson, K.: A new way of thinking about fatigue: a reconceptualisation. Oncol. Nurs. Forum **34**(1), 93–99 (2007). https://doi.org/10.1188/07.ONF.93-99

Romer, L.M., Polkey, M.I.: Exercise-induced respiratory muscle fatigue: implications for performance. J. Appl. Physiol. **104**(3), 879–888 (2008). https://doi.org/10.1152/japplphysiol.01157.2007

Romero, M.L., Butler, L.K.: Int. J. Comp. Psychol. **20**(2), 0–13 (1987). https://escholarship.org/uc/item/87d2k2xz

Senthilvel, S., Vasudevan, S., Anju, P.S., Sukumaran, A., Sureshbabu, J.: Assessment of symptoms and quality of life among postmenopausal women in a tertiary care hospital in Kochi, South India: a hospital-based descriptive study. J. Mid-Life Health **9**(4), 185–190 (2018). https://doi.org/10.4103/jmh.JMH_98_18

Techera, U., Hallowell, M., Stambaugh, N., Littlejohn, R.: Causes and consequences of occupational fatigue: meta-analysis and syste ms model. J. Occup. Envir. Med. **58**(10) (2016). https://journals.lww.com/joem/Fulltext/2016/10000/Causes_and_Consequences_of_Occupational_Fatigue_.1.aspx

Trendall, J.: Concept analysis: Chronic fatigue. J. Adv. Nurs. **32**(5), 1126–1131 (2000). https://doi.org/10.1046/j.1365-2648.2000.01583.x

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Energy, Thermal Comfort and Pathologies—A Current Concern

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Abstract Objective: In view of the flow rate established by law of 10 renewals per hour to protect spilled particles, conclude if these are removed from the domain and the thermal comfort is maintained in the room. Background: Currently, any building or project needs to meet standards of comfort and energy efficiency for certification. It is important to study comfort, but also to study the extraction of particles expelled during a sneeze phenomenon. Particles are studied with particular importance due to the panorama that we experience today with the pandemic situation. The Sars-Cov-2 virus is still a subject of study in several areas, especially due to its easy form of contagion. The study of the behavior of water particles expelled through the mouth facilitates the perception of risk, as well as preventive measures to be adopted. Method: For the study, numerical simulation was used, namely the Ansys® program. For this, a mannequin was modeled inside a 15 m^2 room, whose HVAC system incorporates an insufflation grid and an extraction grid. The mannequin has an associated respiratory cycle and during the same period it suffers a sneeze period expelling water particles. Results: Due to the obtained PMV, the thermal comfort of the occupant cannot be ensured, having to adopt a greater diffusion of the inflated air. The behavior of the particles expelled during a sneeze is predicted.

Keywords Numerical simulation · Thermal comfort · Particle tracking · Internal environment

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1 Introduction

In any new building an energy certification is required, which incorporates an HVAC system to ensure thermal comfort as well as pollutant extraction. A hypothetical hospital waiting room was chosen as the object of study, since it is the object of entry and exit of users who may or may not have COVID-19. With the pandemic situation, thermal comfort can be compromised in the elimination of pollutants by new air insufflation techniques. The study about the flow rate of fresh air to be blown is essential to the good combination of comfort and efficiency of pollutant removal. According to the ordinance 353-A/2013 of the Portuguese legislation, in a normal situation, the fresh air flow rate is determined by occupancy and the type of existing pollutant, and the higher of the two is chosen for application.

However, with the emergence of the Sars-Cov-2 virus, the General health Directorate stipulated a minimum fixed value of 10 ren/h (DGS—Direção Geral da Saúde 2020) of newly insufflated air, and the study was based on this value. The study of thermal comfort and its importance has long been the subject of study by several authors in various applications, such as buildings (Gonçalves et al. 2013), schools (Dias Pereira et al. 2014) and, obviously, hospitals (Rodrigues et al. 2015). In fact, thermal comfort is a subjective term defined by a plurality of sensations, so it is difficult to give a universal definition of this concept (Zhang et al. 2017). However, it is possible through numerical methods to estimate thermal comfort taking into account the environmental conditions of the space and personal variables (Teodosiu et al. 2003), using the determination of PMV (Predicted Mean Vote), as it is a well validated, simple and comprehensive method (Standardization and Normalisation 1987). The PMV provides information about thermal discomfort or thermal dissatisfaction by predicting the percentage of people who are likely to feel too hot or too cold in a given environment, using a comfort index ranging from −3 (cold) to +3 (hot) according to ISO 7730 (Standardization and Normalisation 1987). Thus, this study aims to simulate the thermal comfort of an occupant inside a waiting room and at the same time analyze the flow rate of 10 ren/h in the context of efficacy in removing pollutants and particles, while safeguarding the comfort of the user.

2 Materials and Methods

2.1 Geometry and Mesh

With the impossibility of studying a real waiting room in an hospital regarding the current pandemic, the present study was accomplished through numerical simulation using Ansys Fluent®. The model represents a 15 m^2 room with a height of 3 m. For simplification, a 2D model was created with 5 m long and 3 m height. Dimensions within the specifications of ET 6/2008. The positioning of inlets and outlets followed the recommendations of ASHRAE 2009, with the inlet as close to the ceiling as

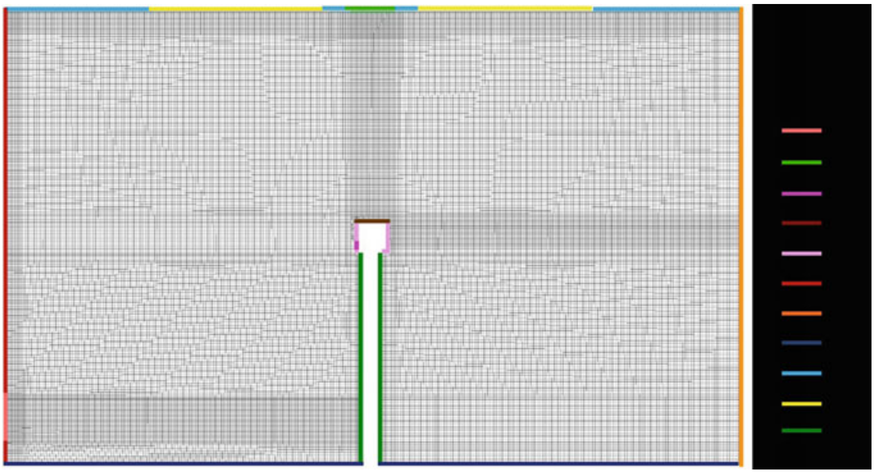

Fig. 1 Mesh generated using the division of geometry and its color legend

possible and outlet neat the floor. Figure 1 shows the created geometry with the mesh for CFD modelling. The mesh has an average orthogonal quality of 0.999 and a minimum value of 0.976, where 1 is an excellent quality. At the right side of Fig. 1 it is also represented the different regions defined for the simulation with a colour scheme. The inlet has 0.3 m length, the lamps have 1.2 m length. Within the room, a simplified human model was also created. This model exchanges heat and is a water vapour and particles source with a mouth of 0.05 m height (Abrishami et al. 2014).

2.2 CFD Model

The CFD simulation was elaborated using FLUENT 2020 R2, from ANSYS®. In addition to the mass and momentum balance, the simulation includes a turbulence model, the energy equation which accounts for thermal exchanges between boundaries and fluid, the radiation model, the species model to follow evaporating species and a discrete phase model (DPM) for particle tracking. For viscosity, the SST k-ω was selected since it allows to account for transition flows with both laminar and turbulent regions (Manual 2000). The radiant heat was accounted with the Surface-to-Surface model (S2S) which accounts for the radiant heat exchange between surfaces in a field of view.

2.3 Boundary Conditions

Defining the numerical model passed through the limitation of the possible solution by providing details in the form of boundary conditions.

The definition of materials is essential to accurately represent their behaviour. This influences the flow in the case of fluid materials and the thermal behaviour for solid materials. The fluid, air, was defined as a mixture of N_2, O_2 and H_2O, according to Berkson 1962; Wolkoff 2018. The solid materials used were skin (Sanchez-Marin et al. 2009), concrete for the walls, glass for the lamps and cotton for clothing.

The particles coming from the mouth have a distribution of diameters that can be represented by a Rosin-Rammler distribution with a minimum diameter of $4.00e^{-5}$ m, a maximum diameter of $9.80e^{-4}$ m and an average diameter of $3.80e^{-4}$ m for a total mass flow of $1.50e^{-6}$ kg/s.

Additionally to the diameter distribution, the particles were also expelled at 37 °C and with a normal velocity of 1,68 m/s (Tang et al. 2013). For a better approximation of the real problem, this velocity was separated into vectorial components of 1 m/s in the X direction and −0.68 m/s in the Y direction. This division allowed to account for the natural tendency of lowering the head during a sneeze. The breathing cycle was defined as a sinusoidal wave for the air velocity, at 37 °C and saturated air. Within this cycle, the sneeze occurred from 2 s to 2.2 s with a peak velocity of 15 m/s that accelerated the particles (Phuong et al. 2016).

The air inlet at the top had a normal velocity of 2.778 m/s and the X component was double in value compared to the Y component. This allowed to simulate the air dispersion provided by the input grill. The air also entered the domain at a temperature of 22 °C and with a relative humidity of 50%. The human body model had a constant temperature of 32 °C, considered at the clothing layer, with an emissivity of 0.77. The lamps were defined with a heat flux of $32\,W/m^2$ and the emissivity of 0.95. Regarding the enclosing walls, the floor has a heat transfer coefficient of $0.4\,W/m^2K$ (Ministério do Trabalho 2016), an emissivity of 0.93 and an external temperature of 15.9 °C (Craveiro et al. 2011). The left wall, was considered as an external wall with a heat transfer coefficient of $0.5\,W/m^2K$ (Ministério do Trabalho 2016), an emissivity of 0.9 and an external temperature of 28 °C (Nuclear-power.net 2021). The remaining walls were interior walls and were considered adiabatic.

3 Results and Discussion

For an operational flow rate of 10 ren/h, that is, a normal velocity of 2.778 m/s, at an insufflation temperature of 22 °C, the average velocity felt by the occupant is 0.234 m/s. From the literature it is recognized that the terminal velocity value of the jet should be less than 0.25 m/s (Campos 2017), which is being met. As for the average temperature that is felt is 24.28 °C. The value obtained is within the comfort temperature range for summer of the standard ISO 7730 (Sensirion Inc. 2019). As

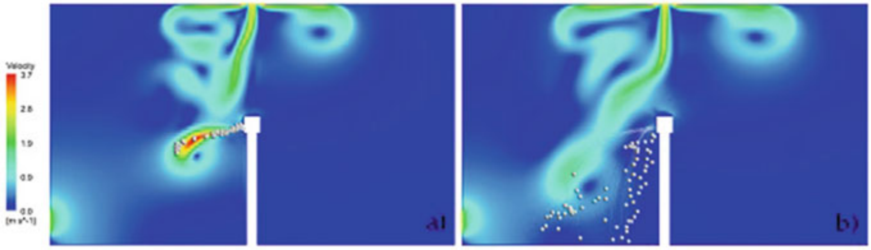

Fig. 2 Particle tracking after a sneeze (**a**) and particle tracking one second after a sneeze (**b**)

for the particles expelled during sneezing—Fig. 2a, they assume 3 types of behavior: they evaporate, get trapped, or escape. Those that evaporate remain suspended in the air, which can be dangerous if the virus is able to survive in the air individually, that is, with water enveloping it. The DGS supports this phenomenon (DGS—Direção Geral da Saúde 2020). The results show that the great tendency of the particles, 67.4%, is to fall on the floor—Fig. 2b, showing that the blown air helps the phenomenon. On the other hand, 23.9% of the particles tend to evaporate, and only a minor part, 8.7%, tends to get stuck to the body, mouth, or get out through the extraction (0.001667%). Here, the solution could be the incorporation of more extraction grids and by placing air purifiers. It is important to note that the discharge of contaminated air should be done outside the building and away from the building and adjacent buildings) (DGS—Direção Geral da Saúde 2020). The maintenance and cleaning of the equipment and its accessories must be properly sanitized because some particles may precipitate on horizontal surfaces (DGS—Direção Geral da Saúde 2020). It is important to refere that it is a 2D study, limiting the dispersion of particles and the air flow in one plan.

Finally, using the Python post-processing routine to calculate the PMV value for each node in the mesh (Rodrigues et al. 2015), (Fig. 3), it was found that the average PMV value in the domain around the user is −1.29795. It was considered for simulation purposes a typical summer insulation, 0.57 Clo (Comiran et al. 2020), a sedentary metabolism of 1 MET (Standardization and Normalisation 1987) and, because it is an indoor environment, it was assumed that there were no significant radiant sources. Thus, if the value obtained is −1.29795, the occupant feels cold (Standardization and Normalisation 1987). To reduce this effect the diffusion process can be improved, that is, the length associated with the vertical velocity can be increased so that the jet is less incident. The room was arbitrated, however, if the ceiling height is higher than the case, 3 m high, the occupant may not be in a situation of discomfort.

On the other hand, the body geometry is approximated and could be improved. For future works, the human model can also be divided into segments and its thermal response also modeled (Teixeira et al. 2010).

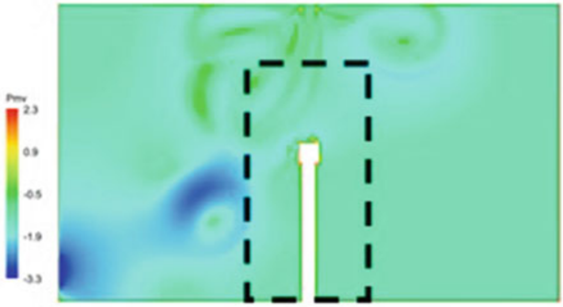

Fig. 3 Analysis domain (dashed) for the determination of the PMV

4 Conclusions

The main objective of the present work was the evaluation of the thermal comfort of an occupant inside a room through the analysis of temperature, speed and average turbulence. On the other hand, nowdays as the Sars-Cov-2 virus is a concern, this study could help to define measures and guidelines that help combat contagion. Following the guidance given by the Directorate-General for Health, the recommended flow rate in the form of normal operating speed was incorporated into the insufflation grid, as well as, the study of particles, since the risk of contagion is associated with contact with the water droplets that encapsulate the virus and make it so easily transmissible. The study allowed not only to predict that the occupant is uncomfortable with the high flow of inflated air, but also the behavior adopted by the water particles that in case of infection, are the means of viral transmission. Thus, using this study and the variables studied, it is possible to predict how comfortable the occupant is, as well as how safe he is. The study can be applied to other rooms whose geometries and HVAC conditions are different from this one, as long as certain attentions and changes are duly taken.

References

Abrishami, M., Shahri, N.M., Zadeh, J.K.: Photographic study of lip anthropometric pattern development in the fars family in mashhad. Anat. Sci. J. **11**(4), 175–182 (2014)

ASHRAE: ASHRAE Handbook of Fundamentals, vol. 30329, Issue 404 (2009)

Berkson, J.: The air we breathe. BMJ **1**(5275), 406–407 (1962). https://doi.org/10.1136/bmj.1.5275.406-c

Campos, V.: Difusão em Climatização - Máquinas Térmicas e de Fluídos (2017)

Comiran, S., Pizzutti, J., Mulazzani, R., Soares, D., Garlet, L., de Quadros, B.M., Mizgier, M.O., Arrefecimento, C.. De., Kim, S.H., Augenbroe, G., Ferreira, D.F., ET 6, 2008, Rotaru, A., Alzubaidi, S., Soori, P. K., Carvalhais, C., Santos, J., Lourenço, I., Teixeira, J. P., ... D.: Thermal comfort applied in hospital environments: A literature review. Journal of Light and Visual Environment **10**(1), 1–22 (2020). https://doi.org/10.1016/j.proeng.2017.09.968

Craveiro, A., Santos, P., Lopes, A.G.: Ventilação e Eficiência Energética em Edifícios Residenciais – Caso de Estudo (2011)
DGS - Direção Geral da Saúde.: Orientação 033/2020: Sistemas AVAC (Aquecimento, Ventilação e Ar Condicionado) nas Unidades de Prestação de Cuidados de Saúde. Direção Geral Da Saúde, pp. 1–7 (2020). https://covid19.min-saude.pt/wp-content/uploads/2020/06/i026411.pdf
Dias Pereira, L., Raimondo, D., Corgnati, S.P., Gameiro da Silva, M.: Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: methodology and results. Build. Environ. **81**, 69–80 (2014). https://doi.org/10.1016/j.buildenv.2014.06.008
Gonçalves, P., Gaspar, A.R., Da Silva, M.G.: Comparative energy and exergy performance of heating options in buildings under different climatic conditions. Energy Build. **61**, 288–297 (2013). https://doi.org/10.1016/j.enbuild.2013.02.023
Manual, A.: Ansys Inc. Canonsburg, PA, 15317(November), pp. 724–746 (2000). www.ansys.com
Ministério do Trabalho, S. e S. S. e E.: Portaria n.o 17-A/2016. Diário Da República n.o 24/2016, 1.a série(2), 378-(2) a 378 (56) (2016). https://data.dre.pt/eli/port/17-a/2016/02/04/p/dre/pt/html
Nuclear-power.net.: Emissivity of Materials | Definition & Examples | nuclear-power.net (2021). https://www.nuclear-power.net/nuclear-engineering/heat-transfer/radiation-heat-transfer/emissivity-emissivity-of-materials/
Phuong, N.L., Yamashita, M., Yoo, S.J., Ito, K.: Prediction of convective heat transfer coefficient of human upper and lower airway surfaces in steady and unsteady breathing conditions. Building and Environment, 100 (May 2019), pp. 172–185 (2016). https://doi.org/10.1016/j.buildenv.2016.02.020
Rodrigues, N.J.O., Oliveira, R.F., Teixeira, S.F.C.F., Miguel, A.S., Teixeira, J.C., Baptista, J.S.: Thermal comfort assessment of a surgical room through computational fluid dynamics using local PMV index. Work **51**(3), 445–456 (2015). https://doi.org/10.3233/WOR-141882
Sanchez-Marin, F.J., Calixto-Carrera, S., Villaseñor-Mora, C.: Novel approach to assess the emissivity of the human skin. (2009). https://doi.org/10.1117/1.3086612
Sensirion Inc.: Determining Thermal Comfort Using a Humidity and Temperature Sensor. AZoSensors., pp. 1–6 (2019). https://www.azosensors.com/article.aspx?ArticleID=487
Standardization, F.O.R., Normalisation, D.E.: International Standard Iso. 1987 (1987)
Tang, J.W., Nicolle, A.D., Klettner, C.A., Pantelic, J., Wang, L., Suhaimi, A. Bin., Tan, A.Y.L., Ong, G.W.X., Su, R., Sekhar, C., Cheong, D.D.W., Tham, K.W.: Airflow dynamics of human jets: sneezing and breathing - potential sources of infectious aerosols. PLoS ONE **8**(4), 1–7 (2013). https://doi.org/10.1371/journal.pone.0059970
Teixeira, S., Leão, C.P., Neves, M., Arezes, P., Cunha, A., Teixeira, J.C.: Thermal comfort evaluation using a CFD study and a transient thermal model of the human body. In: V European Conference on Computational Fluid Dynamics (2010), June, 14–17
Teodosiu, C., Hohota, R., Rusaouën, G., Woloszyn, M.: Numerical prediction of indoor air humidity and its effect on indoor environment. Build. Environ. **38**(5), 655–664 (2003). https://doi.org/10.1016/S0360-1323(02)00211-1
Wolkoff, P.: Indoor air humidity, air quality, and health - An overview. Int. J. Hyg. Environ. Health **221**(3), 376–390 (2018). https://doi.org/10.1016/j.ijheh.2018.01.015
Zhang, H., Hong, S., Feng, H.: The characteristics of the patient's requirement for the ward thermal environment. Proc. Eng. **205**, 288–295 (2017). https://doi.org/10.1016/j.proeng.2017.09.968

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Variables Influencing Heat Stress Response in Humans: A Review on Physical, Clothing, Acclimation and Health Factors

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Abstract Objective: The aim of this work was to investigate on additional variables influencing heat stress response of humans: physical characteristics, type of clothing; acclimation; illness history and medications taking. Background: Exposure to hot thermal environment is present in a great number of indoor and outdoor working activities, posing a risk for the human safety and health. There are six basic factors to take in consideration in heat exposure: air temperature, radiant temperature, relative humidity, air movement, metabolic heat production and clothing. Method: The review was conducted by using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology, by using 32 keywords and expressions, screening through the Brazilian CAPES searching system. Results: The identification process resulted with 1148 articles. After applying the exclusion and inclusion criteria's it resulted with 21 articles included in this review. In this review, 11 variables were analysed. Conclusion: It was concluded that future studies on human exposure to different thermal environments, should consider, apart from the basic factors, a number of other variables which influences heat stress response (the human physical characteristics as body mass index, age, gender, ethnicity, the phase of the menstrual cycle in female participants, illness history and medications intake, and acclimation of the participants).

Keywords Hot thermal environment · Thermoregulation · Human factors · Bias in heat stress

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1 Introduction

Exposure to hot thermal environment is a significant risk factor present indoor in all seasons (foundries, steel mills, bakeries, smelters, glass factories, and furnaces, and highly humid laundries, restaurant kitchens, and canneries) and outdoor during the summer season (in occupations such as road repair, marine, army, agriculture, forestry, mining, factory work, construction work, among summer sport athletic disciplines and related occupations) (Canadian Centre for Occupational Health & Safety 2016). Outdoor exposure to hot is of particular interest for regions near the Equator where the temperatures are high year-round with exceptions of high mountains. Further on, overall global temperatures show a fast increasing trend during the past decades (Carlowicz n.d.).

Further on, heat exposure can lead to a number of illnesses: heat edema, heat rashes, heat cramps, heat exhaustion, heat syncope and heat stroke; and with aggravation in some cases lead to death (Canadian Centre for Occupational Health & Safety 2016; Jacklitsch et al. 2016).

With increased concerns on climate change during recent years, public interest increased attention on the effects of heat exposure (Kjellstrom 2009). Therefore, understanding that heat exposure affects a great population and understanding the level of risk posed by heat exposure, it is important to comprehend factors important for worker's heat stress evaluation.

Past studies concluded that there are six basic factors to take in consideration in heat exposure: air temperature, radiant temperature, relative humidity, air movement, metabolic heat generated by human activity and clothing worn by a person (Parsons 2003). However, while many present studies considered the mentioned basic factors, there is a need to further on the research, adding more factors in order to get consistent and comparable results. In order to do so, this study investigated on additional factors influencing human response on heat exposure, study the importance on each one of them and give suggestions for improving future studies.

The aim of this review was to investigate on additional variables influencing heat stress response in humans: physical characteristics, type of clothing; acclimation; illness history and medications taking. Further on, the importance of the encountered variables will be discussed.

2 Materials and Methods

2.1 Searching Strategy

The academic and clinic PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses was used in creating and modelling this article (Liberati et al. 2009). References were managed using the Mendeley 1.15.3. For searching purposes, the following 31 keywords/expressions were defined: "hot thermal environment*", "hot temperature*" AND exposure*", "hot exposure*", "metab* AND exposure* AND hot", "disease* AND exposure* AND hot", "illness* AND exposure* AND hot", "injur* AND exposure* AND hot", "accident* AND exposure* AND hot", "death AND exposure* AND hot", "clothing AND hot AND exposure*", "physi* AND exposure* AND hot", "psycholog* AND exposure* AND hot", "productivity AND human AND hot", "performance* AND human AND hot", "heat stress AND work*", "hot thermal condition*". Additional 15 keywords and expressions were created by replacing the word "hot" with word "warm" in all previously mentioned keywords and expressions.

Using selected keywords and expressions, the articles were searched by title and subject in 251 electronic databases through the CAPES (Brazilian Coordination of Improvement of Higher Level Personnel) searching system (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior 2017). Additionally, the search was carried out in the magazine IJOOES using the keyword "thermal". When articles were encountered, first exclusion criteria's were applied, afterward the articles were fully downloaded and screened, and inclusion criteria's were applied.

2.2 Selection Criteria's

There was no publishing year limit. Articles were excluded if published in any other language but English. After applying the language exclusion criteria, articles were screened by title and then by abstract. Only research articles considering workers exposed to heat stress were included.

3 Results

The identification process resulted with 1148 articles. After excluding 301 articles published in other language but English, 841 articles were left to screen. By screening article titles and excluding repeated articles, additional 303 articles were excluded, leaving 538 more to screen. After excluding by abstract and including articles which were related to construction workers exposure to heat, it remained 18 articles for screening in full text version. By screening the references of those 18 articles, another 5 were included as were found to be in accordance with the objective of this review. Therefore, in total, 23 articles were fully screened. From those 23, two were excluded as they were not research articles. Finally, 21 articles were included in this review. In Table 1 are illustrated all included studies with 11 selected variables.

Table 1 Included studies and variables consideration

Reference		Clothing	Gender	**Female MC	Age	Ethnicity	Height	Weight	BMI	Illness history	Medications	Acclimation
1	Islam and Khennane (2012)											
2	Rowlinson and Jia (2014)	x	x	x (no)	x	x	x	x	x			x
3	Pérez-Alonso et al. (2011)	x										
4	Jia et al. (2016)	x	x	x (no)	x	x	x	x	x			
5	Inaba et al. (2009)	x	x	x (no)	x		x	x	x	x		x
6	Albert et al. (2012a)	x	x	x (no)	x		x	x		x	x	
7	Albert et al. (2012b)	x	x		x		x	x		x	x	
8	Chan et al. (2013)		x		x		x	x		x	x	
9	Yi et al. (2017)	x	x		x		x	x	x	x	x	x
10	Sett and Sahu (2014)	x	x	x (no)	x		x	x				x
11	Farshad et al. (2015)	x	x		x		x	x		x	x	
12	Morioka et al. (2006)		x		x							
13	Dutta et al. (2015)		x	x (no)	x		x	x	x			x
14	Hajizadeh et al. (2014)		x		x							x
15	Yang and Chan (2017)	x	x		x		x	x	x	x	x	x
16	Heus and Kistemaker (1998)	x	x		x							
17	Mairiaux and Malchaire (1985)	x	x		x			x				x
18	Maiti (2008)	x	x	x (no)	x		x	x		x	x	x
19	Barkokébas Junior et al. (2019)		x		x		x	x	x			
20	Costa et al. (2019)				x		x	x				
21	Carvalho et al. (2018)		x		x		x	x				

*x = variable considered by the study; **Female MC = Studies conducted with female participants, and if they considered the phase of the menstrual cycle

4 Discussion

All included variables were studied separately in order to comprehend the influence of each one of them. Although some of them have a minor influence on the results of the studies, some of them have greater influence and should be taken into consideration in further works evaluating human heat stress exposure. As each variable has its particularity, and the number of variables is high, many variables were not included in this review. Therefore, there is a need for another study considering lifestyle habits influencing human response to heat stress (such as smoking cigarettes, alcohol, coffee, tea, water and food intake, sleeping hours and human physical condition).

The present review restricts to four additional variables influencing heat stress response: human physical characteristics, clothing, acclimation, illness history and medications taking.

Although not included in broader analysis of this study, it is important to mention that all included studies considered environmental variables, as well as noticing that most of them didn't consider all 4 fundamental ambient variables (air temperature, relative humidity, radiant temperature and air movement) which is important for analysing and comparing results from different studies. All of the included articles considered some types of construction working activities (welding and rebar work, brick carriers and molders, masons, carpenters, shutter joiners, benders, and other types of construction working activities). In total 15 of the included studies considered or measured the metabolic rate of workers while conducting their activities (Chan et al. 2013, 2015, 2012a, b; Dutta et al. 2015; Farshad et al. 2015; Hajizadeh et al. 2014; Heus and Kistemaker 1998; Inaba et al. 2009; Islam and Khennane 2012; Joubert et al. 2011; Mairiaux and Malchaire 1985; Maiti 2008; Pérez-Alonso et al. 2011; Rowlinson and Jia 2014; Sett and Sahu 2014) which is found to be important as intensive exercises increase heat production, requiring increases in skin blood flow and sweating (Havenith 2005), and therefore influencing the response of workers to heat stress.

4.1 Clothing

From the selected studies, five didn't consider the type and characteristics of clothing, two mentioned that have considered (Inaba et al. 2009; Sett and Sahu 2014), two described the type of clothing (Mairiaux and Malchaire 1985; Maiti 2008), while nine (Chan et al. 2012a, 2012b; Farshad et al. 2015; Heus and Kistemaker 1998; Jia et al. 2016; Pérez-Alonso et al. 2011; Rowlinson and Jia 2014; Yang and Chan 2017; Yi et al. 2017) give descriptions on clothing type, its characteristics as clothing mass, thickness, material, moisture capacity of clothes, air resistance and water vapor permeability. Protective clothing also restricts evaporative heat loss, therefore with intensive work, higher heat production and reduced cooling, the core body temperature can get dangerously high (Saladin and Miller 1998; Selkirk et al. 2001; Tribuzi and Laurindo 2016). Therefore, it is important for future studies to include clothing type and characteristics in their future experiments on heat stress.

4.2 Human Physical Characteristics

Age and gender were considered by 16 included studies (Chan et al. 2013, 2015, 2012a, b; Dutta et al. 2015; Farshad et al. 2015; Hajizadeh et al. 2014; Heus and Kistemaker 1998; Inaba et al. 2009; Jia et al. 2016; Joubert et al. 2011; Mairiaux and Malchaire 1985; Maiti 2008; Morioka et al. 2006; Rowlinson and Jia 2014; Sett and Sahu 2014; Yang and Chan 2017; Yi et al. 2017). Age is an important human factor to take into consideration as older participants typically respond with the following: reduced sweat gland output, reduced skin blood flow, smaller increase in cardiac output and less redistribution of blood flow from renal and splanchnic circulations (Kenney and Munce 1997). Gender and Body Mass Index (BMI) are important factor to consider, as heat stress response can vary between men and women. Earlier studies concluded that females are at an advantage in humid hot weather due to having a higher surface-to-mass ratio; while males are advantaged in dry hot weather due to a higher sweating capacity (Kenney 1985; Shapiro et al. 1980).

Further on, related to gender, it is important to notice that neither one of the studies which included female participants didn't consider their phase of the menstrual cycle, for which was found to greatly influence the results (Jonge 2003). It is an important factor to take into consideration, as men, and naturally cycling women in the follicular phase have similar average 24 h and minimum temperatures. In comparison, women in the luteal phase and women taking monophasic hormonal contraceptives have core temperatures higher by $\approx$0.4 °C compared to women in the follicular phase (Baker et al. 2001).

Ethnicity is another factor that should be considered in heat stress experiments, as people from different climate zones have adapted their lifestyles to their environmental conditions. Climate zone has shown to influence characteristics as birth weight, body shape, composition, cranial morphology, skin colour and sensitivity (Lambert et al. 2008).

4.3 Illness History and Medications

Illness history was considered by 8 studies (Chan et al. 2013, 2012a, b; Farshad et al. 2015; Inaba et al. 2009; Maiti 2008; Yang and Chan 2017; Yi et al. 2017), while medications taking by 7 studies (Chan et al. 2013, 2012a, b; Farshad et al. 2015; Maiti 2008; Yang and Chan 2017; Yi et al. 2017). The included studies considering illness history, excluded potential participants if they were: not healthy; without history of diagnosed health problems; if had significant difference in the prevalence of past history of heat disorders, heat-related illness; if participants had flu in the week prior to participating; if the participants had history of major health problems including diabetes, hypertension, cardiovascular disease, neurological problem, renal diseases, skin diseases, history of chronic or acute illness, had hypertension or acute rheumatic problem. The studies which considered medication intake, excluded potential participants if they were taking medication on regular basis (especially diuretic medication). Future studies should consider illness history and medications as exclusion criteria's during the participants selection phase. Although illness history and medications taking was considered as significant to consider for participants selection, further study needs to be conducted in order to be able to analyse how much does each of the illnesses or medications affect the heat stress response in humans.

4.4 Acclimation

Acclimatization was one of the most considered factors, being considered by 9 included studies (Dutta et al. 2015; Hajizadeh et al. 2014; Inaba et al. 2009; Mairiaux and Malchaire 1985; Maiti 2008; Rowlinson and Jia 2014; Sett and Sahu 2014; Yang and Chan 2017; Yi et al. 2017). Previous studies show the importance of acclimation in prevention of heat stress. Generally, rectal temperature and heart-rate were lowered in proportion to the duration of the acclimation. In one study (Moran et al. 2002) conducted in environmental temperature of 49 °C and RH 20%, the Tre decreased by ≈0.4 °C (for young participants from ≈39.4 on day 1 to ≈38.9 on days 5–10, and for middle aged participants from ≈39.0 °C on day 1 to 38.6 °C) and HR (for younger participants from ≈164 bmp on day 1 to ≈150 bmp on days 3–10, and for middle aged participants from ≈148 on day 1 to ≈132 on days 4–10.

4.5 Suggestion for Future Studies on Human Thermal Environment

The present study analysed different studies on variables which were considered for evaluating the heat stress response in humans. It gives new information in addition to the previously published study (Zlatar et al. 2018) which focused on lifestyle factors influencing heat stress response: cigarette smoking, alcohol, coffee, tea, water, food and spicy food consumption, sleeping hours, physical exertion and body fat. In addition, the present study gives a perspective on all variables which were considered for their participants and resumed in the Table 2, illustrating in addition to the basic factors, which other variables were considered (in percentage and total number of evaluated studies). This resume should benefit to all those developing future studies on the influence of different thermal environments on the human body. The six basic factors were marked in dark green colour, the next most considered variables (in 33–86% of studies) were marked in bright green colour, while less considered variables were marked in dark and bright orange colour in order to visually facilitate the comprehension of the table.

Table 2 Included studies and variables consideration

Nr	Variables	Considered
1.	air temperature	6 basic factors
2.	radiant temperature	
3.	relative humidity	
4.	air movement	
5.	metabolic heat	
6.	clothing	
7.	gender	86% (18/21)
8.	age	90% (19/21)
9.	BMI*	62% (13/21)
10.	water consumption	67% (8/12)
11.	cigarette smoking	58% (7/12)
12.	acclimation	43% (9/21)
13.	illness history	38% (8/21)
14.	alcohol	42% (5/12)
15.	medication	33% (7/21)
16.	coffee	25% (3/12)
17.	sleeping hours	25% (3/12)
18.	body fat	25% (3/12)
19.	physical condition	17% (2/12)
20.	ethnicity	9% (2/21)
21.	tea	8% (1/12)
22.	food	8% (1/12)
23.	spicy food	0% (0/12)
24.	phase of the menstrual cycle**	0% (0/7/12)

*BMI = Body Mass Index

4.6 Limitations

The limitations of this review lay in considering only studies encountered through the CAPES search and IJOOES magazine. More studies and relevant information might be encountered by including new keywords from present studies.

5 Conclusions

Most of the included studies considered six basic factors: air temperature, radiant temperature, relative humidity, air movement, metabolic heat production and clothing. Among additional factors, the phase of the menstrual cycle was not considered by neither one conducting experiments on female participants. Illness history, medications intake, acclimation and ethnicity were poorly considered, while gender, age, height, weight and BMI were considered in most of them.

Future heat exposure studies should consider additional factors: human physical characteristics as age and gender; the phase of the menstrual cycle in female participants; illness history and medications intake; and acclimation of the participants. Not considering mentioned factors can pose a risk of bias and mislead in the interpretation of the data.

A more thorough review is suggested, including the analysis of methods and procedures used for measuring each of the variables, addressing the effectiveness, precision, cost and complexity of each method. In addition, a more thorough discussion should be conducted in relation to variables necessary to consider when exposed to cool or cold thermal environments.

References

Baker, F.C., Waner, J.I., Vieira, E.F., Taylor, S.R., Driver, H.S., Mitchell, D.: Sleep and 24 hour body temperatures: a comparison in young men, naturally cycling women and women taking oral contraceptives. J. Physiol. **530**(3), 565–574 (2001)

Barkokébas Junior, B., Gorga Lago, E.M., Martins, A.R., Zlatar, T., Mendes da Cruz, F., Vasconcelos, B.M., Moreira Campos, F., Roberto Campos, C.: Health risks in tropical climate agriculture: a set of case studies of sugarcane workers. Int. J. Occup. Environ. Safety **3**(3), 44–52 (2019). https://doi.org/10.24840/2184-0954_003.003_0005

Canadian Centre for Occupational Health & Safety: Hot Environments - Health Effects and First Aid (2016). https://www.ccohs.ca/oshanswers/phys_agents/heat_health.html

Carlowicz, M.: Global temperatures. NASA Earth Observatory (n.d.). Accessed 13 Jan 2017, from http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php

Carvalho, J.P., Barroso, B.I.L., Da Silva, L.B., Neves, A.I.A., Torres, M.G.L., Falcão, C.A., Siqueira, J.C.F., Souza, A.G.L., Souza, E.L., Da Silva, J.F.: Students' blood pressure and heart rate in learning environments with thermal changes. Int. J. Occup. Environ. Safety **2**(1), 29–37 (2018). https://doi.org/10.24840/2184-0954_002.001_0004

Chan, A.P.C, Yang, Y., Wong, F.K.W., Chan, D.W.M., Lam, E.W.M.: Wearing comfort of two construction work uniforms. Constr. Innov. **15**(4), 473–492 (2015). https://doi.org/10.1108/CI-06-2015-00370040517515591773; Chen, S.M., Chang, C.H.: A new method to construct membership functions and generate weighted fuzzy rules from training instances. Cybern. Syst.: Int. J. **36**(4), 397–414 (2005); Chen, S.M., Lee, S.H., Lee, C.H.: A new method for generating fuzzy rules from numerical data for handling classification problems. Appl. Artif. Intell. **15**(7), 645–664 (2001); Guidelines on site safety measures for working in hot wea

Chan, A.P., Wong, F.K., Wong, D.P., Lam, E.W., Yi, W.: Determining an optimal recovery time after exercising to exhaustion in a controlled climatic environment: application to construction works. Build. Environ. **56**, 28–37 (2012a). https://doi.org/10.1016/j.buildenv.2012.02.013

Chan, A.P., Yi, W., Wong, D.P., Yam, M.C., Chan, D.W.: Determining an optimal recovery time for construction rebar workers after working to exhaustion in a hot and humid environment. Build. Environ. **58**(December), 163–171 (2012b). https://doi.org/10.1016/j.buildenv.2012.07.006

Chan, A.P., Yam, M.C., Chung, J.W., Yi, W.: Developing a heat stress model for construction workers. J. Facil. Manag. **10**(1), 59–74 (2013). https://doi.org/10.1108/14725961211200405

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior: Portal Periodicos CAPES (2017). http://www.periodicos.capes.gov.br/

Costa, E.Q., Santos Baptista, J., Carvalho, J.C., Costa, J.T.: Influence of thermal environment on occipital EEG signal amplitude in sedentary activities. Int. J. Occup. Environ. Safety **3**(1), 1–12 (2019). https://doi.org/10.24840/2184-0954_003.001_0001

Dutta, P., Rajiva, A., Andhare, D., Azhar, G., Tiwari, A., Sheffield, P.: Ahmedabad heat and climate study group: perceived heat stress and health effects on construction workers. Indian J. Occup. Environ. Med. **19**(3), 151 (2015). https://doi.org/10.4103/0019-5278.174002

Farshad, A., Montazer, S., Monazzam, M.R.: Heat stress level among construction workers. Iran. J. Public Health **43**(4), 492–498 (2015)

Hajizadeh, R., Golbabaei, F., Monazzam, M.R.: Productivity loss from occupational exposure to heat stress: a case study in brick workshops/Qom- Iran. Int. J. Occup. Hyg. **6**(3), 143–148 (2014)

Havenith, G.: Temperature regulation, heat balance and climatic stress. In: Extreme Weather Events and Public Health Responses, pp. 69–80 (2005). https://doi.org/10.1007/3-540-28862-7_7

Heus, R., Kistemaker, L.: Thermal comfort of summer clothes for construction workers. Environ. Ergon. 273–276 (1998)

Inaba, R., Kurokawa, J., Mirbod, S.M.: Comparison of subjective symptoms and cold prevention measures in winter between traffic control workers and construction workers in Japan. Ind. Health **47**(3), 283–291 (2009). https://doi.org/10.2486/indhealth.47.283

Islam, S.M.S., Khennane, A.: A research framework for assessing the effects of heatstress on construction workers. In: Proceedings of 6th International Struc-Tural Engineering and Construction Conference, ISEC06 – Modern Methods and Advances in Structural Engineering and Construction, January 2012, pp. 978–981 (2012). https://doi.org/10.3850/978-981-08-7920-4

Jacklitsch, B., Williams, W.J., Musolin, K., Coca, A., Kim, J.-H., Turner, N.: NIOSH criteria for a recommended standard: occupational exposure to heat and hot environments. US Department of Health and Human Services, Publication 2016-106 (2016). https://doi.org/Publication2016-106

Jia, Y.A., Rowlinson, S., Ciccarelli, M.: Climatic and psychosocial risks of heat illness incidents on construction site. Appl. Ergon. **53**(August), 25–35 (2016). https://doi.org/10.1016/j.apergo.2015.08.008

Jonge, X.A.K.J.De.: Effects of the menstrual cycle on exercise performance. Sports Med. (Auckland, N.Z.) **33**(11), 833–851 (2003)

Joubert, D., Thomsen, J., Harrison, O.: Safety in the heat: a comprehensive program for prevention of heat illness among workers in Abu Dhabi, United Arab Emirates. Amer. J. Public Health **101**(3), 395–398 (2011). https://doi.org/10.2105/AJPH.2009.189563

Kenney, W.L., Munce, T.A.: Physiology of aging invited review: aging and human temperature regulation. Pandolf KB. Exp. Aging Res. Ageing Res. Rev. Exp. Aging Res. **17**(17), 41–76 (1997)

Kenney, W.L.: A review of comparative responses of men and women to heat stress. Environ. Res. **37**(1), 1–11 (1985). https://doi.org/10.1016/0013-9351(85)90044-1

Kjellstrom, T.: Climate change, direct heat exposure, health and well-being in low and middle-income countries. Glob. Health Action **2**(1), 2–4 (2009). https://doi.org/10.3402/gha.v2i0.1958

Lambert, M.I., Mann, T., Dugas, J.P.: Ethnicity and temperature regulation. In: Thermoregulation and Human Performance, pp. 104–120. KARGER (2008). https://doi.org/10.1159/000151553

Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Ioannidis, J.P.A., Clarke, M., Devereaux, P.J., Kleijnen, J., Moher, D.: Academia and clinic The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions. Ann. Internal Med. **151**(4) (2009)

Mairiaux, P., Malchaire, J.: Workers self-pacing in hot conditions: a case study. Appl. Ergon. **16**(2), 85–90 (1985). https://doi.org/10.1016/0003-6870(85)90209-1

Maiti, R.: Workload assessment in building construction related activities in India. Appl. Ergon. **39**(6), 754–765 (2008). https://doi.org/10.1016/j.apergo.2007.11.010

Moran, D.S., Kenney, W.L., Pierzga, J.M., Pandolf, K.B.: Aging and assessment of physiological strain during exercise-heat stress. Amer. J. Physiol. - Regul. Integr. Comp. Physiol. **282**(4), R1063–R1069 (2002). https://doi.org/10.1152/ajpregu.00364.2001

Morioka, I., Miyai, N., Miyashita, K.: Hot environment and health problems of outdoor workers at a construction site. Ind. Health **44**(3), 474–480 (2006). https://doi.org/10.2486/indhealth.44.474
Parsons, K.C.: Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort and Performance, 2nd edn. Taylor & Francis, Milton Park (2003)
Pérez-Alonso, J., Callejón-Ferre, Á.J., Carreño-Ortega, Á., Sánchez-Hermosilla, J.: Approach to the evaluation of the thermal work environment in the greenhouse-construction industry of SE Spain. Build. Environ. **46**(8), 1725–1734 (2011). https://doi.org/10.1016/j.buildenv.2011.02.014
Rowlinson, S., Jia, Y.A.: Application of the predicted heat strain model in development of localized, threshold-based heat stress management guidelines for the construction industry. Ann. Occup. Hyg. **58**(3), 326–339 (2014). https://doi.org/10.1093/annhyg/met070
Saladin, K., Miller, L.: Anatomy & Physiology. In: Book. OpenStax College. http://www.mccneb.edu/outlines/mathandnaturalsciences/Biology/BIOS2310.doc
Selkirk, G.A., Mclellan, T.M., Stapleton, J.M., Poirier, M.P., Flouris, A.D., Boulay, P., Sigal, R.J., Kenny, G.P., Jay, O., Bain, A.R., Deren, T.M., Sacheli, M., Cramer, M.N., Hanna, E.G., Kjellstrom, T., Bennett, C., Dear, K.: Influence of aerobic fitness and body fatness on tolerance to uncompensable heat stress. J. Appl. Physiol. (Bethesda, Md.: 1985) **91**, 2055–2063 (2001)
Sett, M., Sahu, S.: Effects of occupational heat exposure on female brick workers in West Bengal. India. Glob. Health Action **7**(1), 1–11 (2014). https://doi.org/10.3402/gha.v7.21923
Shapiro, Y., Pandolf, K.B., Avellini, B.A., Pimental, N.A., Goldman, R.F.: Physiological responses of men and women to humid and dry heat. J. Appl. Physiol. **49**, 1–8 (1980). https://doi.org/10.1300/J015V06N01_18
Tribuzi, G., Laurindo, J.B.: Dehydration and rehydration of cooked mussels. Int. J. Food Eng. **12**(2), 173–180 (2016). https://doi.org/10.1515/ijfe-2015-0275
Yang, Y., Chan, A.P.-C.: Role of work uniform in alleviating perceptual strain among construction workers. Ind. Health **55**(1), 76–86 (2017). https://doi.org/10.2486/indhealth.2016-0023
Yi, W., Chan, A.P.C., Wong, F.K.W., Wong, D.P.: Effectiveness of a newly designed construction uniform for heat strain attenuation in a hot and humid environment. Appl. Ergon. **58**, 555–565 (2017). https://doi.org/10.1016/j.apergo.2016.04.011
Zlatar, T., Cruz, F.M. da, Vasconcelos, B.M., Martins, A.R.B., Lago, E.M.G., Martins, L.B., Santos Baptista, J., Barkokébas Jr, B.: Lifestyle factors influencing heat stress response: a review. Ceset J. **23**, 22–31 (2018). https://doi.org/1807-7889

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Physiological Monitoring Systems for Firefighters (A Short Review)

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Abstract Background: Firefighters are safety-sensitive professionals exposed to high ambient temperatures, extreme physical exertion, toxic air pollutants, and psychological stress, and, therefore, with high risks to their health. Wearable physiological monitoring systems might be helpful to track their activities and prevent potential health impairments, and research perspectives should explore this applicability. Objective: This study aims to present the preliminary results of a systematic review regarding the occupational applicability of physiological monitoring systems, focusing on the findings among firefighting personnel. Methodology: The PRISMA methodology was used to systematise and filter the results. Five databases were accessed, and 13 keywords were combined to gather studies addressing the continuous examination of one or more physiological variables during real or simulated firefighting tasks. Results/Discussion: A total of 322 items were first retrieved, and

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10 articles were selected. In general, publications evidenced the physiological cost of firefighting activities and addressed cardiac and thermal metrics. Results helped to obtain an overall perspective on the up-to-date progress on physiological monitoring among firefighting personnel and established potential directions for further research. Conclusions: With this work, the usefulness of real-time monitoring to understand the physiological demands of firefighters was demonstrated. Future investigations should focus on developing classification models to process physiological recordings optimising work-rest cycles, and preventing further health impairments. This review contributed by providing possible departure points in this regard.

Keywords Firefighting · Wearable sensors · Physiological variables

1 Introduction

Firefighting is a highly stressful occupation in which individuals are constantly exposed to a multitude of physical and environmental stresses during regular duties (Walker et al. 2019). In general, firefighting involves strenuous physical activity while wearing heavy and insulating personal protective equipment in extreme conditions. Their tasks can include fire suppression, victims rescue, carrying heavy objects, getting in and out of moving vehicles, entering confined spaces with little visibility and high temperatures, and also with frequent exposition to extreme psychological stress (Hunter et al. 2017; Orr et al. 2019). As a consequence of these occupational factors, firefighters can be at risk of fire-related injuries and impair their overall performance and well-being. There are likely additive or synergistic effects of these potential triggers in susceptible firefighters that may culminate in severe health impairments, such as acute cardiovascular events (Hunter et al. 2017).

Firefighters' continuous individual monitoring could timely advise on the situations leading to adverse health impact. However, these health risk situations are challenging to study in a real-life environment due to unpredictability and time pressures during these emergency situations. In this regard, the emergence of wearable physiological and medical monitoring devices can overcome these limitations and provide an insight into the individual overall health status from the measurement and evaluation in real-time of different parameters (Raskovic et al. 2004; Stacey et al. 2018). This approach offers significant improvements in population-based predictions derived from ambient conditions and the general context of each operation (Friedl 2018).

Wearable physiological monitoring systems have become valuable tools for studying performance in different sports fields and remotely monitor patients with chronic diseases (Sawka and Friedl 2017). Accordingly, related research in both laboratory and free-living spaces have also increased over the last decades (Kristoffersson and Lindén 2020; Rana & Mittal 2020; Ye et al. 2020), but within occupational settings, information is more limited. As a result, the need to systematise up-to-date research progress among workers populations emerges. The current study, developed as a part of an extensive review of physiological monitoring systems' applications among occupational groups, aims to briefly present data related to firefighting personnel. To date, no literature review has summarised physiological monitoring systems applications in these workers, being fundamental to understand what has been done, with what degree of success and where further research is needed.

2 Methodology

This review used a systematic approach to search for relevant articles and was based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA Statement) (Page et al. 2021) and the related protocol proposed by Bustos et al. (2019). Five electronic databases (Scopus, Science Direct, PubMed, Academic Search Complete and Web of Science) were accessed and only English-language publications were retrieved. Major keywords ("physiological monitoring", "noninvasive monitoring", "occupational" and "worker"), as well as their related derivatives, were used for the search. As stated in the protocol, combinations of terms were adapted to each database forming queries in which title, abstract and keywords were selected as fields of search. Within obtained results, the term "firefight*" was additionally inserted to gather only the items addressing firefighting personnel. Later, records were filtered by applying the following restrictions: date (only articles published between 2014 and 2021 were considered), source type (only journal articles were retrieved), document type (research articles published or in press were identified) and language (search was limited to English written publications). Studies selection was performed after a full-text examination in which investigations fulfilling all these conditions were identified: aims addressed prognostic health-related goals, experimental protocols included actual or simulated working activities (developed by active newly recruits, urban and wildland firefighters), and physiological monitoring systems were used. In the resulting items, references were tracked, and newly identified relevant records were also included. Information of interest was then extracted and summarised in a customised table. Given the heterogeneity of the papers, a meta-analysis could not be performed.

3 Results and Discussion

By following the referred methodology, initial 322 items (102 from Scopus, 166 from PubMed, 38 from Science Direct, nine from Academic Search Complete and seven from Web of Science) were retrieved. Then, applying search engines filters, 111 were rejected by date, 41 by article type and two by source type. As a result, 168 items were screened following the exclusion criteria and, then 30 records were left for a full-text assessment. This last process led to the selection of seven papers. After that, backwards reference searching through the snowballing technique (Wohlin 2014) concluded with the inclusion of additional three studies. Consequently, a total of 10 publications were assessed, with their primary outcomes being detailed in this section.

3.1 Studies Characteristics

Table 1 presents the studies characteristics concerning their primary aims, examined samples, included variables and used equipment. In general, the included articles developed investigative procedures among experienced professional firefighters, and two studies addressed firefighter trainees (Angerer et al. 2008; Davis and Gallagher 2014). Their sample sizes varied from nine to 131 active firefighting personnel and participants' mean ages ranged from 22 to 46. Whilst there were some differences between the average age of the different groups, discrepancies in the sex ratios were even more visible in most of the works. Five studies recruited only male participants (Angerer et al. 2008; Carey and Thevenin 2009; Davis and Gallagher 2014; Holmér and Gavhed 2007; Meina et al. 2020), while three engaged a non-significant percentage of females (Al-Zaiti et al. 2015; Horn et al. 2013, 2015), and two papers referred to representative samples of women, including 12 and 15 female firefighters (Siddall et al. 2016; Sol et al. 2018).

Most of the experimental protocols conducted were related to monitoring physiological responses during real-life activities. Six out of the 10 included papers evaluated different training and operational activities, particularly fire suppression (Angerer et al. 2008), hiking and wildfire suppression (Sol et al. 2018), crawling (Davis and Gallagher 2014), fire training exercises (Horn et al. 2013) and a combination of duty activities (Carey and Thevenin 2009; Meina et al. 2020). Two studies involved simulated firefighting tasks (Holmér and Gavhed 2007; Siddall et al. 2016) and the other two combined both laboratory and field monitoring (Al-Zaiti et al. 2015; Horn et al. 2015). Protocols duration were varied, with two studies addressing the most extended continuous recording of 24 h while on duty (Carey and Thevenin 2009; Meina et al. 2020).

Even though all included studies continuously monitored at least one physiological variable, their primary research objectives were diverse. However, three general perspectives were identified since articles aimed to: (i) assess the physiological demands and workload of specific training events (six studies); (ii) evaluate cardiac metrics (three studies) and (iii) explicitly address stress examination (one study). Details on the number of studies within different experimental settings and research objectives are presented in Fig. 1. Concerning wearable sensors used, most of the papers reported using Polar heart rate monitors and Equivital Life Monitors (see Fig. 2), while limited evidence was found on the use of actigraphs and other heart rate monitors. Respectively, examined variables were mainly cardiac metrics, core temperature recordings and oxygen consumption. Finally, regarding data treatment methods, the authors indicated the use of diverse statistical analyses and one study addressed machine learning algorithms to process and classify obtained data.

Table 1 Summary of studies addressing physiological monitoring systems within firefighting personnel

Study	Aim	Examined variables	Used wearable sensors
Al-Zaiti et al. (2015)	To evaluate the impact of high-intensity exertions and heat stress on electrocardiographic changes during fire suppression and recovery	HR and ECG responses	H12+ digital Holter recorder V3.12
Siddall et al. (2016)	To quantify the peak oxygen cost of several simulated firefighting tasks, performed to a minimum acceptable and representative standard for firefighters and, separately, for those in incident command	Anthropometric data, VO2, HR and RPE	Portable breath-by-breath gas analyser K4B2 and chest-mounted Polar HR monitor
Carey and Thevenin (2009)	To establish the feasibility of obtaining high resolutions ECGs of on-duty firefighters to detect ECG predictors for cardiac events	HRV	12-lead ECG Holter H12+
Davis and Gallagher (2014)	To measure the physiological demands experienced by firefighters when crawling in turnout gear during a search exercise	HR, air consumption and body part discomfort	Garmin Forerunner 110 monitors and SCBA regulator
Sol et al. (2018)	To document characteristics of hiking during wildland firefighter training and wildfire suppression	HR, Tco, speed and elevation gain	Wireless thermometer capsule Jonah ingestible sensor, Mini Mitter, Bend; Hidalgo Equivital Physiological Monitor and GPS travel recorder BT—Q1000XT, QStarz

(continued)

Table 1 (continued)

Study	Aim	Examined variables	Used wearable sensors
Horn et al. (2013)	To evaluate Tco and HR during repeated bouts of firefighting activity over three hours	HR and Tco	HR watch S625X, Polar Electro and Gastrointestinal temperature transmitter MiniMitter Vital Sense
Holmér and Gavhed (2007)	To analyse the energetic and respiratory demands during a simulated firefighting exercise in a training house and to propose values for classification of work	VO2, respiratory minute volumes, metabolic rate, HR and RPE	Portable gas analysis equipment Metamax, Cortex Sporttester Polar Electronics
Angerer et al. (2008)	To determine cardiocirculatory and thermal strain during fire suppression in firefighters and compare it with the strain during medical and performance evaluations	HR, ECG, Tco (tympanic), blood parameters and RPE	Thoracic belt Polar S710; First Temp Genius 3000 A, Kendall/Tyco Healthcare, Neustadt, Germany and Holter ECG registrations with custo tera 400
Horn et al. (2015)	To examine the effect of different firefighter exercise protocols on metabolic stress and physiological responses to firefighting activities	HR, Tco, self-perceived conditions, accelerometry counts, maximum oxygen uptake, RPE, perception of respiratory distress, and perception of thermal sensation	Physiological status monitor Equivital, Phillips Respironics; core temperature pill from VitalSense; open-circuit spirometry system K4b2, Cosmed Srl, Rome, Italy and accelerometers ActiGraph, Pensacola, FL, USA
Meina et al. (2020)	To investigate methodological	HR, tri-axial acceleration, Tsk, RR and self-assessed stress	EquivitalTM EQ-02 Life Monitor sensor belts means to assess the level of stress experienced by firefighters in the field

Heart rate (HR), heart rate variability (HRV), electrocardiogram signal (ECG), core temperature (Tco), respiratory rate (RR), skin temperature (Tsk) and rates of perceived exertion (RPE)

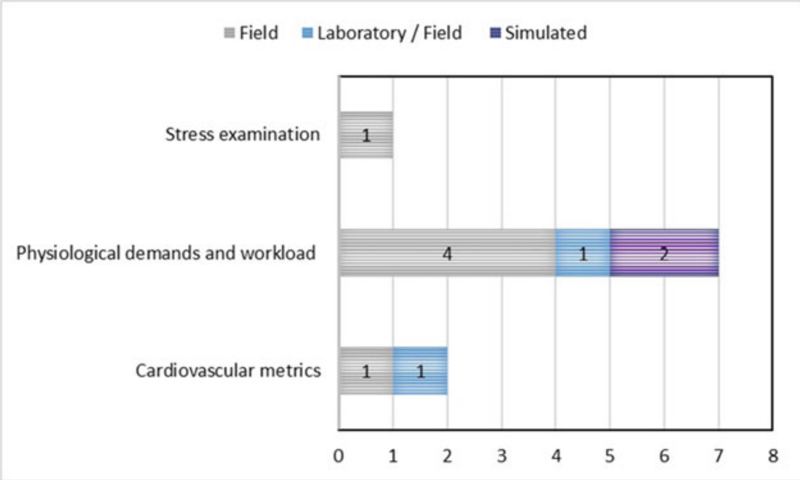

Fig. 1 Number of studies based on experimental context and general research applications

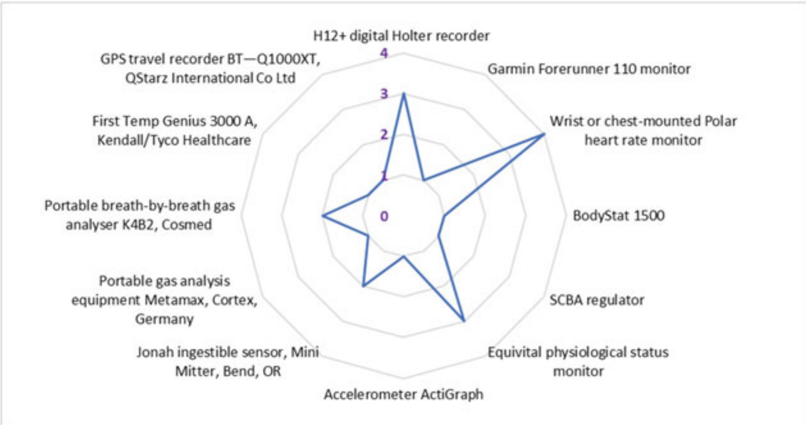

Fig. 2 Identified sensors among selected papers

3.2 Heart Rate Related Metrics Assessment

Heart rate is recognised as an essential indicator of physical activity and overload (Achten and Jeukendrup 2003; Seravalle et al. 2021), with its rate variability being demonstrated as an effective health and performance tool in tactical environments (Smith et al. 2016; Tomes et al. 2020). Among firefighters, intense physical activity combined with additional risk factors (e.g. sleep deprivation, metabolic syndrome and heat strain) leads to cardiovascular strain and heart diseases (Al-Zaiti et al. 2015). As a result, continuous tracking of their physiological state is essential to prevent associated health impairments, with this review revealing both the feasibility and usefulness of heart rate to characterise firefighters' activity. All analysed articles included one or more heart rate-derived variables in their assessments, and two studies focused explicitly on the electrocardiographic responses from fire suppression (Al-Zaiti et al. 2015) and a combination of regular duty activities (Carey and Thevenin 2009). Results demonstrated that firefighters participating in prolonged or very intense fire suppression, independent from work duration, experienced prolonged tachycardia which suggested they were physiologically unprepared for a second bout of fire suppression in the same shift (Al-Zaiti et al. 2015). On the other hand, authors also proved the feasibility of obtaining high-resolution electrocardiograms to understand the relationship between professional lifestyle and high cardiac risks (Carey and Thevenin 2009). In general, studies revealed the importance of developing algorithmic guidelines designed to route at-risk firefighters for optimal cardiac care that would reduce their cardiovascular risk factors, and future perspectives should be oriented in this regard.

3.3 Physiological Demands and Workload of Firefighting Activity

Vast information in the literature has shown firefighting duties as a civilian employment with high variability of exposure to physical stress and risks (Igboanugo et al. 2021; Perroni et al. 2014). Although this workload is difficult to measure, previous research has addressed increases in heart rate, core temperature, blood lactate levels, and psychological stress resulting from these practices (Christison et al. 2021; Smith et al. 2016). In this review, corresponding physiological alterations were observed, and most of the analysed papers were found examining the physiological demands and workload of specific firefighting activities. Despite the differences in their aims and experimental protocols, some expected outcomes were evidenced, and firefighting proved to be associated with a high cardiac and thermal load that often goes beyond normative or clinical criteria.

In Davis and Gallagher (2014) study, results from crawling monitoring were compared with the American College of Sports Medicine guidelines, that indicated limits of age-predicted HRmax and HRreserve (85% and 70%, respectively) after which exercise should be stopped (ACSM 2013). Both criteria were reached in most of the evaluated firefighters and evidenced the remarkable physiological cost and resultant heavy physical exertion that may also be associated with an increased risk of cardiac events (Seravalle et al. 2021). Similarly, another investigation (Holmér and Gavhed 2007) compared firefighting metabolic and respiratory demands with classes of metabolic rates in occupational work referred to in ISO 8996 (ISO 2004). Results showed that the established categories were unsuitable for rescue and firefighting work since the obtained metabolic rates were much higher than the upper class from the standard. Consequently, the authors proposed two new classes to classify metabolic and respiratory responses that may represent the intense periods of strain experienced by tactical personnel (e.g., firefighters, police officers, military).

As firefighting involves a high physiological demand and workload, findings point to the importance of sufficient recovery to prevent health-related effects. In fact, authors proved the strong correlation of the recovery of heart rate and core temperature with the time allowed between work cycles (Horn et al. 2013) and the relevance of efficiently managing work: rest ratios to avoid excessive accumulation of heat strain (Sol et al. 2018). Furthermore, authors remarked on the importance of regular physical activity to decrease the stress associated with firefighters duty since there appears to be a moderate inverse correlation between physical work capacity and time spent on leisure-time sport activities (Angerer et al. 2008). Therefore, the success of job performance depends on the ability of firefighters to respond to intense physical activity and the strategies to recover from that activity. In all evaluated cases, physiological monitoring systems proved to be helpful tools leading to strategies to improve firefighters performance.

3.4 Physiological Variables and Perceived Stress Levels

The impact of stress on health condition is well recognised (Rodrigues et al. 2018), and previous studies have evidenced how stress perceptions activate physiological responses. Within this review, results demonstrated that in highly stressful occupations (such as firefighting), real-time psychophysiological monitoring could become an early screening for symptoms of chronic stress and a basis for further contact with professional care. In this regard, one study (Meina et al. 2020) proved that combined psychological and physiological measurements are reliable indicators of stress even in natural settings and appear promising for chronic stress monitoring. This study was the only one found explicitly addressing stress levels through a multivariable physiological approach.

However, preceding investigations have already addressed the effects of perceived stress on physiological responses within laboratory environments (Rodrigues et al. 2018) and medical settings (Kim et al. 2018). They agreed that the most significant changes could be observed in some heart rate variability parameters under the influence of stress and highlighted the importance of online platforms and devices that help integrate psychophysiological stress information (Carbonaro et al. 2011; Castaldo et al. 2015). Therefore, directions for future research should be oriented toward developing these platforms, including classification models that translate physiological responses into stress levels or health indicators to be used by firefighter personnel or any known stressful profession.

3.5 Limitations

Within this review, some limitations were encountered. First, since no unpublished data was included, publication bias might be present in this study. Also, due to language restrictions (only English-written papers were selected), other relevant studies may have been excluded. Furthermore, heterogeneity among articles retrieved did not allow a comparison and respective meta-analysis of them, which can also be considered a limitation of the review. Finally, and even though a preselection of keywords were tested, search limited to selected combinations may have disregarded other valuable terms.

4 Conclusions

This study reports the preliminary results of a review addressing the occupational applications of physiological monitoring systems, focusing on the findings related to firefighting personnel. Current research confirms the feasibility of devices using physiological signals to examine the impact of firefighting practices and improve the management of health-related consequences. Among retrieved papers, a tendency to assess cardiac and thermal load was observed, and the usefulness of real-time monitoring for examining the unique physiological demands of firefighters during their regular duties was demonstrated. Future perspectives should focus on developing classification models to process and categorise physiological recordings along with stress perceptions. Sensory data should be able to provide simple indicators advising on the current overall condition of firefighters aiming to optimise work-rest cycles and, therefore, prevent further health impairments. This review contributed by providing possible departure points in this regard.

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References

Achten, J., Jeukendrup, A.E.: Heart rate monitoring. Sports Med. **33**(7), 517–538 (2003). https://doi.org/10.2165/00007256-200333070-00004

ACSM, A.C.O.S.M.: ACSM's health-related physical fitness assessment manual. Lippincott Williams & Wilkins (2013)

Al-Zaiti, S., Rittenberger, J.C., Reis, S.E., Hostler, D.: Electrocardiographic responses during fire suppression and recovery among experienced firefighters. J. Occup. Environ. Med. **57**(9), 938–942 (2015). https://doi.org/10.1097/JOM.0000000000000507

Angerer, P., Kadlez-Gebhardt, S., Delius, M., Raluca, P., Nowak, D.: Comparison of cardiocirculatory and thermal strain of male firefighters during fire suppression to exercise stress test and aerobic exercise testing. Am. J. Cardiol. **102**(11), 1551–1556 (2008). https://doi.org/10.1016/j.amjcard.2008.07.052

Bustos, D., Guedes, J.C., Torres Costa, J.: Evidencing the applicability of physiological monitoring for health management within occupational settings: protocol for a systematic review. Int. J. Occup. Environ. Saf. **3**(1), 68–76 (2019)

Carbonaro, N., Anania, G., Mura, G.D., Tesconi, M., Tognetti, A., Zupone, G., Rossi, D.D.: Wearable biomonitoring system for stress management: a preliminary study on robust ECG signal processing. In: 2011 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (2011). Last accessed 20–24 June 2011

Carey, M.G., Thevenin, B.J.M.: High-resolution 12-lead electrocardiograms of on-duty professional firefighters: a pilot feasibility study. J. Cardiovasc. Nurs. **24**(4), 261–267 (2009). https://doi.org/10.1097/JCN.0b013e3181a4b250

Castaldo, R., Melillo, P., Bracale, U., Caserta, M., Triassi, M., Pecchia, L.: Acute mental stress assessment via short term HRV analysis in healthy adults: a systematic review with meta-analysis. Biomed. Signal Process. Control **18**, 370–377 (2015). https://doi.org/10.1016/j.bspc.2015.02.012

Christison, K.S., Gurney, S.C., Sol, J.A., Williamson-Reisdorph, C.M., Quindry, T.S., Quindry, J.C., Dumke, C.L.: Muscle damage and overreaching during wildland firefighter critical training. J. Occup. Environ. Med. **63**(4), 350–356 (2021). https://doi.org/10.1097/JOM.0000000000002149

Davis, J., Gallagher, S.: Physiological demand on firefighters crawling during a search exercise. Int. J. Ind. Ergon. **44**(6), 821–826 (2014). https://doi.org/10.1016/j.ergon.2014.10.001

Friedl, K.E.: Military applications of soldier physiological monitoring. J. Sci. Med. Sport (2018). https://doi.org/10.1016/j.jsams.2018.06.004

Holmér, I., Gavhed, D.: Classification of metabolic and respiratory demands in fire fighting activity with extreme workloads. Appl. Ergon. **38**(1), 45–52 (2007). https://doi.org/10.1016/j.apergo.2006.01.004

Horn, G.P., Blevins, S., Fernhall, B., Smith, D.L.: Core temperature and heart rate response to repeated bouts of firefighting activities. Ergonomics **56**(9), 1465–1473 (2013). https://doi.org/10.1080/00140139.2013.818719

Horn, G.P., Kesler, R.M., Motl, R.W., Hsiao-Wecksler, E.T., Klaren, R.E., Ensari, I., Petrucci, M.N., Fernhall, B., Rosengren, K.S.: Physiological responses to simulated firefighter exercise protocols in varying environments. Ergonomics **58**(6), 1012–1021 (2015). https://doi.org/10.1080/00140139.2014.997806

Hunter, A.L., Shah, A.S., Langrish, J.P., Raftis, J.B., Lucking, A.J., Brittan, M., Venkatasubramanian, S., Stables, C.L., Stelzle, D., Marshall, J.: Fire simulation and cardiovascular health in firefighters. Circulation **135**(14), 1284–1295 (2017)

Igboanugo, S., Bigelow, P.L., Mielke, J.G.: Health outcomes of psychosocial stress within firefighters: a systematic review of the research landscape. J. Occup. Health **63**(1), e12219 (2021). https://doi.org/10.1002/1348-9585.12219

ISO: Ergonomics of Thermal Environments-Determination of Metabolic Heat Production. International Organization for Standardization, Geneva (2004)

Kim, H.-G., Cheon, E.-J., Bai, D.-S., Lee, Y.H., Koo, B.-H.: Stress and heart rate variability: a meta-analysis and review of the literature. Psychiatry Investig. **15**(3), 235–245 (2018). https://doi.org/10.30773/pi.2017.08.17

Kristoffersson, A., Lindén, M.: Wearable sensors for monitoring and preventing noncommunicable diseases: a systematic review. Information **11**(11), 521 (2020). https://doi.org/10.3390/info11110521

Meina, M., Ratajczak, E., Sadowska, M., Rykaczewski, K., Dreszer, J., Bałaj, B., Biedugnis, S., Węgrzyński, W., Krasuski, A.: Heart rate variability and accelerometry as classification tools for monitoring perceived stress levels—a pilot study on firefighters. Sensors **20**(10) (2020). https://doi.org/10.3390/s20102834

Orr, R., Simas, V., Canetti, E., Schram, B.: A profile of injuries sustained by firefighters: a critical review. Int. J. Environ. Res. Public Health **16**(20) (2019). https://doi.org/10.3390/ijerph16203931

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hròbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D.: The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ **372**, n71 (2021). https://doi.org/10.1136/bmj.n71

Perroni, F., Guidetti, L., Cignitti, L., Baldari, C.: Psychophysiological responses of firefighters to emergencies: a review. Open Sport. Sci. J. **7**(1) (2014)

Rana, M., Mittal, V.: Wearable sensors for real-time kinematics analysis in sports: a review. IEEE Sens. J. **21**(2), 1187–1207 (2020). https://doi.org/10.1109/JSEN.2020.3019016

Raskovic, D., Martin, T., Jovanov, E.: Medical monitoring applications for wearable computing. Comput. J. **47**(4), 495–504 (2004). https://doi.org/10.1093/comjnl/47.4.495

Rodrigues, S., Paiva, J.S., Dias, D., Pimentel, G., Kaiseler, M., Cunha, J.P.S.: Wearable biomonitoring platform for the assessment of stress and its impact on cognitive performance of firefighters: an experimental study. Clin. Pract. Epidemiol. Ment. Health?: CP & EMH **14**, 250–262 (2018). https://doi.org/10.2174/1745017901814010250

Sawka, M.N., Friedl, K.E.: Emerging wearable physiological monitoring technologies and decision aids for health and performance. J. Appl. Physiol. **124**(2), 430–431 (2017). https://doi.org/10.1152/japplphysiol.00964.2017

Seravalle, G., Quarti Trevano, F., Grassi, G.: Heart rate as a predictor of cardiovascular risk. Minerva Med. **112**(1), 130–143 (2021). https://doi.org/10.23736/S0026-4806.20.06695-1

Siddall, A.G., Stevenson, R.D.M., Turner, P.F.J., Stokes, K.A., Bilzon, J.L.J.: Development of role-related minimum cardiorespiratory fitness standards for firefighters and commanders. Ergonomics **59**(10), 1335–1343 (2016). https://doi.org/10.1080/00140139.2015.1135997

Smith, D.L., Haller, J.M., Benedict, R., Moore-Merrell, L.: Firefighter incident rehabilitation: interpreting heart rate responses. Prehospital Emerg. Care **20**(1), 28–36 (2016). https://doi.org/10.3109/10903127.2015.1037477

Sol, J.A., Ruby, B.C., Gaskill, S.E., Dumke, C.L., Domitrovich, J.W.: Metabolic demand of hiking in wildland firefighting. Wilderness Environ. Med. **29**(3), 304–314 (2018). https://doi.org/10.1016/j.wem.2018.03.006

Stacey, M.J., Hill, N., Woods, D.: Physiological monitoring for healthy military personnel. Br. Med. J. Publ. Group (2018)

Tomes, C., Schram, B., Orr, R.: Relationships between heart rate variability, occupational performance, and fitness for tactical personnel: a systematic review. Front. Public Health **8** (2020)

Walker, A., Pope, R., Schram, B., Gorey, R., Orr, R.: The impact of occupational tasks on firefighter hydration during a live structural fire. Safety **5**(2) (2019). https://doi.org/10.3390/safety5020036

Wohlin, C.: Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering (2014)

Ye, S., Feng, S., Huang, L., Bian, S.: Recent progress in wearable biosensors: from healthcare monitoring to sports analytics. Biosensors **10**(12), 205 (2020). https://doi.org/10.3390/bios10120205

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Fatigue Assessment Through Physiological Monitoring During March-Run Series: Preliminary Results

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Abstract Background: Conditions of overexertion easily lead to situations of fatigue, which can result in problems for workers' health and safety. In military personnel, the severe conditions of their duties can quickly lead to fatigue affecting their health and performance. Objective: To answer this issue, an algorithm to detect fatigue combining the assessment of different physiological variables was developed. The algorithm performance was evaluated within laboratory trials, and this work presents the preliminary results of a retrospective assessment of military training recordings to validate its functioning. Method: Data from three soldiers participating in march-run training were assessed. The algorithm translated physiological sensory data into minute alarms according to fatigue levels determined through the conjunction of normative and related research criteria. Results/Discussion: Outcomes showed the high physiological cost of military practices and helped to overview the

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impact of each training period. Furthermore, results demonstrated the importance of individual and contextualised assessment for accurately characterise the subject fatigue status. Conclusions: It is concluded that the developed model can improve the management of real-time fatigue, allowing its early detection and preventing further physical impairments. Finally, it can promote the enhancement of work-rest cycles, not only for tactical personnel but also for any safety-sensitive occupation.

Keywords Physiological monitoring · Physical exertion · Fatigue detection · Military

1 Introduction

Fatigue is a complex and multidimensional phenomenon resulting from various factors; however, it is commonly identified when feeling tired or weary (Techera et al. 2016). In general, fatigue is recognised as a decreased ability to develop activities at the desired level due to lassitude or exhaustion of mental or physical strength (Hallowell 2010; Ream and Richardson 1996), and it is considered a major health and safety-related challenge among workers (Anwer et al. 2021). Prolonged fatigue affects workers' performance, leading to increased accident risk values, sick days, and disability from work (Swaen et al. 2003). Individuals and organisations that do not properly manage fatigue are at high risk of causing injuries and errors that can lead to various harmful and lasting consequences (Knoop et al. 2021; Williamson et al. 2011). Since this condition significantly increases the risk of adverse health issues, recent studies have determined it to be a predictor for these negative health outcomes rather than just a tiredness symptom (Knoop et al. 2021).

Fatigue is a critical employee safety and well-being issue for military organisations (Frone and Blais 2019). Besides typical operational stressors, soldiers, potentially more than any other working group, must deal with stressful situations that can lead to a state of fatigue, non-functional overreaching, and eventually overtraining conditions (Friedl 2012; Parnell et al. 2018). As a result, early detection and real-time monitoring of fatigue play a vital role in the military (Friedl 2012; Stacey et al. 2018). In general, literature has evidenced that traditional methods to assess fatigue, such as subjective measurements and self-reported fatigue (Fang et al. 2015; Lee et al. 1991; Rachmawati et al. 2020; Zhang et al. 2015), are biased by situational and individual perceptions and might be limited to some occupational environments (Anwer et al. 2021). On the other hand, biochemical workload markers offer reliable measurements of the individual's physical exertion (Horta et al. 2019) but do not allow a continuous non-invasive examination during normal working activities.

To overcome these limitations, researchers have attempted to use various non-invasive physiological variables such as heart rate, skin temperature, electromyography and jerk metrics to monitor real-time fatigue in any occupational setting (Friedl 2018; Lee et al. 2017). However, this obtained information needs to be translated into actionable data that can be used to prevent further physical impairments and improve individuals' performance in the workplace (Friedl 2018). As a result, an algorithm for fatigue detection and continuous assessment through physiological monitoring was developed. This decision-based system has been previously tested in laboratory trials (Bustos et al. 2019) and, this study aims to present the preliminary results of its application within a march-run military event.

2 Materials and Methods

2.1 Volunteers

Three male subjects were randomly selected to participate in the study and, their anthropometric characteristics are detailed in Table 1. They were regular elements from the Portuguese Army undertaking the 131st Commando Course. Before investigative procedures, participants gave their written consent and were briefed on the purpose, potential risks, and benefits of the experiences. Additionally, they underwent a medical examination (as a standard requirement to take part in the course) and did not present cardiac, vascular, pulmonary, or any allergic diseases; they were considered mentally healthy and were not prescribed any regular medication.

Physiological recordings were continuously collected while volunteers participated in a march-run series training. Before the event, subjects donned the physiological monitoring system as indicated. Contrarily to a previous laboratory maximal exertion test (Bustos et al. 2019), there were not predefined experimental protocols and recordings were gathered during normal training conditions. After obtaining the algorithm data, details about the event were requested and related to the evaluation carried out by the algorithm. The march-run training is a physical test involving running and marching with loads within a 42km path without time restrictions, with an approximate completion duration ranging from 4 to 6 h. This exercise intends to develop physical endurance and lower limb strength and encourage other qualities, such as teamwork, sacrifice spirit and discipline (Exército 2002). Following the event, blood test samples were also collected to assess indicators of stress levels and health-related effects and their results were compared with the alert-based system.

Table 1 Participants anthropometrics

Assigned code	Age	Height (cm)	Weight (kg)	Body fat mass (kg)	Body Fat (%)	Body Mass Index (kg/m2)
S1	28	176	70.15	8.20	11.69	22.65
S2	21	184	92.80	10.93	11.77	27.40
S3	21	178	76.05	11.48	15.09	24.03

2.2 Equipment

Initially, body composition was assessed using bioelectrical impedance analysis with the body composition analyser InBody230 (Karelis et al. 2013). During the training session, physiological measurements were recorded every 15 s through a chest belt physiological monitoring system: EquiVital LifeMonitor equipment (Hidalgo Ltd., Cambridge, U.K.), a “wear and forget” system type already validated for research purposes (Liu et al. 2013). For core temperature recordings, ingestible thermometer pills from Vital Sense were used (range: $-32^{\underline{o}}$C to $42^{\underline{o}}$C, accuracy $\pm 0.1\,^{\circ}$C). These pills travel along the digestive tract harmlessly and leave the body naturally within 24 to 72 h.

2.3 Data Analysis

Physiological monitoring records were posteriorly assessed using an algorithm (implemented using Python 3.6) that enables analysis and provides an integrated assessment of variables per minute and has already been described and tested in a previous study (Bustos et al. 2019). Its main feature lies in classifying received sensory information into health alarm levels that refer from a good overall health status (alarm 1) to four different fatigue levels (alarms 1.5, 2, 3 and 4) and a specific warning when the sensor is not functioning correctly (alarm -1). The default number of examined physiological variables is three (heart rate, breathing rate, and core temperature), another two referring to body position and the last one determining the validity of the sensor recordings. However, if one or more of these variables are found to be ’noisy’ (with invalid values), they are filtered, and the algorithm assesses the rest of the available information. Nevertheless, the more of these variables are included, the higher the reached accuracy.

3 Results and Discussion

The proposed algorithm has been evaluated previously in controlled laboratory conditions during a short maximal exertion test and showed reliable results (Bustos et al. 2019). After some improvements, this study presents the preliminary results from a retrospective assessment throughout a march-run military training event. In general, outcomes demonstrated that despite the different time completions of the exercise and the individual nature of physiological information, the system was able to evidence the various stages of training and the resulting physical demands on subjects throughout the event. Furthermore, its results and the blood test outcomes were consistent and allowed a complete view of the physiological state of participants.

3.1 Alert-Based System Results

In the three assessed cases, the algorithm proved to be a promising and simple approach for detecting physically demanding periods and the physiological impairment resulting from the most stressful situations, suggesting it can be extrapolated to various occupational and physically intense training settings. Results from the algorithm were obtained per minute and Fig. 1 presents the time percentage under each alarm category. Contrary to the laboratory experience (Bustos et al. 2019), higher alert levels and a higher time percentage in those levels were expected since prolonged intermittent exercises are proved to be more physically demanding than short continuous practices (Edwards et al. 1973, 1972; Kraning 2nd and Gonzalez 1991). In general, this was corroborated within obtained assessments.

Complementarily, and given the time variations under each alarm level, outcomes revealed the importance of individual and contextualised information to assess fatigue. All the subjects went through the same training periods, but they did not respond equally. For instance, two participants reached a maximal exertion alert (alarm 4), while only one reported almost 50% of the time under an alarm 2. Participant S1 proved to be the most resilient to the training showing the most stable tendency with more than 70% of the time under a good overall condition. In contrast, volunteers S2 and S3 reported periods of abrupt heart rate increases (registered by alarm 1.5) and the last subject also indicated the highest mean and peak values.

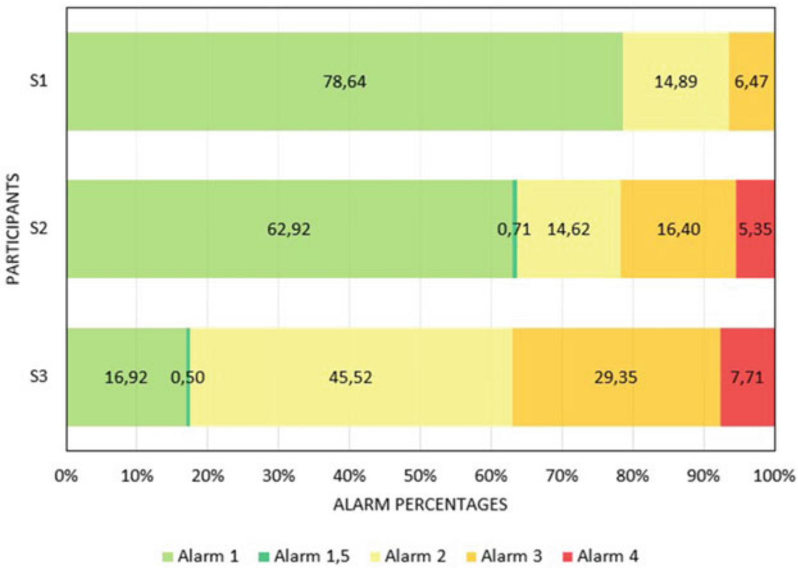

Fig. 1 Alarm percentages for each subject

Table 2 Summarised results per subject

Variable	S1	S2	S3
Mean heart rate (rpm)	125.66	128.42	148.43
Peak heart rate (rpm)	176.23	176.68	174.18
Mean breathing rate (rpm)	28.03	42.00	37.67
Peak breathing rate (rpm)	50.73	66.40	68.48
Mean core temperature (ºC)	37.45	37.67	38.36
Peak core temperature (ºC)	38.71	39.14	39.21

Overall, the trends were similar and delimited the effects of each exercise part. Still, aiming to detect any negative health indicator, outcomes need to be continuously and individually assessed (based on each subject's variations instead of absolute values that are not representative of individuals health condition) and diagnosis should not be made through only one variable (Buller et al. 2017; Friedl 2018; Tharion et al. 2019). Furthermore, and despite the differences in physiological responses, some similarities were observed. Two participants spent more than half of the time under a no fatigue condition, showing their physical capacity to continue training, and all of them reported a fatigued state only after 50 min. Since this test involved mainly an extended physical performance evaluation simulating a marathon, it was anticipated to obtain high alarm levels and high time percentages under fatigue but not immediately (like in a maximal exertion test). Fatigue was expected as the result of sustained effort and exertion, which was indeed observed among participants.

Referring to the physiological responses determining the alarms, Table 2 helps understand their influence on the high obtained alerts. Outcomes revealed that there were periods in which heart rate values reached 177 bpm and the breathing rate was above 60 rpm, denoting the elevated physiological cost associated with these practices. However, the most significant values were observed in core temperature since there were phases in which they went above 39 °C and maintained those high numbers over several minutes. This fact attests to the severe acute stress under which soldiers are exposed and verifies what is evidenced in literature during military field events (Lieberman et al. 2005, 2016; Ralph et al. 2017).

However, recorded physiological values are not conclusive indicators by separate. Given the multidimensional nature of fatigue and the several stressors faced by soldiers, the alteration of one of these variables does not provide a definite diagnosis of any health impairment. For example, an elevated heart rate can mean either a normal reaction to high physical demand, psychological stress or risk of cardiovascular stroke (Tadic et al. 2018). Similarly, core temperature reaching up to 40ºC can be associated with both peak demand or heat strain (Rizzo and Thompson 2017). Consequently, the integrated assessment proposed by this system appears as a reliable approach to represent fatigue manifestations. To the best available knowledge, selected physiological variables (heart rate, breathing rate and core temperature) together provide helpful insights into many situations requiring medical attention. However, a continued assessment of days or weeks is essential to characterise individual responses and future research will be oriented on this regard.

3.2 Results Versus Blood Test Values

The impact of the march-run test was also reflected in the alterations among some blood biomarkers. Figs. 2, 3 and 4 present the standardized results from each blood parameter, and red dashed lines represent their minimum and maximum reference values. Figure 2 shows that outcomes from the three participants were within the limit values for erythrogram markers, evidencing an average oxygenation level and blood cells flow. However, Figs. 3 and 4 revealed some alterations that go beyond clinic limits. Specifically, responses from leukocytes and neutrophils were visibly increased for S1 and S2, while lymphocyte results were under minimum reference numbers for all participants. These results illustrate how exercise and physically demanding activities influence the immune system parameters and correspond to previous studies on the expected immunological response to exercise (Cross et al. 1996; DuBose et al. 2003; Mitchell et al. 2002).

Moreover, the most remarkable outcomes were observed among renal and hepatic function indicators (Fig. 4). Urea and creatinine (markers of kidney function) were visibly altered, while liver enzymes (ASAT and ALAT) showed proportional changes.

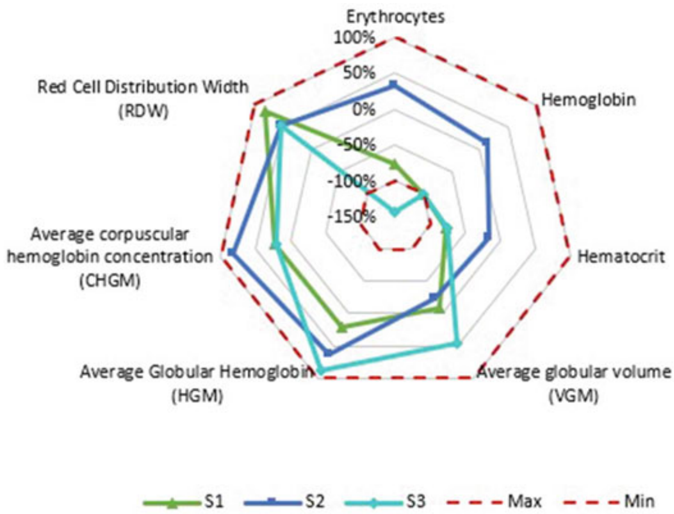

Fig. 2 Oxygenation level and blood cells flow

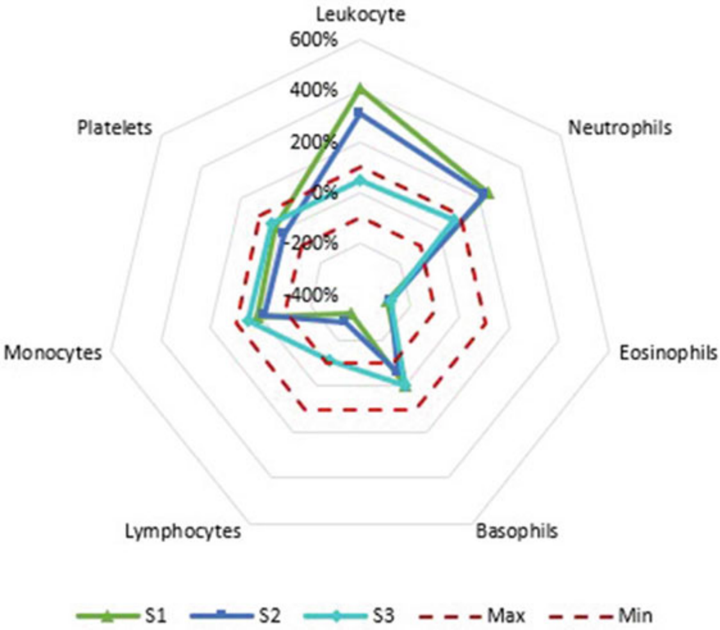

Fig. 3 Immune response

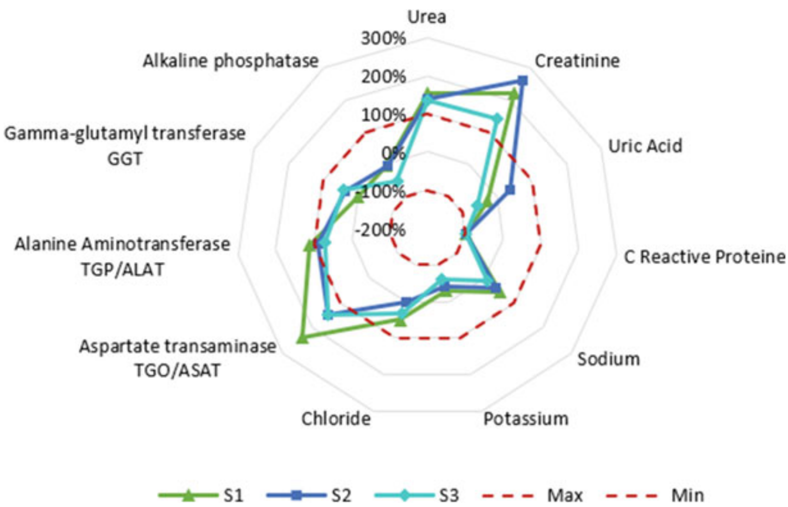

Fig. 4 Renal and hepatic function

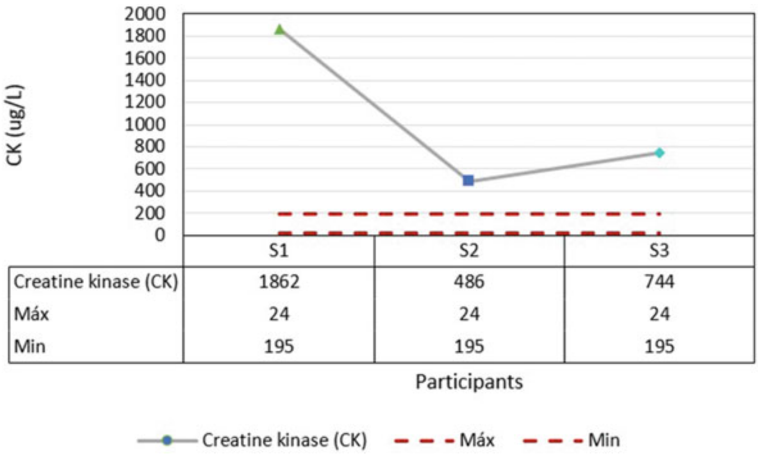

Fig. 5 Muscle damage results

Evidence of kidney alterations and hepatic responses have previously been reported due to military practices. In most individuals, these symptoms are transient and often completely reversible (Ward et al. 2020) and, follow-up assessments are crucial to confirm or not this recovery. In addition, potential muscular injury was observed as another consequence of the training. Figure 5 describes the CK (a well-known indicator of muscular damage; (Baird et al. 2012) severe increases in all participants. These alterations are expected during the first day of intensive activity but should be normalized within 24–48 h (Tomczak et al. 2020; Ward et al. 2020), suggesting the need for constant monitoring throughout all training activities and the establishment of sufficient recovery after these practices.

In general, blood tests and obtained alarms led to corresponding results on the effects this training test had on participants. For instance, S3 revealed both a high time percentage under alarm 4 and a significant increase in CK values. In addition, S2 showed the highest creatinine blood concentrations, which were consistent with his physiological alterations (high peak values of heart rate and breathing rate and core temperature reaching up to 39ºC). On the other hand, S1 proved to have a stable physiological load during the exercise but presented the highest CK values. This physiological resistance to training is a clear indicator of his good overall performance and ability to cope with the practice (Burley et al. 2020). The high CK responses might be attributed to the muscular activation he went through to support this good general performance.

Additionally, literature has described how individuals who regularly participate in high-volume intense exercise tend to have significantly raised base levels of CK compared to sedentary and moderately exercising subjects, and therefore, suggests that CK increases are a natural reaction to regular exercise (Baird et al. 2012; Chevion et al. 2003). This might have been the case of S1, with a potentially better physical condition than the other two subjects, thus, indicating a possible association between his physical endurance and muscular reaction through CK. Further studies, including base and follow-up assessments, will help corroborate these findings.

3.3 Limitations

Since this investigation refers to field measurements and was not conducted with data from a controlled laboratory environment, some unavoidable limitations were observed. Due to safety and security considerations, it was not possible to periodically verify whether sensors were functioning correctly during the training, much less whether or not valid data were being collected. As a result, there were some differences in testing times and quantity of available information. In addition, some recordings had to be dismissed due to their compromised validity, which did not allow a complete overview of all physiological variables. Furthermore, the small sample referred for assessment did not permit the drawing of generalisable conclusions. Finally, the time course for complete recovery from the training could not be determined since there were no follow-up assessments.

4 Conclusions

In this study, the preliminary outcomes from the validation of a decision-based algorithm for fatigue detection within a march-run training test are reported. Based on these initial results, it was demonstrated that the proposed alert-based system was able to provide reliable outcomes and led to the accurate identification of the most physically demanding periods and their direct impact on physiological variables. The assessment of more individuals undertaking this practice will help establish the intensity of each training period clearly and can also lead to better planning and management of training and work-rest cycles. Overall, by providing a multivariate approach, it is believed that this assessment method, with further modifications, can improve fatigue management among military populations and be included in the onboard processors from wearable sensors and provide a real-time assessment. For future work, its validity will be tested through a more significant sample, and additional variables will be added to the assessment system for more specificity and accuracy.

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References

Anwer, S., Li, H., Antwi-Afari, M.F., Umer, W., Wong, A.Y.L.: Evaluation of physiological metrics as real-time measurement of physical fatigue in construction workers: state-of-the-art review. J. Constr. Eng. Manag. **147**(5), 03121001 (2021). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002038

Baird, M.F., Graham, S.M., Baker, J.S., Bickerstaff, G.F.: Creatine-Kinase- and exercise-related muscle damage implications for muscle performance and recovery. J. Nutr. Metab. **2012**, 960363 (2012). https://doi.org/10.1155/2012/960363

Buller, M.J., Welles, A.P., Friedl, K.E.: Wearable physiological monitoring for human thermal-work strain optimization. J. Appl. Physiol. **124**(2), 432–441 (2017)

Burley, S.D., Drain, J.R., Sampson, J.A., Nindl, B.C., Groeller, H.: Effect of a novel low volume, high intensity concurrent training regimen on recruit fitness and resilience. J. Sci. Med. Sport. **23**(10), 979–984 (2020). https://doi.org/10.1016/j.jsams.2020.03.005

Bustos, D., Guedes, J., Alvares, M., Vaz, M., Torres Costa, J.: Real time fatigue assessment: identification and continuous tracing of fatigue using a physiological assessment algorithm. In: Occupational and Environmental Safety and Health. In Press (2019). https://doi.org/10.1007/978-3-030-14730-3_28

Chevion, S., Moran, D.S., Heled, Y., Shani, Y., Regev, G., Abbou, B., Berenshtein, E., Stadtman, E.R., Epstein, Y.: Plasma antioxidant status and cell injury after severe physical exercise. Proc. Natl. Acad. Sci. U. S. A. **100**(9), 5119–5123 (2003). https://doi.org/10.1073/pnas.0831097100

Cross, M.C., Radomski, M.W., Vanhelder, W.P., Rhind, S.G., Shephard, R.J.: Endurance exercise with and without a thermal clamp: effects on leukocytes and leukocyte subsets. J. Appl. Physiol. **81**(2), 822–829 (1996). https://doi.org/10.1152/jappl.1996.81.2.822

DuBose, D.A., Bruce Wenger, C., Flinn, S.D., Judy, T.A., Dubovtsev, A.I., Morehouse, D.H.: Distribution and mitogen response of peripheral blood lymphocytes after exertional heat injury. J. Appl. Physiol. **95**(6), 2381–2389 (2003). https://doi.org/10.1152/japplphysiol.00039.2003

Edwards, R., Ekelund, L.-G., Harris, R., Hesser, C., Hultman, E., Melcher, A., Wigertz, O.: Cardiorespiratory and metabolic costs of continuous and intermittent exercise in man. J. Physiol. **234**(2), 481–497 (1973)

Edwards, R., Melcher, A., Hesser, C., Wigertz, O., Ekelund, L.G.: Physiological correlates of perceived exertion in continuous and intermittent exercise with the same average power output. Eur. J. Clin. Investig. **2**(2), 108–114 (1972)

Exército, C.D.: Regulamento de Educação Física do Exército (2002)

Fang, D., Jiang, Z., Zhang, M., Wang, H.: An experimental method to study the effect of fatigue on construction workers' safety performance. Saf. Sci. **73**, 80–91 (2015)

Friedl, K.E.: Predicting human limits-the special relationship between physiology research and the Army mission. In: Friedl, K.E., Santee, W.R. (eds.) Military Quantitative Physiology: Problems and Concepts in Military Operational Medicine: Problems and Concepts in Military Operational Medicine, pp. 1–38 (2012)

Friedl, K.E.: Military applications of soldier physiological monitoring. J. Sci. Med. Sport (2018)

Frone, M.R., Blais, A.-R.: Work fatigue in a non-deployed military setting: assessment, prevalence, predictors, and outcomes. Int. J. Environ. Res. Public Health **16**(16) (2019). https://doi.org/10.3390/ijerph16162892

Hallowell, M.R.: Worker fatigue. Prof. Saf. **55**(12), 18 (2010)

Horta, T.A.G., Bara Filho, M.G., Coimbra, D.R., Miranda, R., Werneck, F.Z.: Training load, physical performance, biochemical markers, and psychological stress during a short preparatory period in brazilian elite male volleyball players. J. Strength Cond. Res. **33**(12), 3392–3399 (2019). https://doi.org/10.1519/JSC.0000000000002404

Karelis, A.D., Aubertin-Leheudre, M., Duval, C., Chamberland, G.: Validation of a portable bioelectrical impedance analyzer for the assessment of body composition. Appl. Physiol., Nutr. Metab. **38**(1), 27–32 (2013). https://doi.org/10.1139/apnm-2012-0129

Knoop, V., Cloots, B., Costenoble, A., Debain, A., Vella Azzopardi, R., Vermeiren, S., Jansen, B., Scafoglieri, A., Bautmans, I., Bautmans, I., Verté, D., Beyer, I., Petrovic, M., De Donder, L., Kardol, T., Rossi, G., Clarys, P., Scafoglieri, A., Cattrysse, E., de Hert, P., Jansen, B.: Fatigue and the prediction of negative health outcomes: a systematic review with meta-analysis. Ageing Res. Rev. **67**, 101261 (2021). https://doi.org/10.1016/j.arr.2021.101261

Kraning, K., 2nd., Gonzalez, R.R.: Physiological consequences of intermittent exercise during compensable and uncompensable heat stress. J. Appl. Physiol. **71**(6), 2138–2145 (1991)

Lee, K.A., Hicks, G., Nino-Murcia, G.: Validity and reliability of a scale to assess fatigue. Psychiatry Res. **36**(3), 291–298 (1991). https://doi.org/10.1016/0165-1781(91)90027-M

Lee, W., Lin, K.-Y., Seto, E., Migliaccio, G.C.: Wearable sensors for monitoring on-duty and off-duty worker physiological status and activities in construction. Autom. Constr. **83**, 341–353 (2017)

Lieberman, H.R., Bathalon, G.P., Falco, C.M., Kramer, F.M., Morgan, C.A., Niro, P.: Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. Biol. Psychiatry **57**(4), 422–429 (2005)

Lieberman, H.R., Farina, E.K., Caldwell, J., Williams, K.W., Thompson, L.A., Niro, P.J., Grohmann, K.A., McClung, J.P.: Cognitive function, stress hormones, heart rate and nutritional status during simulated captivity in military survival training. Physiol. Behav. **165**, 86–97 (2016)

Liu, Y., Zhu, S.H., Wang, G.H., Ye, F., Li, P.Z.: Validity and reliability of multiparameter physiological measurements recorded by the equivital life monitor during activities of various intensities. J. Occup. Environ. Hyg. **10**(2), 78–85 (2013)

Mitchell, J.B., Dugas, J.P., McFarlin, B.K., Nelson, M.J.: Effect of exercise, heat stress, and hydration on immune cell number and function. Med. Sci. Sport. Exerc. **34**(12), 1941–1950 (2002). https://doi.org/10.1097/00005768-200212000-00013

Parnell, N., Rye, K., Greenberg, N.: Health and well-being management in the military: a systematic review of genetic studies. J. R. Army Med. Corps **164**(4), 302–308 (2018). https://doi.org/10.1136/jramc-2017-000765

Rachmawati, S., Aktsari, M., Suryaningsih, A., Hawali Abdul Matin, H., Suryadi, I.: Assesment work fatigue to workers in environment underground mining areas based on fatigue assesment scale questionnaires. In: E3S Web of Conferences (2020)

Ralph, C.S., Vartanian, O., Lieberman, H.R., Morgan, C.A., Cheung, B.: The effects of captivity survival training on mood, dissociation, PTSD symptoms, cognitive performance and stress hormones. Int. J. Psychophysiol. **117**, 37–47 (2017)

Ream, E., Richardson, A.: Fatigue: a concept analysis. Int. J. Nurs. Stud. **33**(5), 519–529 (1996)

Rizzo, L., Thompson, M.W.: Cardiovascular adjustments to heat stress during prolonged exercise. J. Sport. Med. Phys. Fit. **58**(5), 727–743 (2017). https://doi.org/10.23736/s0022-4707.17.06831-1

Stacey, M.J., Hill, N., Woods, D.: Physiological monitoring for healthy military personnel. Br. Med. J. Publ. Group (2018)

Swaen, G.M.H., van Amelsvoort, L.G.P.M., Bültmann, U., Kant, I.J.: Fatigue as a risk factor for being injured in an occupational accident: results from the Maastricht Cohort Study. Occup. Environ. Med. **60**(suppl 1), i88 (2003). https://doi.org/10.1136/oem.60.suppl_1.i88

Tadic, M., Cuspidi, C., Grassi, G.: Heart rate as a predictor of cardiovascular risk. Eur. J. Clin. Investig. **48**(3), e12892 (2018)

Techera, U., Hallowell, M., Stambaugh, N., Littlejohn, R.: Causes and consequences of occupational fatigue: meta-analysis and systems model. J. Occup. Environ. Med. **58**(10) (2016). https://journals.lww.com/joem/Fulltext/2016/10000/Causes_and_Consequences_of_Occupational_Fatigue_.1.aspx

Tharion, W.J., Friedl, K. E., Buller, M.J., Arango, N.H., Hoyt, R.W.: Evolution of physiological status monitoring for ambulatory military applications. In: Human Performance Optimization, pp. 142–164. Oxford University Press

Tomczak, A., Jówko, E., Rózański, P.: Survival training effects on oxidative stress and muscle damage biomarkers of naval cadets. Aerosp. Med. Hum. Perform. **91**(9), 720–724 (2020). https://doi.org/10.3357/AMHP.5536.2020

Ward, M.D., King, M.A., Gabrial, C., Kenefick, R.W., Leon, L.R.: Biochemical recovery from exertional heat stroke follows a 16-day time course. PLoS ONE **15**(3), Article e0229616 (2020). https://doi.org/10.1371/journal.pone.0229616

Williamson, A., Lombardi, D.A., Folkard, S., Stutts, J., Courtney, T.K., Connor, J.L.: The link between fatigue and safety. Accid. Anal. Prev. **43**(2), 498–515 (2011). https://doi.org/10.1016/j.aap.2009.11.011

Zhang, M., Sparer, E.H., Murphy, L.A., Dennerlein, J.T., Fang, D., Katz, J.N., Caban-Martinez, A.J.: Development and validation of a fatigue assessment scale for US construction workers. Am. J. Ind. Med. **58**(2), 220–228 (2015)

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Insight into the Potential of Urinary Biomarkers of Oxidative Stress for Firefighters' Health Surveillance

Bela Barros, Marta Oliveira, and Simone Morais

Abstract Objective: This chapter reviews scientific information related to urinary biomarkers of oxidative stress assessed in a firefighting context and their potential for being used in future biomonitoring studies. Background: Firefighters are exposed to several hazard chemicals and physical and mentally-demanding activities than can disrupt body homeostasis. Oxidative stress results from a disequilibrium in oxidation/reduction reactions which can mainly lead to lipid peroxidation and DNA oxidation. There are several urinary biomarkers that can be used for biomonitoring of oxidative stress (e.g., isoprostane, malondialdehyde, and oxidized guanine species). Method: Literature data until April 2021 were retrieved from the main scientific databases and thoroughly analyzed. Results: Information is scarce and available studies have only considered so far wildland firefighting (wildland fires and prescribed burns), with no significant cross-shift changes in lipid peroxidation biomarkers. However, the DNA oxidation biomarker, 8-hydroxy-2'-deoxyguanosine significantly increased in wildland firefighters after exposure to fire emissions. In addition, data are needed to understand the impact of structural firefighting in 8-isoprostane and malondialdehyde urinary levels. Conclusion: Even though there are few studies exploring urinary biomarkers of oxidative stress, they present the potential to be applied in cross-sectional and cohort studies in several types of firefighters. Application: Firefighters' health monitoring and occupational medicine.

Keywords Biomonitoring · Firemen · DNA oxidation · Lipid peroxidation · Urine

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1 Introduction

Firefighting is an occupational environment that frequently deals with all kinds of fire emissions (e.g., wildland, prescribed burns, and structural), thus, the amount of exposure to persistent and non-persistent pollutants can vary considerably (Beitel et al. 2020; Fent et al. 2020; Oliveira et al. 2016). Nevertheless, occupational risks are not exclusively related with hazard exposure, but are also connected with mentally stressful situations, as well as strenuous physical exertion in high temperature environments (Hunter et al. 2014; Kim et al. 2018; Smith et al. 2001; Swiston et al. 2008). The International Agency for Research on Cancer has classified firefighting as possible carcinogenic (IARC 2010). Several epidemiological studies have observed an increase in morbidity and mortality among firefighters that are mainly related with respiratory, cardiovascular diseases and cancer (Casjens et al. 2020; Glass et al. 2017; Navarro et al. 2019; Soteriades et al. 2011). Human biomonitoring studies are crucial to evaluate the association between occupational exposure and health outcomes (Vorkamp et al. 2021). Firefighting has been linked with oxidative stress, inflammation and related diseases (Adetona et al. 2013; 2019; Gaughan et al. 2014; Gianniou et al. 2016; Peters et al. 2018). In an oxidative stress state, several reactive oxygen and nitrogen species are formed, which can react with biological macromolecules such as proteins, lipids (e.g., in the cellular membrane) and nucleotides (e.g., in DNA). At the molecular level, oxidative stress is responsible for lipid peroxidation and DNA oxidation. Therefore, the extension of this oxidative stress state creates several stimuli that can lead to disease development (Senoner and Dichtl 2019). Monitoring biomarkers of oxidative stress pathways allow a more complete evaluation of firefighters' occupational exposure and the associated health-risks. This chapter aims to discuss the results of currently available publications that have determined urinary biomarkers of oxidative stress in firefighters and explored the potential of these biomarkers for future occupational safety biomonitoring campaigns.

2 Methods

An extensive search without date range and with the keywords "oxidative stress, firefighters, and urinary biomarkers" was done in Science Direct, ISI Web of science, PubMed, and Google Scholar databases. This search originated a total of 110 scientific papers and abstract screening was done based on the following eligible criteria: (i) to include healthy and active firefighters and (ii) to determine urinary biomarkers of oxidative stress in firefighting context. Only six studies fitted these criteria and were included in this work (Adetona et al. 2013; 2019; Gaughan et al. 2014; Missoula Technology and Development Center [MTDC] 2000; Wu, Adetona et al. 2020; Wu, Warren et al. 2020).

3 Results and Discussion

3.1 Urinary Biomarkers of Oxidative Stress

Available biomonitoring studies have included the determination of biomolecules involved in lipid peroxidation (8-isoprostane (i.e., 8-iso-prostaglandin F2α) and malondialdehyde (MDA)), and DNA oxidation (e.g., 8-hydroxy-2'-deoxyguanosine (8-OHdG)), which are known biomarkers of oxidative stress. Urine is the most characterized matrix since it is non-invasive. Table 1 presents the levels of oxidative stress biomarkers, namely 8-isoprostane (n = 3), MDA (n = 3), and 8-OHdG (n = 5) determined in the urine of firefighters.

3.2 Lipid Peroxidation

With lipid peroxidation, several free lipid radicals are formed as a result of oxidative lipid degradation of the cellular membrane (Thimmulappa et al. 2020). The instability of lipid peroxides can decompose lipid free radical into secondary highly reactive compounds such as MDA (Sies et al. 2017). However, the main products of lipid peroxidation, derivatives of arachidonic acid such as 8-isoprostane, are more stable, and thus, a more powerful and reliable biomarker of oxidative stress (Nam 2011). Literature as acknowledge 8-isoprostane as a standard biomarker to characterize lipid peroxidation status (Nam 2011). Also, in contrast with MDA, urinary concentrations of 8-isoprostane are not affected by diet (Adetona et al. 2019). Therefore, urinary 8-isoprostane and MDA are the most characterized biomarkers of lipid peroxidation. Both biomarkers have been determined in the urine of firefighters involved in firefighting of wildfires and prescribed burns (Table 1).

So far, only three studies determined the levels of urinary 8-isoprostane in firefighters (Table 1). Overall, urinary levels increased from 0.2 to 1.05 μg/g creatinine on pre-shift samples to 0.3–1.72 μg/g creatinine on post-shift/next morning samples after participation in prescribed burns (Adetona et al. 2019; Gaughan et al. 2014; Wu, Warren et al. 2020). Gaughan et al. (2014) observed an association between wildland firefighting and oxidative stress score. The authors reported 8-isoprostane levels of 0.72 ng/mL (Table 1). Variables such as age, career length, use of smokeless tobacco, and diet had no effect on the urinary levels of 8-isoprostane (Adetona et al. 2019). At prescribed burn-days, which are thought to present a less toxic environment than wildland fires, firefighters presented 2.64 times greater levels of urinary 8-isoprostane than in non-burn days (Wu, Warren, et al. 2020). Wu, Warren, et al. (2020) reported firefighters' personal exposure to high levels (5-fold higher) of particulate matter with aerodynamic diameter of 2.5 μm or lower ($PM_{2.5}$), which were 3 to 5-fold more mutagenic in their study (conducted in the Midwest USA) in comparison to the others (firefighters from Southeastern USA) (Wu, Warren, et al., 2020). Therefore, this fact could help to explain the significantly different 8-isoprostane levels observed in

Table 1 Reported data of oxidative stress biomarkers in the urine of firefighters

Reference	Firefighters	Exposure	n	Age	Concentration (mean ± SD)	Main findings
8-isoprostane ($\mu g/g$ creatinine, unless indicated otherwise)						
(Gaughan et al. 2014)	USA Wildland	The Sand Gulch fire §	♂38	29 ± 4.34	0.72 ± 2.63[a]	Correlated with urinary levoglucosan levels No difference according with the history of smoking
(Adetona et al. 2019)	USA Wildland/work-certified volunteers	Prescribed burns	12 ♂9 ♀3	33 ± 5.4	Burn days: Pre-shift: 0.4 (0.3, 0.5)[b] Post-shift: 0.3 (0.2, 0.4)[b] Next morning: 0.3 (0.2, 0.4)[b] Non-burn days: Pre-shift: 0.2 (0.2, 0.3)[b] Post-shift: 0.4 (0.3, 0.5)[b] Next morning: 0.3 (0.2, 0.4)[b]	No significant effect of work tasks (lighting or holding), age, wildland firefighter career length, work-shift duration, days since last prescribed burn, use of smokeless tobacco (chew), or grilled foods

(continued)

Table 1 (continued)

Reference	Firefighters	Exposure	n	Age	Concentration (mean ± SD)	Main findings
(Wu, Warren, et al. 2020)	USA Wildland	Prescribed burns	19 ♂17	35.0±7.2	Burn days:	Correlated with malondialdehyde urinary levels
			♀2		Pre-shift: 1.05 ± 0.21	2.64 times greater increase on burn-days than in non-burn days
					Post-shift: 1.72±0.36	No significant correlation with work tasks (lighting or holding)
					Next morning: 1.72 ± 0.47	
					Non-burn days:	
					Pre-shift: 0.82 ± 0.13	
					Post-shift: 0.50 ± 0.12	
					Next morning: 0.96 ± 0.20	
Malondialdehyde (µmol/g creatinine, unless indicated otherwise)						
(Adetona et al. 2013)	USA Wildland	Prescribed burns	17	29.8 ± 6.1	Pre-shift: 0.78±0.43	Neither $PM_{2.5}$, age nor the length of firefighting career were a significant factor
			♂16		Post-shift: 0.95 ± 0.30	No correlation with 8-hydroxy-2'-deoxyguanosine levels
			♀1			

(continued)

Table 1 (continued)

Reference	Firefighters	Exposure	n	Age	Concentration (mean ± SD)	Main findings
(Wu, Warren et al. 2020)	USA Wildland	Prescribed burns	19	35.0 ± 7.2	Burn days:	Correlated with black carbon personal exposure concentration
			♂17		Pre-shift: 3.28 ± 0.29	Correlated with 8-isoprostane urinary levels
			♀2		Post-shift: 3.43 ± 0.23	No correlation with work tasks (lighting or holding)
					Next morning: 4.17 ± 0.45	
					Non-burn days:	
					Pre-shift: 4.94 ± 0.61	
					Post-shift: 4.15 ± 0.45	
					Next morning: 3.81 ± 0.59	
(Adetona et al. 2019)	USA Wildland/work-certified volunteers	Prescribed burns	12	33±5.4	Burn days:	Correlated with urinary mutagenicity
			♂9		Pre-shift: 0.80 (0.69, 0.94)[b,c]	No correlation with effects for age, work tasks (lighting or holding), firefighter career length, work-shift duration, days since last prescribed burn, use of smokeless tobacco (chew), or grilled foods
			♀3		Post-shift: 0.76 (0.67, 0.86)[b,c]	
					Next morning: 0.67 (0.59, 0.76)[b,c]	
					Non-burn days:	
					Pre-shift: 0.73 (0.59, 0.91)[b,c]	
					Post-shift: 0.89 (0.67, 1.13)[b,c]	
					Next morning: 0.71 (0.54, 0.93)[b,c]	
8-hydroxy-2'-deoxyguanosine (µg/g creatinine, unless indicated otherwise)						

(continued)

Table 1 (continued)

Reference	Firefighters	Exposure	n	Age	Concentration (mean ± SD)	Main findings
(Hong et al. 2000)	Korean firefighters	A fire within 5 d of the study	♂73	21–58	Exposure >8 h (n = 13): 14.1	Significantly increased concentrations were attributed to cigarette smoking
					Exposed <8 h (n = 36): 12.3	No differences between active, less active and non-exposed firefighters No correlation with diet and alcohol
(MTDC 2000)	USA Wildland	Wildland fire	10	n.r.	♂ firefighters: 1.28[d]	Significant effect for gender, especially for females
			♂ ♀		♀ firefighters: 1.68[d]	No significant differences from early to late fire exposure
(Adetona et al. 2013)	USA Wildland	Prescribed burns	17	29.8 ± 6.1	Pre-shift: 81 ± 122	Correlated with both age and the length of firefighting career for shorter career length (≤2 years)
			♂16		Post-shift: 70 ± 90	No correlation with $PM_{2.5}$ exposure
			♀1			
(Gaughan et al. 2014)	USA Wildland	The Sand Gulch fire §	♂38	29 ± 4.34	5.62 ± 2.29[a]	Correlated with levoglucosan urinary exposure Significant differences between recently exposed and no recent exposure, but after adjusting for levoglucosan No difference between smoking and non-smoking participants

(continued)

Table 1 (continued)

Reference	Firefighters	Exposure	n	Age	Concentration (mean ± SD)	Main findings
(Wu, Warren et al. 2020)	USA Wildland	Prescribed burns	19	35.0±7.2	Burn days:	3-fold increased difference between burn-day and non-burn days
			♂17		Pre-shift: 83.04 ± 16.06 ¥	No significant correlation between work tasks. (lighting or holding) and cross-shift changes
			♀2		Post-shift: 67.54 ± 15.55 ¥	
					Next morning: 134.77 ± 31.34 ¥	
					Non-burn days:	
					Pre-shift: 101.99 ± 32.67 ¥	
					Post-shift: 91.46 ± 38.25 ¥	
					Next morning: 55.21± 17.11 ¥	

USA: United States of America; $PM_{2.5}$: particulate matter with aerodynamic diameter lower than 2.5 µm. n.r.: not reported

[a]Data are presented as ng/mL and was originally expressed as Log_{10}

[b]Data are expressed as mean (95% Confidence Limits)

[c]Data are presented as µmol/mol creatinine

[d] Data are presented as (ng/mL)/creatinine (mM); § 495-acre wildland fire at 7000 ft elevation in high difficulty terrain (Gaughan et al. 2014); ¥Data refer to all oxidized guanine species

this study (Wu, Warren, et al., 2020) as opposed to the others (Adetona et al. 2017, 2019; Adetona et al. 2013). Moreover, occupational exposure may be significantly influenced by the type of burned (bio)materials. Though available data are limited and not sufficient to associate exposure to fires emissions with increased levels of urinary 8-isoprostane, future studies should explore this biomarker in firefighters, including participation in other toxic environments such as structural fires (Keir et al. 2017).

A previous study performed in healthy young adults highlighted the potential and usefulness of urinary MDA as a biomarker of systemic oxidative stress in a population exposed to air pollution (Gong et al. 2013). Regarding firefighters' exposure to fires emissions released from prescribed burns events, urinary MDA levels ranged from pre-shift 0.78–3.28 μmol/g creatinine to post-shift/next morning 0.95–4.17 μmol/g creatinine (and 74.4–84.3 μmol/mol creatinine (Adetona et al. 2019)) (Table 1). Adetona et al. (2019) reported an unexpected (although non-significant) decrease in MDA levels from pre- to post-shift on burn days (89.2 vs. 84.3 μmol/mol creatinine), and an increase on non-burn days though not significant (81.6 vs. 98.6 μmol/mol creatinine). This profile could have been due to not documented exposure or other confounders such as lipid intake through the diet (Adetona et al. 2019). Once again, the highest cross-shift changes were observed in the study of Wu, Warren et al. (2020) (Table 1). However, this difference cannot be solely attributed to distinct emissions composition as mentioned before (Midwest USA versus Southeastern and Western USA). The most probable cause could have been the different analytical methods applied, i.e., colorimetric assays (Wu, Warren et al. 2020) versus high-performance liquid chromatography (HPLC) preferred by the other authors (Adetona et al. 2013; 2019). Thus, standardization of methods is essential for research data comparability and reproducibility. On the other hand, no association was observed between MDA levels and $PM_{2.5}$ exposure, work tasks, age, diet (e.g., consumption of grilled food), firefighting career length, and smokeless tobacco consumption (chew) (Adetona et al. 2019). However, the current findings in firefighters also indicated a correlation between MDA cross-shift urinary levels and personal air black carbon exposure (Wu, Warren et al. 2020). Some authors found a significant association between urinary concentrations of 8-isoprostane in USA firefighters with urinary levels of levoglucosan, well-known biomarker of exposure to wood smoke (Gaughan et al. 2014) and with MDA levels (Wu, Warren et al. 2020). Moreover, in addition to the correlation between these two biomarkers of lipid peroxidation, concentrations of urinary MDA also positively correlated with urinary mutagenicity ($p = 0.0010$), probably due to the mutagenic properties of the emissions that wildland firefighters were exposed to. Also, MDA is potentially mutagenic, that can further lead to DNA lesions or alterations that may consequently contribute to disease development (Adetona et al. 2019).

Overall, available studies suggest an increase on the urinary biomarkers of lipid peroxidation after firefighting, however, differences between pre- to post-shifts were mostly not significant. Therefore, more biomonitoring studies are urgently needed to better understand the relation between firefighters' occupational exposure and the stimulation of oxidative stress pathways. Moreover, levels of urinary 8-isoprostane have been related with several cardiovascular (e.g., atherosclerosis, heart failure) and respiratory (e.g., asthma and chronic obstructive pulmonary disorder) diseases, diabetes, and cancer, while concentrations of urinary MDA have been linked with atherosclerosis, cancer, multiple sclerosis, and obesity (Sies et al. 2017). In the firefighting context, an association between the concentrations of urinary biomarkers of oxidative stress (8-isoprostane and 8-OHdG) and arterial stiffness in wildland firefighters has been reported (Gaughan et al. 2014). Future longitudinal cohort studies are needed to explore the actual research gaps regarding the potential of using urinary biomarkers of lipid peroxidation in firefighters' biomonitoring assays, which will contribute to a more realistic health risk assessment.

3.3 DNA Oxidation

Determination of DNA oxidation is an important metric to evaluate the extent of DNA damage in an individual. Guanine is the most prone nucleotide to undergo oxidation, and 8-OHdG and 8-hydroxyguanine (8-OHGua) are among the most characterized DNA lesions (Valavanidis et al. 2009). These lesions are important precursors of carcinogenic mechanisms involving mutations, DNA methylation pattern alterations, and DNA damage (Hayes et al. 2020; Valavanidis et al., 2009; Zhou et al. 2019). So far, only five studies have determined the urinary levels of 8-OHdG in firefighting forces (Table 1). Available literature has shown that firefighters who were recently exposed to wildland fires and prescribed burns presented significantly higher concentrations of urinary 8-OHdG than those with no recent exposure to fire emissions (Pre-shift: 83.04 versus next morning: 134.77 μg/g creatinine; Table 1). However, differences observed by Gaughan et al. (2014) became marginally significant ($p = 0.07$) when values were adjusted with the urinary levoglucosan levels. On the other hand, Wu, Warren et al. (2020) quantified all oxidized guanine species in the urine of North American firefighters after participation in prescribed burns. Those authors observed a significant 3-fold increase ($p = 0.02$) in the urinary levels of 8-OHdG from pre- to next morning on burn days comparatively with non-exposed days and the consequently decrease overtime in non-burn days (Wu, Warren et al. 2020). Additionally, Adetona et al. (2013) also reported a significant increase in the urinary levels of 8-OHdG in firefighters with a short-career ($\leq$2 years). This can be explained by the time needed for body's adjustment to firefighting activities, thus, in higher career length stages, firefighters' body could have already developed defense mechanisms that can better control the excess of oxidative stress. Moreover, female firefighters might be more susceptible to DNA oxidation than male firefighters (MTDC 2000). Firefighters exposed to the emissions of prescribed burns presented levels of urinary 8-OHdG that correlated with levoglucosan levels [regression estimate 0.41 (95% CI: 0.04,0.79)] (Gaughan et al. 2014). Evidence suggest that 8-OHdG concentrations were not influenced by firefighter' work task, diet, and alcohol consumption; smoking history showed mixed results: Hong et al. (2000) observed a direct correlation contrasting with Gaughan et al. (2014) who did not find any association (Table 1).

Urinary levels of 8-OHdG have been directly linked with cancer development pathways (Hayes et al. 2020; Sies et al. 2017). Therefore, this biomarker of effect can be a useful tool to explore the relation and causality between firefighting and cancer incidence and related mortality among firefighters.

Few studies have been performed in firefighters, yet, studies have been also implemented with other workers such as coke oven, e-waste dismantlers, and boilermakers. Correlations were reported between urinary 1-hydroxypyrene (biomarker of exposure to polycyclic aromatic hydrocarbons (PAH)) and lipid peroxidation biomarkers as well as DNA damage in coke oven workers (Deng et al. 2014; Kuang et al. 2013). Exposure to other hazardous chemicals such as polychlorinated dibenzo-p-dioxins, polybrominated diphenyl ethers, and polychlorinated biphenyls (more frequently identified in structural fires) were associated with elevated 8-OHdG urinary levels in e-waste dismantler workers (Wen et al. 2008). Even among the general population correlations were found between urinary MDA and 8-OHdG levels and PAH metabolites in urine of healthy adults (Bortey-sam et al. 2017; Sun et al. 2017) and children (Li et al. 2015; Wang et al. 2017). Regarding ambient metal exposure, urinary concentration of metals significantly correlated with urinary 8-isoprostane, 8-OHdG and MDA in people living near a coking plant (Hu et al. 2021). Moreover, a cohort study (Framingham Offspring cohort) including 2035 non-occupational exposed participants reported positive associations of urinary MDA and 8-isoprostane with $PM_{2.5}$ and black carbon (Li et al. 2016). Therefore, crossing this information with the one available concerning firefighters further motivates the exploitation of urinary biomarkers of oxidative stress in the diversified occupational exposure context that is experienced by firefighters.

4 Conclusions

This study characterized the impact of firefighting on urinary biomarkers of oxidative stress, namely 8-isoprostane, MDA and 8-OHdG. Data are emerging for wildland firefighting context while no information exists regarding structural firefighters, which can suffer more severe oxidative stress response due to the complex mix of toxic pollutants in structural fire smoke. Available information showed a significant increase of urinary 8-OHdG related with wildland firefighting, especially in the first career years. Therefore, the potential use of this biomarker of DNA oxidation to monitor disease risk development, particularly cancer among firefighters, was demonstrated. Moreover, given the importance of lifestyle and exercise under hot conditions on body redox balance, these variables should be taken in consideration to better understand the contribution of exposure to air pollutants to oxidative stress scores. Moreover, the simultaneous use of both exposure and oxidative stress biomarkers during firefighting activities would be extremely useful for occupational characterization.

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References

Adetona, A.M., Adetona, O., Gogal, R.M., DIaz-Sanchez, D., Rathbun, S.L., Naeher, L.P.: Impact of work task-related acute occupational smoke exposures on select proinflammatory immune parameters in wildland firefighters. J. Occup. Environ. Med. **59**(7), 679–690 (2017). https://doi.org/10.1097/JOM.0000000000001053

Adetona, A.M., Kyle Martin, W., Warren, S.H., Hanley, N.M., Adetona, O., Zhang, J., Simpson, C., Paulsen, M., Rathbun, S., Wang, J.S., DeMarini, D., Naeher, L.P.: Urinary mutagenicity and other biomarkers of occupational smoke exposure of wildland firefighters and oxidative stress. Inhalation Toxicol. **31**(2), 73–87 (2019). https://doi.org/10.1080/08958378.2019.1600079

Adetona, O., Zhang, J., Hall, D.B., Wang, J.S., Vena, J.E., Naeher, L.P.: Occupational exposure to woodsmoke and oxidative stress in wildland firefighters. Sci. Total Environ. **449**, 269–275 (2013). https://doi.org/10.1016/j.scitotenv.2013.01.075

Beitel, S. C., Flahr, L. M., Hoppe-Jones, C., Burgess, J.L., Littau, S.R., Gulotta, J., Moore, P., Wallentine, D., Snyder, S.A.: Assessment of the toxicity of firefighter exposures using the PAH CALUX bioassay. Environ. Int. **135**(August 2019), 105207 (2020). https://doi.org/10.1016/j.envint.2019.105207

Bortey-sam, N., Ikenaka, Y., Akoto, O., Nakayama, S.M.M., Asante, K.A., Baidoo, E., Obirikorang, C., Saengtienchai, A., Isoda, N., Nimako, C., Mizukawa, H., Ishizuka, M.: Oxidative stress and respiratory symptoms due to human exposure to polycyclic aromatic hydrocarbons (PAHs) in Kumasi, Ghana *. Environ. Pollut. **228**, 311–320 (2017). https://doi.org/10.1016/j.envpol.2017.05.036

Casjens, S., Brüning, T., Taeger, D.: Cancer risks of firefighters: a systematic review and meta-analysis of secular trends and region-specific differences. Int. Arch. Occup. Environ. Health **93**(7), 839–852 (2020). https://doi.org/10.1007/s00420-020-01539-0

Deng, Q., Dai, X., Guo, H., Huang, S., Kuang, D., Feng, J., Wang, T., Zhang, W., Huang, K., Hu, D., Deng, H., Zhang, X., Wu, T.: Polycyclic Aromatic Hydrocarbons-Associated MicroRNAs and Their Interactions with the Environment: Influences on Oxidative DNA Damage and Lipid Peroxidation in Coke Oven Workers (2014)

Fent, K.W., Toennis, C., Sammons, D., Robertson, S., Bertke, S., Calafat, A.M., Pleil, J.D., Wallace, M.A.G., Kerber, S., Smith, D., Horn, G.P.: Firefighters' absorption of PAHs and VOCs during controlled residential fires by job assignment and fire attack tactic. J. Eposure Sci. Environ. Epidemiol. **30**(2), 338–349 (2020). https://doi.org/10.1038/s41370-019-0145-2

Gaughan, D.M., Siegel, P.D., Hughes, M.D., Chang, C.Y., Law, B.F., Campbell, C.R., Richards, J.C., Kales, S.F., Chertok, M., Kobzik, L., Nguyen, P., son, O'Donnell, C.R., Kiefer, M., Wagner, G.R., Christiani, D.C.: Arterial stiffness, oxidative stress, and smoke exposure in wildland firefighters. Am. J. Ind. Med. **57**(7), 748–756 (2014). https://doi.org/10.1002/ajim.22331

Gianniou, N., Katsaounou, P., Dima, E., Giannakopoulou, C.E., Kardara, M., Saltagianni, V., Trigidou, R., Kokkini, A., Bakakos, P., Markozannes, E., Litsiou, E., Tsakatikas, A., Papadopoulos, C., Roussos, C., Koulouris, N., Rovina, N.: Prolonged occupational exposure leads to allergic airway sensitization and chronic airway and systemic inflammation in professional firefighters. Respir. Med. **118**, 7–14 (2016). https://doi.org/10.1016/j.rmed.2016.07.006

Glass, D.C., Del Monaco, A., Pircher, S., Vander Hoorn, S., Sim, M.R.: Mortality and cancer incidence among male volunteer Australian firefighters. Occup. Environ. Med. **74**(9), 628–638 (2017). https://doi.org/10.1136/oemed-2016-104088

Gong, J., Zhu, T., Kipen, H., Wang, G., Hu, M., Ohman-Strickland, P., Lu, S.E., Zhang, L., Wang, Y., Zhu, P., Rich, D.Q., Diehl, S.R., Huang, W., Zhang, J.: Malondialdehyde in exhaled breath condensate and urine as a biomarker of air pollution induced oxidative stress. J. Eposure Sci. Environ. Epidemiol. **23**(3), 322–327 (2013). https://doi.org/10.1038/jes.2012.127

Hayes, J.D., Dinkova-Kostova, A.T., Tew, K.D.: Oxidative stress in cancer. Cancer Cell **38**(2), 167–197 (2020). https://doi.org/10.1016/j.ccell.2020.06.001

Hong, Y.C., Park, H.S., Ha, E.H.: Influence of genetic susceptibility on the urinary excretion of 8-hydroxydeoxyguanosine of firefighters. Occup. Environ. Med. **57**(6), 370–375 (2000). https://doi.org/10.1136/oem.57.6.370

Hu, W., Wang, Y., Wang, T., Ji, Q., Jia, Q., Meng, T., Ma, S., Zhang, Z., Li, Y., Chen, R., Dai, Y., Luan, Y., Sun, Z., Leng, S., Duan, H., Zheng, Y.: Ambient particulate matter compositions and increased oxidative stress: exposure-response analysis among high-level exposed population. Environ. Int. **147**, 106341 (2021). https://doi.org/10.1016/j.envint.2020.106341

Hunter, A.L., Unosson, J., Bosson, J.A., Langrish, J.P., Pourazar, J., Raftis, J.B., Miller, M.R., Lucking, A.J., Boman, C., Nyström, R., Donaldson, K., Flapan, A.D., Shah, A.S.V., Pung, L., Sadiktsis, I., Masala, S., Westerholm, R., Sandström, T., Blomberg, A., Mills, N.L.: Effect of wood smoke exposure on vascular function and thrombus formation in healthy fire fighters. Part. Fibre Toxicol. **11**(1), 1–13 (2014). https://doi.org/10.1186/s12989-014-0062-4

IARC: Monographs on the Evaluation of Carcinogenic Risks to Humans. Painting, Firefighting, and Shiftwork, vol. 98 (2010). https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Painting-Firefighting-And-Shiftwork-2010

Keir, J.L.A., Akhtar, U.S., Matschke, D.M.J., Kirkham, T.L., Chan, H.M.: Elevated Exposures to Polycyclic Aromatic Hydrocarbons and Other Organic Mutagens in Ottawa Firefighters Participating in Emergency, On-Shift Fire Suppression. Environ. Sci. Technol. **51**, 12745-12755 (2017).

Kim, S., H-j, L., D-m, S., B-s, K., J-h, O., B-j, C., J-y, M.: Cardiovascular Risk in Fire Academy Instructors During Live-Fire Simulation Activity Risque Cardio-Vasculaire Chez Les Pompiers Instructeurs Lors De Sessions D'Entraînement En Conditions Réelles, pp. 313–321. Annals of Burns and Fire Disasters, XXXI(December) (2018)

Kuang, D., Zhang, W., Deng, Q., Zhang, X., Huang, K., Guan, L., Hu, D., Wu, T., Guo, H.: Dose-Response Relationships of Polycyclic Aromatic Hydrocarbons Exposure and Oxidative Damage to DNA and Lipid in Coke Oven Workers (2013)

Li, J., Lu, S., Liu, G., Zhou, Y., Lv, Y., She, J., Fan, R.: Co-exposure to polycyclic aromatic hydrocarbons, benzene and toluene and their dose - effects on oxidative stress damage in kindergarten-aged children in Guangzhou. China. Sci. Total Environ. **524–525**, 74–80 (2015). https://doi.org/10.1016/j.scitotenv.2015.04.020

Li, W., Wilker, E.H., Dorans, K.S., Rice, M.B., Schwartz, J., Coull, B.A., Koutrakis, P., Gold, D.R., Keaney, J.F., Lin, H., Vasan, R.S., Benjamin, E.J., Mittleman, M.A. (2016). Short-term exposure to air pollution and biomarkers of oxidative stress: the framingham heart study. J. Am. Heart Assoc. **5**(5). https://doi.org/10.1161/JAHA.115.002742

MTDC: Wildland Firefighters Health & Safety Report (2000). https://www.fs.fed.us/eng/pubs/htmlpubs/htm00512825/toc.htm

Nam, T.G.: Lipid peroxidation and its toxicological implications. Toxicol. Res. **27**(1), 1–6 (2011). https://doi.org/10.5487/TR.2011.27.1.001

Navarro, K.M., Kleinman, M.T., Mackay, C.E., Reinhardt, T.E., Balmes, J.R., Broyles, G.A., Ottmar, R.D., Naher, L.P., Domitrovich, J.W.: Wildland firefighter smoke exposure and risk of lung cancer and cardiovascular disease mortality. Environ. Res. **173**(November 2018), 462–468 (2019). https://doi.org/10.1016/j.envres.2019.03.060

Oliveira, M., Slezakova, K., Alves, M.J., Fernandes, A., Teixeira, J.P., Delerue-Matos, C., Pereira, M., do C., Morais, S.: Firefighters' exposure biomonitoring: Impact of firefighting activities on levels of urinary monohydroxyl metabolites. Int. J. Hyg. Environ. Health **219**(8), 857–866 (2016). https://doi.org/10.1016/j.ijheh.2016.07.011

Peters, B., Ballmann, C., Quindry, T., Zehner, E.G., McCroskey, J., Ferguson, M., Ward, T., Dumke, C., Quindry, J.C.: Experimental woodsmoke exposure during exercise and blood oxidative stress. J. Occup. Environ. Med. **60**(12), 1073–1081 (2018). https://doi.org/10.1097/JOM.0000000000001437

Senoner, T., Dichtl, W.: Oxidative stress in cardiovascular diseases: still a therapeutic target? Nutrients **11**(9), 2090 (2019). https://doi.org/10.3390/nu11092090

Sies, H., Berndt, C., Jones, D.P.: Oxidative stress. Ann. Rev. Biochem. **86**, 715–748 (2017). https://doi.org/10.1146/annurev-biochem-061516-045037

Smith, D.L., Petruzzello, S.J., Chludzinski, M.A., Reed, J.J., Woods, J.A.: Effect of strenuous live-fire fire fighting drills on hematological, blood chemistry and psychological measures. J. Therm. Biol **26**(4–5), 375–379 (2001). https://doi.org/10.1016/S0306-4565(01)00047-X

Soteriades, E.S., Smith, D.L., Tsismenakis, A.J., Baur, D.M., Kales, S.N.: Cardiovascular disease in US firefighters: A systematic review. Cardiol. Rev. **19**(4), 202–215 (2011). https://doi.org/10.1097/CRD.0b013e318215c105

Sun, H., Hou, J., Zhou, Y., Yang, Y., Cheng, J., Xu, T., Xiao, L., Chen, W., Yuan, J.: Chemosphere Dose-response relationship between urinary polycyclic aromatic hydrocarbons metabolites and urinary 8-hydroxy-2 0 -deoxyguanosine in a Chinese general population. Chemosphere **174**, 506–514 (2017). https://doi.org/10.1016/j.chemosphere.2017.01.104

Swiston, J.R., Davidson, W., Attridge, S., Li, G.T., Brauer, M., Van Eeden, S.F.: Wood smoke exposure induces a pulmonary and systemic inflammatory response in firefighters. Eur. Respir. J. **32**(1), 129–138 (2008). https://doi.org/10.1183/09031936.00097707

Thimmulappa, R.K., Chattopadhyay, I., Rajasekaran, S.: Oxidative Stress Mechanisms in the Pathogenesis of Environmental Lung Diseases. In Oxidative Stress in Lung Diseases, pp. 103–137. Springer, Singapore (2020). https://doi.org/10.1007/978-981-32-9366-3_5

Valavanidis, A., Vlachogianni, T., Fiotakis, C.: 8-Hydroxy-2’ -deoxyguanosine (8-OHdG): a critical biomarker of oxidative stress and carcinogenesis. J. Environ. Sci. Health - Part C Environ. Carcinog. Ecotoxicol. Rev. **27**(2), 120–139 (2009). https://doi.org/10.1080/10590500902885684

Vorkamp, K., Castaño, A., Antignac, J.P., Boada, L.D., Cequier, E., Covaci, A., Esteban López, M., Haug, L.S., Kasper-Sonnenberg, M., Koch, H.M., Pérez Luzardo, O., Osīte, A., Rambaud, L., Pinorini, M.T., Sabbioni, G., Thomsen, C.: Biomarkers, matrices and analytical methods targeting human exposure to chemicals selected for a European human biomonitoring initiative. Environ. Int. **146**(July 2020), 106082 (2021). https://doi.org/10.1016/j.envint.2020.106082

Wang, I.J., Karmaus, W.J.J., Chang, C.: Polycyclic aromatic hydrocarbons exposure, oxidative stress, and asthma in children. International Archives of Occupational and Environmental Health (2017). https://doi.org/10.1007/s00420-017-1198-y

Wen, S., Yang, F.-X., Gong, Y., Zhang, X.-L., Hui, Y., Li, J.-G., Liu, A.-L., Wu, Y.-N., Lu, W.-Q., Xu, Y.: Elevated levels of urinary 8-hydroxy-2’-deoxyguanosine in male electrical and electronic equipment dismantling workers exposed to high concentrations of polychlorinated dibenzo- p -dioxins and dibenzofurans, polybrominated diphenyl ethers, and polychlorin. Environ. Sci. Technol. **42**(11), 4202–4207 (2008). https://doi.org/10.1021/es800044m

Wu, C.M., Adetona, A., Song, C., Naeher, L., Adetona, O.: Measuring acute pulmonary responses to occupational wildland fire smoke exposure using exhaled breath condensate. Arch. Environ. Occup. Health **75**(2), 65–69 (2020). https://doi.org/10.1080/19338244.2018.1562413

Wu, C.M., Warren, S.H., Demarini, D.M., Song, C.C., Adetona, O.: Urinary mutagenicity and oxidative status of wildland firefighters working at prescribed burns in a Midwestern US forest. Occup. Environ. Med. **1–8**,(2020). https://doi.org/10.1136/oemed-2020-106612

Zhou, J., Jenkins, T.G., Jung, A.M., Jeong, K.S., Zhai, J., Jacobs, E.T., Griffin, S.C., Dearmon-Moore, D., Littau, S.R., Peate, W.F., Ellis, N.A., Lance, P., Chen, Y., Burgess, J.L.: DNA methylation among firefighters. PLoS ONE **14**(3), 1–18 (2019). https://doi.org/10.1371/journal.pone.0214282

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Prevalence of Patellofemoral Pain Syndrome in Selective Garbage Collection Workers—Cross Sectional Study

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Abstract Background: Patellofemoral Pain Syndrome (PFPS) is a Musculoskeletal Disorder (MSD) not commonly studied in an occupational context. Its prevalence in the general population is 22.7%. There is, however, little evidence of the prevalence of PFPS in specific populations working in industry and services. In this context, this study aimed to assess the PFPS prevalence among workers in a garbage collection company. Methods: All 20 workers that drove the truck and worked in the collection of garbage dumped in the recycling bins of a company of selective garbage collection in recycling bins in Portugal were assessed by an occupational physician between March and December 2020. Results: Six workers (30%) were diagnosed with an PFPS. Discussion/Conclusion: This study showed a higher prevalence of PFPS than in the general population. Thus, our findings show the importance of studying the problem deeply and taking effective preventive measures in the work of selective garbage collection.

Keywords Prevalence · "Selective garbage collection" · Prevention · "Worker's health" · "musculoskeletal disorder"

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1 Introduction

According to a 2016 consensus, the patellofemoral pain syndrome (PFPS) is defined as a musculoskeletal disorder (MSD) that is characterized by acute peripatellar pain, with or without irradiation, of a gradual nature, which worsens with squatting and going up or down the stairs (Crossley et al. 2016). In the occupational context, there are still very few studies of FPFS with non-athlete populations so it is not possible to define its prevalence in most sectors of activity, namely in industrial and services sectors (Neal et al. 2019; Smith et al. 2018).

In Europe, approximately 30% of workers with MSD complaints report unspecific lower limb MSDs (feet, knees, thigh, muscle, bone, tendon, joints) (Jan de Kok et al. 2019). However, as these data do not have an associated cause-effect relationship with any task, it is impossible to clearly understand whether MSD is related or not with work.

When considering specifically PFPS, estimates in the work context vary between 13.5% in the military context (Boling et al. 2010), 29.3% in ballet dancers (professionals) (Winslow and Yoder 1995), 35.7% in professional cyclists during the competition season (Clarsen et al. 2010) and 34.9% in workers at a large Iranian automobile manufacturing company (Sharifian et al. 2020).

Selective garbage collection workers are an occupational group particularly vulnerable to exposure to ergonomic risks. The repetitive movement of climbing up and down vertical stairs to access the truck crane (Fig. 1) during the work shift is particularly damaging. The tasks performed require movements that are harmful to the knee joint, such as the extension of the thigh with the knees flexed above 60° (Powers et al. 2017; Willy et al. 2019).

Fig. 1 Up and down movement demonstration (using the stairs to the crane)

Thus, considering the risk of PFPS in workers who perform selective garbage collection, the objective of the present study was to estimate the prevalence of PFPS in this population of workers.

1.1 Materials and Methods

The data collection was carried out by an occupational physician of a Portuguese garbage collection company between March 8 and December 21, 2020.

The methodology of this study consists of a cross-sectional study, in which a population sample was monitored for a nine months-long period, observing the prevalence of PFPS. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) methodology for cross-sectional studies was chosen (Gharaibeh et al. 2014; von Elm et al. 2008).

The study sample was chosen due to the previously assessed high exposure to ergonomic risk of these workers: repeatedly going up and down vertical stairs throughout the work shift. The study sample consisted of selective collection workers, totalling 20 individuals, 2 women and 18 men, with a history of work in the company between 6 and 18 years.

The workers included in this study perform the ascending and descending of a vertical ladder with five steps over the 8-hour shift (Fig. 1), a total of approximately 50 times (one for each Ecopoint), which implies the approximate movement of 100 times of ascents and descents corresponding to 500 steps per day (250 on the way up and 250 on the way down) (Fig. 2), computing one movement every 9.6 min.

From the general population of the garbage collection company, a sample of workers who met the following eligibility criteria was selected: 1. Selective garbage collection workers that drove the truck and worked in the collection of garbage dumped in the recycling bins 2. Workers who do not participate in sports activities simultaneously with work.

The diagnosis criteria used by the occupational physician for the diagnosis of PFPS (Crossley et al. 2016; Souza et al. 2017) in the selected workers were: 1. Presence of acute peripatellar pain with or without irradiation, with gradual nature, worsening with squatting and when going up and down stairs during anamnesis. 2. Positive Clarke signal on physical examination.

After a medical evaluation, all sample data were treated in Excel 2016 (Bonita et al. 2010).

Fig. 2 Vertical ladder used to ascend and descend at each stop of Eco points

2 Results

Among the twenty exposed workers (18 men and 2 women), six male workers (30%) had PFPS.

There were no previous data for the 20 evaluated workers to know the existence of PFPS in the admission exams. For the 14 workers without the disease, there was no new case report of PFPS from the beginning until the end of the study period.

3 Discussion

According to a recent meta-analysis, the prevalence of PFPS in the general population is 22.7% (Smith et al. 2018), considering variations for specific activities. In the context of the studied sample of workers who drive the truck and who work in the collection of garbage dumped in the recycling bins, it was possible to find a prevalence of 30% of people with the disease, which corresponds to 7.3% above the nominal value of the prevalence of the general population.

Few studies have assessed the prevalence of PFPS with worker samples (Smith et al. 2018). In the context of industrial work or services, there is little evidence in the literature to date (Neal et al. 2019; Smith et al. 2018).

In our sample, the high prevalence of PFPS may be a warning sign for occupational health and safety specialists (Crossley et al. 2019; Jan de Kok et al. 2019; Neal et al. 2019; Powers et al. 2017). The need to go up and down five steps on vertical stairs, approximately 100 times a day, is an aggravating factor for PFPS due to the high torque value applied to the knees. This joint bends at an angle greater than 90° (Powers et al. 2017; Willy et al. 2019), as shown in Fig. 1. In this context, engineering measures are needed to avoid the problem, redesigning the steps or, even better, placing the crane controls accessible from the ground.

Despite the scarcity of evidence in the literature in working populations regarding PFPS, further studies are needed to recognize PFPS as an Occupational Disease and include it in the list of diseases recognized by ILO as occupational (International Labour Organization and ILO 2010).

3.1 Limitations

The most significant limitations of the work were the low sample size, the lack of information prior to the evaluation period and the short period of the studied population follow-up.

4 Conclusions

Aiming to contribute to the knowledge of the Patellofemoral Pain Syndrome prevalence among drivers of selective waste collection, it was possible to obtain a high prevalence of FPFS in the studied sample.

Thus, despite the sample size, our findings shows the importance of studying the problem deeply and taking effective preventive measures in the work of selective garbage collection, thus preventing the development of the disease.

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References

Boling, M., Padua, D., Marshall, S., Guskiewicz, K., Pyne, S., Beutler, A.: Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scand. J. Med. Sci. Sport. **20**(5), 725–730 (2010). https://doi.org/10.1111/j.1600-0838.2009.00996.x

Bonita, R., Beaglehole, R., Kjellström, T.: Epidemiologia Básica 2 a edição. In: Editora, G.G. (ed.) 2nd ed. World Health Organization (WHO) (2010). https://apps.who.int/iris/bitstream/handle/10665/43541/9788572888394_por.pdf?sequence=5&isAllowed=y

Clarsen, B., Krosshaug, T., Bahr, R.: Overuse injuries in professional road cyclists. Am. J. Sport. Med. **38**(12), 2494–2501 (2010). https://doi.org/10.1177/0363546510376816

Crossley, K.M., Stefanik, J.J., Selfe, J., Collins, N.J., Davis, I.S., Powers, C.M., McConnell, J., Vicenzino, B., Bazett-Jones, D.M., Esculier, J.-F.F., Morrissey, D., Callaghan, M.J.: 2016 patellofemoral pain consensus statement from the 4th international patellofemoral pain research retreat, Manchester. Part 1: terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome M. Br. J. Sport. Med. **50**(14), 839–843. https://doi.org/10.1136/bjsports-2016-096384

Crossley, K.M., van Middelkoop, M., Barton, C.J., Culvenor, A.G.: Rethinking patellofemoral pain: prevention, management and long-term consequences. Best Pract. Res.: Clin. Rheumatol. **33**(1), 48–65 (2019). https://doi.org/10.1016/j.berh.2019.02.004

de Kok, Jan, Vroonhof, P., Snijders, J., Roullis, G., Clarke, M., Peereboom, K., van Dorst, P., Isusi, I.: Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. In: European Agency for Safety and Health at Work (2019). https://doi.org/10.2802/66947

de Souza, C.E.A., Silva, T.A.B., Duarte, G.W., da Souza, J.P.S.: Evaluation in adolescents practitioners and non-practitioners of futsal to detect positivity for patellar chondromalacia. Revista Dor **18**(2), 141–144 (2017). https://doi.org/10.5935/1806-0013.20170028

Gharaibeh, A., Koppikar, S., Bonilla-Escobar, J.F.: Strengthening the reporting of observational studies in epidemiology (STROBE). Int. J. Med. Stud. **2**(2), 36–37 (2014). https://doi.org/10.5195/ijms.2014.76

International Labour Organization, ILO.: LIST OF OCCUPATIONAL DISEASES (revised 2010). Identification and recognition of occupational diseases: criteria for incorporating diseases in the ILO list of occupational diseases. In: International Labour Organization ILO, vol. 74 (2010). https://doi.org/10.1017/CBO9781107415324.004

Neal, B.S., Lack, S.D., Lankhorst, N.E., Raye, A., Morrissey, D., Van Middelkoop, M.: Risk factors for patellofemoral pain: a systematic review and meta-analysis. Br. J. Sport. Med. **53**(5), 270–281 (2019). BMJ Publishing Group. https://doi.org/10.1136/bjsports-2017-098890

Powers, C.M., Witvrouw, E., Davis, I.S., Crossley, K.M.: Evidence-based framework for a pathomechanical model of patellofemoral pain: 2017 patellofemoral pain consensus statement from the 4th international patellofemoral pain research retreat, Manchester, UK: part 3. Br. J. Sport. Med. **51**(24), 1713–1723 (2017). https://doi.org/10.1136/bjsports-2017-098717

Sharifian, S.A., Chinichian, M., Halimimilani, A., Mehrdad, R.: Prevalence and risk factors of patellofemoral pain in an automobile manufacturing factory. Malays. J. Med. Health Sci. **16**(2) (2020)

Smith, B.E., Selfe, J., Thacker, D., Hendrick, P., Bateman, M., Moffatt, F., Rathleff, M.S., Smith, T.O., Logan, P.: Incidence and prevalence of patellofemoral pain: a systematic review and meta-analysis. PLoS ONE **13**(1), e0190892 (2018). https://doi.org/10.1371/journal.pone.0190892

von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gøtzsche, P.C., Vandenbroucke, J.P.: The Strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. J. Clin. Epidemiol. **61**(4), 344–349 (2008). https://doi.org/10.1016/j.jclinepi.2007.11.008

Willy, R.W., Hoglund, L.T., Barton, C.J., Bolgla, L.A., Scalzitti, D.A., Logerstedt, D.S., Lynch, A.D., Snyder-Mackler, L., McDonough, C.M.: Patellofemoral pain clinical practice guidelines linked to the international classification of functioning, disability and health from the academy

of orthopaedic physical therapy of the American physical therapy association. J. Orthop. Sport. Phys. Ther. **49**(9), CPG1–CPG95 (2019). https://doi.org/10.2519/jospt.2019.0302
Winslow, J., Yoder, E.: Patellofemoral pain in female ballet dancers: correlation with iliotibial band tightness and tibial external rotation. J. Orthop. Sport. Phys. Ther. **22**(1), 18–21 (1995). https://doi.org/10.2519/jospt.1995.22.1.18

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Indoor Air Quality Under Restricted Ventilation and Occupancy Scenarios with Focus on Particulate Matter: A Case Study of Fitness Centre

Klara Slezakova, Cátia Peixoto, Maria do Carmo Pereira, and Simone Morais

Abstract Objective: This work assessed particulate matter (PM_1, $PM_{2.5}$, PM_5 and PM_{10}) and thermal comfort parameters (temperature, relative humidity) in indoor air of fitness centre, under restricted ventilation and occupancy scenarios. Background: Exercising on regular basis provides countless health benefits, which might be countered if done in environments with poor air. Methods: PM was continuously (24 h) monitored for two weeks in one fitness club situated Oporto Metropolitan Area, Portugal. Various indoor spaces (body building and cardio fitness areas, studios) were assessed. Results: Across all spaces, PM_{10} ranged 13–298 $\mu g\ m^{-3}$, (mean 56 $\mu g\ m^{-3}$) exceeding Portuguese limit of 50 $\mu g\ m^{-3}$. PM_5 (4–196 $\mu g\ m^{-3}$; 42 $\mu g\ m^{-3}$) were highly correlated with PM_{10} ($|rs| = 0.937$), whereas $PM_{2.5}$ (3.8–49 $\mu g\ m^{-3}$; 14 $\mu g\ m^{-3}$) and PM_1 (1.6–26 $\mu g\ m^{-3}$; 7.5 $\mu g\ m^{-3}$) accounted for, respectively, 25% and 15% of PM_{10}. Finally, relative humidity was well below the indicated guideline range. Conclusions: The obtained results suggest possible inhalation risks and discomforts for the occupants of the respective fitness centre. Reasonable measures should be used to regulate indoor air quality, even under restricted conditions, in order to ensure safe and comfortable environments.

Keywords Indoor air · PM_{10} · $PM_{2.5}$ · Ventilation · Sport facilities

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1 Introduction

Despite the known benefits of exercising, the worldwide trend has shifted towards less total daily physical activity; it has been estimated that approximately 30% of the worldwide adult population is insufficiently active (Hallal et al. 2012). This trend was further enforced by the recent coronavirus disease 2019 (COVID-19) pandemic, which brought profound challenges to society. While its spread has been mitigated through various strategies, including social distancing (working and studying from home); these changes may result in the further adoption of a sedentary lifestyle. Insufficient physical activity has been linked to a higher risk for cardiovascular diseases (Carnethon 2010; Lee et al. 2012). Thus, various organizations promote increased physical activity (WHO 2016). It is necessary to enhance that these activities do not necessarily need to be conducted indoors, however, current society spends ca. 90% of time indoors. The associations between indoor environment and public health is then indisputable. Exposure to air pollution has been linked with increased mortalities and cardiorespiratory morbidity including many adverse health effects (cancers of different organs, impaired neuro- and cognition development, diabetes – type 2; Holgate 2017). Furthermore, the prolonged time duration of being indoors, while at the same time the lesser degree of pollutant dispersion and/or dilution in confined spaces, may ultimately result in indoor exposures of several magnitudes larger than those from ambient air (Goodman et al. 2017; Hodas et al. 2016). In addition, humans and their activities are significant contributors to indoor pollution (Braniš and Šafránek 2011; Buonanno et al. 2012). Thus, it is particularly relevant to assess places, where a significant part of the air pollution and its impact are assumingly caused by the occupants (Buonanno et al. 2012; Žitnik et al. 2016), and at the same time the increased inhalation (from physical activities) may lead to much higher degree of exposure (Pacitto et al. 2020; Wagner and Clark 2018). Particulate matter (PM) is among the most health relevant indoor pollutants (WHO 2010). It is a complex mixture of solid and/or liquid particles of different sizes (WHO 2010). The size of the particle is especially relevant as it determines its deposition in respiratory system (Holgate 2017); the smallest PM can enter into the deepest parts of the respiratory and deposit in lungs. Substantial body of evidence shows that exposure to particles, both short-term and long-term, is of particular concern with regard to adverse health effects (Shi et al. 2016). Indoors, PM may be produced by various activities which include operation and maintenance practices, housekeeping practices, cooking printing, etc. They can also result from infiltration of outdoor emissions, through cracks and gaps in the building envelope and via natural and mechanical ventilation (Chen and Zhao 2011), the latter being likely source of ambient PM in commercial buildings.

This study is part of ongoing project, which main aim is to asses indoor air quality in fitness centres and sport facilities. Specifically, it reports levels of PM (PM_1, $PM_{2.5}$, PM_5, and PM_{10}) in one fitness club conducted in spring 2021, under specific scenarios for indoor occupancy and ventilation.

2 Materials and Methods

Indoor air quality assessment was conducted in indoor air of one fitness centre that belongs to a chain of low-cost clubs. It was situated in Oporto Metropolitan Area (north of Portugal) inside of a shopping mall. The club organization included: main bodybuilding area (BB) with various machines and further equipment, cardio fitness zone (CF; with treadmills, rowing and elliptical machine), studios for group exercise (GS), bathrooms and locker rooms with associated functions, administrative and support spaces (reception, storage room or support for staff), and enhanced spaces (fitness assessment spaces, vending machine). The club did not have swimming pool or any outdoor facilities, and its architectural layout was rather unusual. The main areas of the club (bodybuilding and cardio fitness zones) were situated in open-air of the shopping mall mezzanine, directly above restaurants and food areas. There were no barriers that would separate the air environment in these two zones from the rest of the shopping mall; air conditions in these places depended on air quality of the shopping mall, with two extra fans providing additional air movements. The studios and the administrative/support spaces were enclosed spaces/rooms that were located in the interiors of the club (apart from the mezzanine), with installed HVAC ventilation system. However, due to the health restrictions to limit the spread of COVID-19 at the time of sampling, the ventilation system was constantly switched-off (even when group classes took place). As what concern to the mall area, the air was renovated every hour and maximum number of people that could simultaneously be present was also controlled.

The air sampling was conducted continuously (during 24 h) in indoor air of the one fitness club for a period of two weeks (May 2021) during all week days (Mon–Fri) and weekends (Sat–Sun). Particles in a range of 0.3–25 μm were monitored by Lighthouse Handheld particle counter (model 3016 IAQ; Lighthouse Worldwide Solutions, Fremont, USA) that was equipped with an additional probe to monitor thermal comfort parameters (temperature and relative humidity). The equipment was positioned on a support (approximately at 1.3 ± 0.2 m above the floor surface) and at least 1.5 m from walls in order to minimize the influence on particle dispersion (Holmberg and Li 1998; Jin et al. 2013) and avoiding all direct emission sources that might interfere with data acquisition (i.e. air conditioners, ventilation points, and exists). The logging interval was 60 s, resulting in a large set of PM measurements (n = 72000); prior to sampling the sampler was calibrated at manufacturer. All necessary precautions were taken in order to maintain the safety of all subjects (exercisers as well as study researchers).

During the data collection, a member of the research team was always present at site to register all relevant data (such as gym occupancies, class activities and etc.) or any pertinent information related to potential emission sources and ventilations. When necessary, the staff of the fitness centre clarified further details. Statistical analyses of the data were conducted using SPSS (IBM SPSS Statistics 20) and Microsoft Excel 2013 (Microsoft Corporation). As obtained data did not display normal distributions (confirmed by Shapiro-Wilk's test), medians were compared through the nonparametric Mann-Whitney U test. Statistical significance was set as $p < 0.05$.

3 Results and Discussion

The statistics for different PM fractions collected in one fitness centre are summarized in Fig. 1. Overall, indoor levels of all PM fractions demonstrated large variations of the obtained data. The concentrations of fine particles ($PM_{2.5}$ and PM_1) were relatively low. PM_1 ranged between 1.6 and 26 $\mu g\, m^{-3}$ (mean of 7.5 $\mu g\, m^{-3}$), whereas it was 3.8–49 $\mu g\, m^{-3}$ (mean of 14 $\mu g\, m^{-3}$) for $PM_{2.5}$. In two previous studies (Almeida et al. 2016; Ramos et al. 2014) evaluating indoor air quality of 11 fitness centres (Lisbon; majority centres with mechanical ventilation), the authors reported concentration of $PM_{2.5}$ in similar ranges: 0.9–43 $\mu g\, m^{-3}$ (for centres with controlled ventilations). Coarse particles (PM_{10} and PM_5) evaluated in this fitness club were higher than elsewhere (Bralewska et al. 2019). PM_5 ranged between 4.0 and 196 $\mu g\, m^{-3}$ (mean of 39 $\mu g\, m^{-3}$) whereas values were 13–298 $\mu g\, m^{-3}$ (mean of 51 $\mu g\, m^{-3}$) for PM_{10}. It is necessary to point out that coarse PM in the club were much higher (approximately 2–3 times) than those previously reported in fitness centres with similar settings and ventilation systems (i.e. sophisticated HVAC systems with use of air filtration supply; Ramos et al. 2014; Slezakova et al. 2018), most likely due to the unusual architectural layout of the club. Further, in terms of PM_{10},

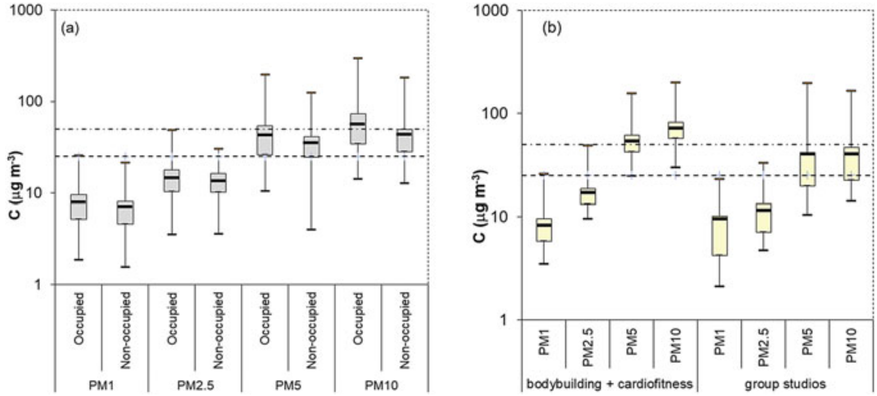

Fig. 1 Concentrations of different fractions of particulate matter (■ mean; □ 25–75%, and ⌶ range) in the studied fitness centre: **a** according to the occupancy periods (i.e. during the opened hours and when closed); **b** in different functional areas (during occupied periods). Dashed lines represent the existent limit values (50 and 25 $\mu g\, m^{-3}$ for PM_{10} and $PM_{2.5}$, respectively) settled by the national legislation Decreto-Lei 118/2013. Note: Y axes are scaled to logarithmic mode to adequately display the concentration ranges

the observed levels were similar to indoor air of gyms with natural ventilations (i.e. by windows opening; Slezakova et al. 2018), which typically reflects in overall much higher indoor particulate pollution (Montgomery et al. 2015).

As there is no consensual threshold (below which PM would not pose any health risks), currently there is no unique value or guideline standards. Recommendations of WHO for PM indoor air is based on the guidelines for ambient air (in a view that there is no conclusive evidence concerning the hazardousness of indoor-emitted PM in a comparison of the ambient one; WHO 2010). The respective values (for 24 h concentrations) are available for PM_{10} and $PM_{2.5}$ with 50 and 25 $\mu g\, m^{-3}$, respectively. These values were adopted by Portuguese legislation on indoor air quality of public buildings (Decreto-Lei 118/2013), but opposed to WHO, they are expressed as 8-h means. While $PM_{2.5}$ values fulfilled the limits in all functional spaces (means ranging between 7.2 and 18 $\mu g\, m^{-3}$ for BB, CF and GS), PM_{10} concentrations in the body building and cardio fitness areas exceeded the respective limits during the occupied periods, therefore indicating possible inhalation risks for the respective occupants (both staff and exercisers). As inadequate indoor air quality in places for fitness activity can easily counteract the benefits of the well-being due to physical exercise (Fei Qin et al. 2019; Reche et al. 2020; Wagner and Clark 2018), PM levels in these environments should be further characterized in order to correctly assess the respective exposures.

$PM_{2.5}$, PM_5, and PM_{10} means were statically different between the various functional spaces ($p < 0.05$) of one fitness club. As shown in Fig. 1b, higher means (and variations) of PM levels were observed in the bodybuilding and cardio fitness areas than in enclosed studios, with the respective PM concentrations being higher (35–78%). These results of this study were contrary to previous works that reported elevated PM pollution in confined studios due to the high number of exercising people, various activity patterns and different types of human "movement" (Sacks and Shendell 2014a, b; Slezakova et al. 2019). Firstly, due to the enforced health-based guidelines to prevent the spread of COVID-19 at the time of the study, human occupancy in groups studios was strictly restricted and controlled (3–9 people max., depending on the class). Secondly, large spaces of the bodybuilding and cardio fitness zones in the fitness centres typically allow for the dilution and spread of respective emissions. However, the direct connection to the shopping mall areas, and its emission sources (restaurant zone, ventilations, outdoor infiltrations, etc.) clearly contributed to increased coarse PM. Human-induced PM resuspensions in the shopping mall is significant indoor source of PM; Qian et al. (2014) estimated PM_{10} emissions from walking range from 1 to 10 mg per minute.

In addition, the $PM_{2.5}$–to–PM_{10} mass concentrations ratios were rather low in the fitness centre (range 0.14–0.52). On average, $PM_{2.5}$ composed only 25% of PM_{10}. Furthermore, fine and coarse particles were positively, though not highly correlated (Spearman correlation coefficient; $|rs|=0.711$). On contrary, strong associations were found between both fine particles (PM_1 verses $PM_{2.5}$: $|rs| = 0.905$) as well as between both PM_5 and PM_{10} ($|rs| = 0.937$). These results indicate that fine and coarse fractions might originate from different emission sources. Furthermore, the daily profiles of PM also differed (Fig. 2). Typically, PM_1 and $PM_{2.5}$ exhibited just one peak of

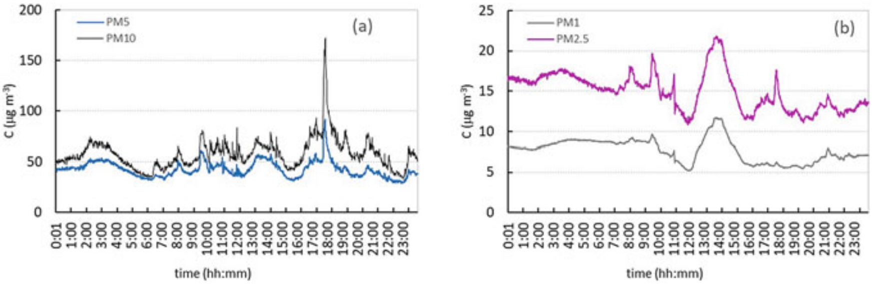

Fig. 2 Example of 24 h temporal variations of different PM in studied fitness centre: **a** coarse particles—PM_{10} and PM_5; **b** fine particles—$PM_{2.5}$ and PM_1. Note: Y axes are scaled to different ranges in order to adequately display the obtained levels

elevated concentrations (between 14:00 and 15:00) when occupancy of the club was relatively low. It might be assumed that cooking emissions from surrounding restaurants and food stands could be the sources of the fine PM (Board on Population Health and Public Health Practice 2016). On the contrary, PM_5 and PM_{10} exhibited several daily maxima. Similarly to fine particles, the concentrations raised up around 14:00, but also during morning hours (at 10:00–12:00), with the highest concentrations occurring during the late afternoon (17:00–18:00). The latter two peaks corresponded to the busier periods in the club (in terms of number of exercisers/clients registered). These results suggest that coarse PM originated from the occupant's and their activities in the club (resuspension of particulate matter due to exercising and human emissions; Alves et al. 2013, 2014; Ramos et al. 2014; Žitnik et al. 2016), as well from the activities and occupancy people in the shopping mall. Concerning the group activity classes, the registered maxima of PM temporal variations occurred in the studios when fitness classes were in sessions.

Relative humidity (RH) and temperature (T) affect thermal comfort of the respective occupants in indoor spaces. RH levels recommended by different organizations range from 30 to 60% (ANSI ASHRAE 2013; USEPA 2008). For RH of 30 and 60%, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends indoor T ranges 23.0–26.6 °C and 23.0–25.8 °C, respectively (ASHRAE 2017). ASHRAE also recommends that indoor relative humidity be maintained below 65% (ANSI ASHRAE 2013). However, specifically for sport facilities the existent T guidelines (for summer season) are 18–25 °C, whereas the RH should be maintained between 55 and 75% (SEJD 2008). The indoor T of various spaces was within the recommended guidelines, though on the upper end of the recommended range: median of 25 °C in BB, CF, and in GC. On contrary, RH was excessively low in all areas of the fitness centre (median of 35% in CF, 44% in BB, and 45% in GS), which can cause potential discomfort to exercising subjects (drying of nose, throat, mucous membranes and skin; Bélanger et al. 2014; Sylvester et al. 2016). The results showed that indoor RH significantly increased with the intensity of an activity and/or number occupants of the fitness centre, with the highest RH observed during the spinning classes (range: 49–59%, median 53%). In agreement, Žitnik et al. 2016 reported increased RH in indoor air when exercising (due to water vapour generated by human breathing and body perspiration). Further, high RH can lead to capillary condensation between a particle and a surface, strongly enhancing adhesion and suppressing particle resuspension (Kim et al. 2019); high RH may increase the size of particulate matter thus influencing the respective atmospheric residence and depositions (Zhang et al. 2017).

Limitations Fine particles composed atypically low part of the indoor PM in the studied fitness centre, which might be due to the different ventilation scheme, as well as untypical architectural layout of the club. Higher number of fitness centres thus should be assessed in order to confirm these findings. In addition, analysing further particle size distributions in indoor air of the respective fitness centres and associations between PM and other gaseous pollutants would be important to identify the possible emission sources and to identity the respective exposures.

4 Conclusions

This work assessed particulate pollution in indoor air of one fitness centre under restricted ventilation scenarios due to the current health guidelines. Across four PM fractions, the levels have shown large temporal and spatial variations. The indoor air quality in the fitness centre indicated possible risks for the respective indoor occupants as shown by PM_{10} concentrations during the occupied periods, which surpassed health guideline of 50 $\mu g\ m^{-3}$ defined by WHO (WHO 2010). In addition, due to the restricted ventilations relative humidity was well below the indicated range causing possible discomforts for the respective occupants. Suitable quality of indoor air is of outmost importance, especially in places where inhalation intake of PM is elevated. Thus, reasonable measures should be used in order to regulate indoor air quality, even under current conditions, to ensure healthy and comfortable indoor environments.

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References

Almeida, S.M., Ramos, C.A., Almeida-Silva, M.: Exposure and inhaled dose of susceptible population to chemical elements in atmospheric particles. J. Radioanal. Nucl. Chem. **309**(1), 309–315 (2016). https://doi.org/10.1007/s10967-015-4673-5

Alves, C., Calvo, A.I., Marques, L., Castro, A., Nunes, T., Coz, E., Fraile, R.: Particulate matter in the indoor and outdoor air of a gymnasium and a fronton. Environ. Sci. Pollut. Res. **21**(21), 12390–12402 (2014). https://doi.org/10.1007/s11356-014-3168-1

Alves, C.A., Calvo, A.I., Castro, A., Fraile, R., Evtyugina, M., Bate-Epey, E.F.: Indoor air quality in two university sports facilities. Aerosol Air Quality Res. **13**(6), 1723–1730 (2013). https://doi.org/10.4209/aaqr.2013.02.0045

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE): ASHRAE Technical FAQ ID 92, Accessed online July 2021 (2017). https://www.ashrae.org/File%20Library/docLib/Technology/.../TC-02.01-FAQ-92.pdf

ANSI ASHRAE Standard 55: Thermal environmental conditions for human occupancy. ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute, USA (2013). www.ashrae.org

Bélanger, D., Gosselin, P., Valois, P., Abdous, B.: Perceived adverse health effects of heat and their determinants in deprived neighbourhoods: a cross-sectional survey of nine cities in Canada. Int. J. Environ. Res. Public Health **11**(11), 11028–11053 (2014). https://doi.org/10.3390/ijerph111111028

Board on Population Health and Public Health Practice, Health and Medicine Division, National Academies of Sciences, Engineering, and Medicine: Health Risks of Indoor Exposure to Particulate Matter: Workshop Summary. Washington (DC), National Academies (US) (2016). https://doi.org/10.17226/23531

Braniš, M., Šafránek, J.: Characterization of coarse particulate matter in school gyms. Environ. Res. **111**(4), 485–491 (2011). https://doi.org/10.1016/j.envres.2011.03.010

Bralewska, B., Rogula-Kozłowska, W., Bralewski, A.: Size-segregated particulate matter in a selected sports facility in Poland. Sustainability **11**(24), 6911 (2019). https://doi.org/10.3390/su11246911

Buonanno, G., Fuoco, F.C., Marini, S., Stabile, L.: Particle resuspension in school gyms during physical activities. Aerosol Air Quality Res. **12**(5), 803–813 (2012). https://doi.org/10.4209/aaqr.2011.11.0209

Carnethon, M.R.: Physical activity and cardiovascular disease: how much is enough? Am. J. Lifestyle Med. **3**(1 Suppl), 44S-49S (2010). https://doi.org/10.1177/1559827609332737

Chen, C., Zhao, B.: Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. Atmosp. Environ. **45**(2), 275–288 (2011). https://doi.org/10.1016/j.atmosenv.2010.09.048

Decreto-Lei 118/2013. O sistema de certificação energética dos edifícios, o regulamento de desempenho energético dos edifícios de habitaçṹo e o regulamento de desempenho Energético dos edifícios de comércio e serviços (in Portuguese). Diário da República 1.a série – N.o **235**, 6644(1)–6644 (10) (2013)

Goodman, N.B., Steinemann, A., Wheeler, A.J., Paevere, P.J., Cheng, M., Brown, S.K.: Volatile organic compounds within indoor environments in Australia. Build. Environ. **122**, 116–125 (2017). https://doi.org/10.1016/j.buildenv.2017.05.033

Hallal, P.C., Andersen, L.B., Bull, F.C., Guthold, R., Haskell, W., Ekelund, U.: Lancet physical activity series working group: global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet **380**(9838), 247–257 (2012). https://doi.org/10.1016/S0140-6736(12)60646-1

Hodas, N., Loh, M., Shin, H.-M., Li, D., Bennett, D., McKone, T.E., Jolliet, O., Weschler, C.J., Jantunen, M., Lioy, P., Fantke, P.: Indoor inhalation intake fractions of fine particulate matter: review of influencing factors. Indoor Air **26**(6), 836–856 (2016). https://doi.org/10.1111/ina.12268

Holgate, S.T.: Every breath we take. Clinical Medicine. J. R. Coll. Phys. Lond. **17**(1), 8–12 (2017). https://doi.org/10.7861/clinmedicine.17-1-8

Holmberg, S., Li, Y.: Modelling of the indoor environment e particle dispersion and deposition. Indoor Air **8**, 113–122 (1998). https://www.aivc.org/sites/default/files/airbase_11617.pdf

Jin, H., He, C., Lu, L., Fan, J.: Numerical investigation of the wall effect on airborne particle dispersion in a test chamber. Aerosol Air Quality Res **13**, 786–794 (2013). https://doi.org/10.4209/aaqr.2012.04.0106

Kim, J.J., Hann, T., Lee, S.J.: Effect of flow and humidity on indoor deposition of particulate matter. Environ. Pollut. **255**, 113263 (2019). https://doi.org/10.1016/j.envpol.2019.113263

Lee, I.M., Shiroma, E.J., Lobelo, F., Puska, P., Blair, S.N., Katzmarzyk, P.T., Lancet Physical Activity Series Working Group: Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet **380**(9838), 219–229 (2012). https://doi.org/10.1016/S0140-6736(12)61031-9

Montgomery, J.F., Storey, S., Bartlett, K.: Comparison of the indoor air quality in an office operating with natural or mechanical ventilation using short-term intensive pollutant monitoring. Indoor Built Environ. **24**(6), 777–787 (2015). https://doi.org/10.1177/1420326X14530999

Pacitto, A., Amato, F., Moreno, T., Pandolfi, M., Fonseca, A., Mazaheri, M., Stabile, L., Buonanno, G., Querol, X.: Effect of ventilation strategies and air purifiers on the children's exposure to airborne particles and gaseous pollutants in school gyms. Sci. Total Environ.**712**, 135673 (2020). https://doi.org/10.1016/j.scitotenv.2019.135673

Qian, J., Peccia, J., Ferro, A.R.: Walking-induced particle resuspension in indoor environments. Atmos. Environ. **89**, 464–481 (2014). https://doi.org/10.1016/j.atmosenv.2014.02.035

Qin, F., Yang, Y., Wang, S.T., Dong, Y.N., Xu, M.X., Wang, Z.W., Zhao, J.X.: Exercise and air pollutants exposure: a systematic review and meta-analysis. Life Sci. **218**, 153–164 (2019). https://doi.org/10.1016/j.lfs.2018.12.036

Ramos, C.A., Wolterbeek, H.T., Almeida, S.M.: Exposure to indoor air pollutants during physical activity in fitness centers. Build. Environ. **82**, 349–360 (2014). https://doi.org/10.1016/j.buildenv.2014.08.026

Reche, C., Viana, M., van Drooge, B.L., Fernández, F., J., Escribano, M., Castaño-Vinyals, G., Nieuwenhuijsen, M., Adami, P.E., Bermon, S.: Athletes' exposure to air pollution during world athletics relays: a pilot study. Sci. Total Environ. **717**, 137161 (2020). https://doi.org/10.1016/j.scitotenv.2020.137161

Sacks, D.E., Shendell, D.G.: Case study: particle concentrations at a local gym dependent on mechanical ventilation in a retrofitted industrial building in Central NJ. Proceedings, Indoor Air 2014, July 7–12, Hong Kong, China (2014a). https://www.researchwithrutgers.com/en/publications/case-study-particle-concentrations-at-a-local-private-gym-depende

Sacks, D.E., Shendell, D.G.: Case study: ventilation and thermal comfort parameter assessment of a local gym dependent on mechanical ventilation in a retrofitted industrial building in Central NJ. Proceedings, Indoor Air 2014, July 7–12, Hong Kong, China (2014b). https://www.researchwithrutgers.com/en/publications/case-study-ventilation-and-thermal-comfort-parameter-assessment-o

SEJD: Ginásios: Diploma relativo à construção, instalação e funcionamento. Secretariat of State for Youth and Sport, Lisbon Portugal. Presidency of the Council of Ministers, Secretariat of State for Youth and Sport (2008). http://www.cd.ubi.pt/artigos/Gin%C3%A1sios.pdf

Shi, L., Zanobetti, A., Kloog, I., Coull, B. A., Koutrakis, P., Melly, S.J., Schwartz, J.D.: Low-concentration PM2.5 and mortality: Estimating acute and chronic effects in a population-based study. Environ. Health Perspect. **124**(1):46–52 (2016). https://doi.org/10.1289/ehp.1409111

Slezakova, K., Peixoto, C., Pereira, M.C., Morais, S.: Indoor air quality in health clubs: impact of occupancy and type of performed activities on exposure levels. J. Hazard. Mater. **359**, 56–66 (2019). https://doi.org/10.1016/j.jhazmat.2018.07.015

Slezakova, K., Peixoto, C., Oliveira, M., Delerue-Matos, C., Pereira, M.C., Morais, S.: Indoor particulate pollution in fitness centres with emphasis on ultrafine particles. Environ. Pollut. **233**, 180–193 (2018). https://doi.org/10.1016/j.envpol.2017.10.050

Sylvester, J.E., Belval, L.N., Casa, D.J., O'Connor, F.G.: Exertional heat stroke and American football: what the team physician needs to know. Am. J. Orthop. **45**(6), 340–348 (2016). https://cdn.mdedge.com/files/s3fs-public/ajo045090340.PDF

US Environmental Protection Agency (USEPA): Care for your air: a guide to indoor air quality. EPA 402/F-08/008 (2008). https://www.epa.gov/sites/production/files/2014-08/documents/careforyourair.pdf

Wagner, D.R., Clark, N.C.: Effects of ambient particulate matter on aerobic exercise performance. J. Exer. Sci. Fitness **16**(1), 12–15 (2018). https://doi.org/10.1016/j.jesf.2018.01.002

World Health Organization: Physical activity strategy for the WHO European Region 2016–2025. WHO Regional Office for Europe, Copenhagen, Denmark (2016). https://apps.who.int/iris/handle/10665/329407

World Health Organization: WHO guidelines for indoor air quality: selected pollutants. WHO Regional Office for Europe, Copenhagen, Denmark (2010). https://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

Zhang, L., Cheng, Y., Zhang, Y., He, Y., Gu, Z., Yu, C.: Impact of air humidity fluctuation on the rise of PM mass concentration based on the high-resolution monitoring data. Aerosol Air Quality Res. **17**, 543–552 (2017). https://doi.org/10.4209/aaqr.2016.07.0296

Žitnik, M., Bučar, K., Hiti, B., Barba, Ž, Rupnik, Z., Založnik, A., Žitnik, E., Rodrìguez, L., Mihevc, I., Žibert, J.: Exercise-induced effects on a gym atmosphere. Indoor Air **26**(3), 468–477 (2016). https://doi.org/10.1111/ina.12226

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Ergonomics and Biomechanics

Patellofemoral Pain Syndrome Risk Factors Analysis in Selective Garbage Truck Drivers

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Abstract Background: Patellofemoral Pain Syndrome (PFPS) is a disease with gradual worsening, affecting 22.7% of the general population, clinically described as a peripatellar pain aggravated when going up and/or downstairs. Objective: To identify risk factors for the emergence or aggravation of PFPS present in selective waste collection workers in their daily activity. Method: The experimental protocol first consisted of a thorough evaluation of the workstation. After, the movements executed by the driver were registered and analysed, task by task. Results: The results report that the worker's workplace characteristics and the and the postures and movements carried out contribute to the emergence and worsening of PFPS. Conclusions—It was concluded that, since the work tasks entail climbing and descending a vertical ladder more than one hundred times (twice at each stop, at least), there is a causal link between PFPS and the performed task. Therefore, the workstation requires immediate intervention.

Keywords Risk analysis · Selective garbage collection · Prevention · Worker's health · Musculoskeletal disorder

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1 Introduction

For the last couple of years, Patellofemoral Pain Syndrome (PFPS) has been studied and analysed in the light of sports and rehabilitation fields. Representing a gradual deteriorating pain, this syndrome is characterised by a specific pain in the anterior knee, peripatellar or retro-patellar, described as “stabbing, without irradiation and intermittent”, which worsens when squatting, climbing and/or descending stairs, and while seated for extended periods (Brechter and Powers 2002; Collins et al. 2018; Crossley Callaghan and Van Linschoten 2016; Crossley et al. 2016; Fredericson and Yoon 2006; Piazza et al. 2012; Powers Witvrouw et al. 2017).

This syndrome’s annual prevalence reflects in 22.7% of the general population, varying according to age and activity (Dey et al. 2016; Smith et al. 2018). The values found in the literature shows a prevalence of this syndrome of 6% in adolescents (Mølgaard, Rathleff and Simonsen 2011) and recreational runners (Collins et al. 2018; Crossley et al. 2019), 13.5% in the military (Lankhorst et al. 2012; Neal et al. 2019) and 35% in amateur cyclists (Boling et al. 2010; Weiss 1985).

Similarly, as what happens with other types of musculoskeletal disorders, the syndrome’s risk factors are multifactorial (Powers et al. 2017). Recent systematic review studies mention muscle imbalances as a primary risk factor (Crossley et al. 2019). However, other individual factors, such as bone misalignments are also referred to in the literature, but with little evidence (Crossley et al. 2019; Willy et al. 2019).

In adults, studies carried out in the military and weakness in the quadriceps muscle were evidenced as the leading risk factor for this syndrome (Lankhorst et al. 2012). On the other hand, in adolescents, this relation was not found, as it was identified that the increased strength in the hip abductor muscles in relation to the other thigh muscles is the main risk factor for PFPS (Neal et al. 2019).

Recent studies have also pointed out that psychosocial factors, such as anxiety and depression, may be indirect risk factors for PFPS (Maclachlan et al. 2017). Nevertheless, more research needs to be developed in this area to sustain these results (Crossley et al. 2019).

Other risk factors described in the literature are knee flexion movements above 60° and knee movement ahead of the toes (Brechter and Powers 2002; Crossley et al. 2004; Powers et al. 2017), fundamental for the prevention of harmful movements in the working context (Fry et al. 2003). Rehabilitation studies have shown that bodybuilding applied with protocols of strength exercises in the muscles of the hips and quadriceps, together with work tasks, are protective factors, decreasing the PFPS incidence (Coppack et al. 2011; Dolak et al. 2011; Ferber et al. 2015; Herrington and Al-Sherhi 2007; Khayambashi et al. 2014; Pereira et al. 2020).

Some studies in ergonomics (Coppack et al. 2011; Flanagan et al. 2004; Neal et al. 2019) have shown that PFPS impairs workers’ health, not only in their working context but also in their daily life. In load handling tasks with squat overuse, some studies have confirmed a direct relation between squatting and the PFPS occurrence (Dali et al. 2013; Lee et al. 2016; Sadler et al. 2013).

This work aimed to identify the emergence or aggravation of PFPS risk factors in the workers of selective waste collection when performing their usual tasks.

2 Materials and Methods

This study was carried out on a Portuguese waste collection company in 2020 and can be divided into two main phases, Occupational Medicine analysis and Occupational Safety analysis:

1. Clinical analysis;
2. Workstation assessment;
3. Worker postures assessment.

Fig. 1 Workstation analysis

Table 1 Final score outcome versus action between OWAS and REBA methods (Hignett & McAtamney, 2000; Karhu et al. 1977)

OWAS method		
Score	Action category	
1	No corrective measures are needed	
2	Corrections are needed in the near future	
3	Corrections are needed as soon as possible	
4	Immediate corrections are needed	
REBA method		
Score	Meaning	Intervention
1	Insignificant risk	Not needed
2–3	Low risk	May be needed
4–7	Average risk	Needed
8–10	High risk	Needed as soon as possible
11 or more	Very high risk	Needed immediately

The workstation (Fig. 1) consisted of an adapted vehicle that comprises the truck cabin (maximum distance to the ground is 1.28 m), and the access to the crane by the vertical ladder (maximum distance to the ground is 1.96 m), built to access the machine. The first step of the ladder is about 47 cm above the ground, and the distance between steps is 35 cm. The last step is distanced 44 cm from the upper part of the platform. Regarding the steps' wideness, the first two steps are 18 cm wide, while the two upper steps are 25 cm. The main objective of assessing the workstation was to identify functions with the potential to lead to the emergence/worsening of PFPS.

Each task's movements were filmed from two different angles with a NIKON Coolpix NS9500 camera for greater precision. The data was then processed by computer, and leg postures were evaluated according to the risk criteria: knee flexion above 60° and the tibial translation movement in the anterior plane ahead of toes reported in the literature (Brechter and Powers 2002; Collins et al. 2013; Crossley et al. 2004; Fry et al. 2003; Powers et al. 2017) were used to assess the risk of injury.

For comparison purposes, the scoring criteria of the OWAS method were used, but only for the evaluation of the lower limb and loads. The objective was to find out if the risk criteria observed in the footage could be evidenced by existing ergonomic methods.

Literature research was conducted to find ergonomic assessment methods that could be adapted to these work tasks. However, the results showed that only two methods used enough detail (regarding the scope of this work): Rapid Entire Body Assessment (REBA) (Hignett and McAtamney 2000a) and The Ovako Working Posture Analysis System) (Karhu et al. 1977, 1981). Both methods have a checklist-based protocol, which requires a "performed movement" observation and consequent assessment according to specific criteria. The final results of the used methods relate to the severity of the risk, considering the main actions, and are summarized in

Table 1. Each posture is linked with a severity score (quantitive assessment) at the end of the evaluation process., with a specific value that can be classified as "risk level" in OWAS method (1–4), and "stages of intervention" in the REBA method (between 0 and 11, or higher). The choice of scoring parameters for lower limbs of the OWAS Method as a criterion for comparing the risks described in the literature for lower limbs, was due to the OWAS method using more criteria in the comparison with REBA: seven criteria levels against just four. Additionally, the differential analysis of the carried load weights in the OWAS method presents a maximum score above 20 Kg, while REBA, the maximum score occurs above 10 Kg.

3 Results

3.1 Workstation Evaluation

It was noticed that the stairs are very narrow (Figs. 1 and 2) in the first two steps (18 cm), which does not allow putting both feet in safe conditions. Additionally, the distance between some of the steps (in height) is excessive, according to the Portuguese Standard for Equipment Safety (NP EN ISO 14122-3 2001).

Regarding the tasks performed by truck drivers who work in selective collection, it was registered that they collect between 50 and 55 recycling bins per business day. At each stop, workers descend from the cabin, climb the crane ladder (vertical), descend from the crane and return to the cabin. Considering that these workers perform the movement of going up and down a vertical 5-step ladder for approximately 100 times per 8 h work shift, meaning 500 steps/shift, representing more than one movement

Fig. 2 Postural assessment—rear view

Table 2 OWAS assessment criteria (Karhu et al. 1977)

OWAS method		
Score	Action category	
1	No corrective measures are needed	
2	Corrections are needed in the near future	
3	Corrections are needed as soon as possible	
4	Immediate corrections are needed	
REBA method		
Score	Meaning	Intervention
1	Insignificant risk	Not needed
2–3	Low risk	May be needed
4–7	Average risk	Needed
8–10	High risk	Needed as soon as possible
11 or more	Very high risk	Needed immediately

every 10 min, where PFPS's risk criteria are observed (Brechter and Powers 2002, Collins et al. 2013, Crossley et al. 2004, Fry et al. 2003, Powers et al. 2017).

3.2 Worker Postures Assessment

During the analysis of the worker's movement when climbing the ladder, it was observed that its width hinders a straight movement on the climb since the beginning of the ladder, it is only possible to place one foot on each step (Figs. 2 and 3). In the ascending movements, it was detected that on both legs occurs external rotation (Figs. 3 and 4). In the postural analysis, the angles made by the worker required great torque force, with knee flexions above 90°. Moreover, it was observed that the workers overweight increases the tension on the knees during the movement up and down the ladder.

The evaluation criteria used through OWAS (Karhu et al. 1981) are summarized in Table 2.

4 Discussion

The workstation's direct analysis is fundamental from the medical point of view to identify the casualty nexus of PFPS with work tasks (Papadopoulos et al. 2015; Willy et al. 2019).

The workstation's assessment showed that the measurements between two steps of the vertical ladder had an excessive distance between them. Considering the Portuguese Standard NP EM ISO 14122-3, the heights between the steps must be 25 cm, and the first step should have an increase or decrease of 15% (NP EN ISO 14122-3 2001).

Considering the ergonomic evaluation instruments, there is no specific method regarding ergonomics for lower limbs (Hita-Gutiérrez et al. 2020; Kee 2020; Santos 2020), thus selecting the Ovako working posture analysis system (OWAS) (Karhu et al. 1981, 1977), specifically using its severity scoring elements are used only for the lower limbs (Table 2). By analysing the method scoring criteria and observing the considered postures, the maximum severity score was observed. Comparing the work tasks results of the machine operators (who drive the selective waste collection trucks) with the risk existing factors discussed in the literature for PFPS as knee flexion above 60° and the tibial translation movement in the anterior plane ahead of toes (Brechter and Powers 2002; Collins et al. 2013; Crossley et al. 2004; Fry

Fig. 3 Postural assessment—lateral view

Fig. 4 Postures on both legs of external rotation

et al. 2003; Powers et al. 2017), all injurious postures were identified. Furthermore, non-linear movements in the worker's action on the stairs, such as the foot's external rotation in the movement up the stairs, were also observed and the postures evaluated.

From the point of view of preventing PFPS in the work context, it is important to identify harmful movements with the support of criteria identified in the literature. This allows for better decision making to improve the working environment.

4.1 Limitations

It is recognised as a limitation the non-possibility of applying a specific method that would allow the creation of 3D avatars for a more detailed analysis of the movements, namely the measurement of the forces exerted on the joints. Future studies should be carried out on larger samples to verify the disease's prevalence in the population studied or similar functions.

5 Conclusions

Considering that the work task's main objective was to identify whether the PFPS in selective garbage collection truck drivers can be affected by the work task, it was concluded that there is a causal link. This was considered because the work task requires the climb and descent of a vertical ladder with more than one hundred movements with high angle postures, counting more than 400 steps per work shift. Therefore, turning this specific profession a risk factor for the emergence or worsening of PFPS. As there is no possibility of applying any existing ergonomic assessment method specific to the lower limbs, it was concluded by the study that filming the execution of the task is a method that can be applied in this context so to draw a more effective examination. This can be accomplished by the recognition and identification of critical moments throughout the movement analysis. As actions to be implemented, changing the workstation to avoid the operator's need to climb the stairs will decrease PFPS risk and reduce the risk of accidents. Consequently, the present work identifies the specific factors for PFPS in the task performed by selective collection of waste truck drivers, finding a causal link for the appearance and/or aggravation of PFPS, and it can be concluded that this is a disease that can be included in the list of occupational diseases.

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References

Boling, M., Padua, D., Marshall, S., Guskiewicz, K., Pyne, S., Beutler, A.: Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scand. J. Med. Sci. Sport. **20**(5), 725–730 (2010). https://doi.org/10.1111/j.1600-0838.2009.00996.x

Brechter, J.H., Powers, C.M.: Patellofemoral joint stress during stair ascent and descent in persons with and without patellofemoral pain. Gait Posture **16**(2), 115–123 (2002). https://doi.org/10.1016/S0966-6362(02)00090-5

Collins, N.J., Barton, C.J., Van Middelkoop, M., Callaghan, M.J., Rathleff, M.S., Vicenzino, B.T., Crossley, K.M.: 2018 Consensus statement on exercise therapy and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: recommendations from the 5th international patellofemoral pain research retreat, Gold Coast, Australia, 2017. Br. J. Sport. Med. **52**(18), 1170–1178 (2018). https://doi.org/10.1136/bjsports-2018-099397

Collins, N.J., Bierma-Zeinstra, S.M.A., Crossley, K.M., Van Linschoten, R.L., Vicenzino, B., Van Middelkoop, M.: Prognostic factors for patellofemoral pain: a multicentre observational analysis. Br. J. Sport. Med. **47**(4), 227–233 (2013). https://doi.org/10.1136/bjsports-2012-091696

Coppack, R.J., Etherington, J., Wills, A.K.: The effects of exercise for the prevention of overuse anterior knee pain: a randomised controlled trial. Br. J. Sport. Med. **39**(5), 940–948 (2011). https://doi.org/10.1177/0363546510393269

Crossley, K.M., Callaghan, M.J., Van Linschoten, R.: Patellofemoral pain. Br. J. Sport. Med. **50**(4), 247–250 (2016). https://doi.org/10.1136/bjsports-2015-h3939rep

Crossley, K.M., Cowan, S.M., Bennell, K.L., McConnell, J.: Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. J. Orthop. Res. **22**(2), 267–274 (2004). https://doi.org/10.1016/j.orthres.2003.08.014

Crossley, K.M., Stefanik, J.J., Selfe, J., Collins, N.J., Davis, I.S., Powers, C.M., Callaghan, M.J.: 2016 Patellofemoral pain consensus statement from the 4th international patellofemoral pain research retreat, Manchester. Part 1: terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome m. Br. J. Sport. Med. **50**(14), 839–843 (2016). https://doi.org/10.1136/bjsports-2016-096384

Crossley, K.M., van Middelkoop, M., Barton, C.J., Culvenor, A.G.: Rethinking patellofemoral pain: prevention, management and long-term consequences. Best Pract. Res.: Clin. Rheumatol. **33**(1), 48–65 (2019). https://doi.org/10.1016/j.berh.2019.02.004

Dali, S., Justine, M., Ahmad, H., Othman, Z.: Comparison of ground reaction force during different angle of squatting. J. Hum. Sport. Exerc. **8**(3) (2013). https://doi.org/10.4100/jhse.2013.83.02

Dey, P., Callaghan, M., Cook, N., Sephton, R., Sutton, C., Hough, E., Selfe, J.: A questionnaire to identify patellofemoral pain in the community: an exploration of measurement properties. BMC Musculoskelet. Disord. **17**(1), 237 (2016). https://doi.org/10.1186/s12891-016-1097-5

Dolak, K.L., Silkman, C., Mckeon, J.M., Hosey, R.G., Lattermann, C., Uhl, T.L.: Hip strengthening prior to functional exercises reduces pain sooner than quadriceps strengthening in females with patellofemoral pain syndrome: A randomized clinical trial. J. Orthop. Sport. Phys. Ther. **41**(8), 560–570 (2011). https://doi.org/10.2519/jospt.2011.3499

Ferber, R., Bolgla, L., Earl-Boehm, J.E., Emery, C., Hamstra-Wright, K.: Strengthening of the hip and core versus knee muscles for the treatment of patellofemoral pain: a multicenter randomized controlled trial. J. Athl. Train. **50**(4), 366–377 (2015). https://doi.org/10.4085/1062-6050-49.3.70

Flanagan, S.P., Wang, M.Y., Greendale, G.A., Azen, S.P., Salem, G.J.: Biomechanical attributes of lunging activities for older adults. J. Strength Cond. Res. **18**(3), 599–605 (2004). https://doi.org/10.1519/1533-4287 (2004) 18<599:BAOLAF>2.0.CO;2

Fredericson, M., Yoon, K.: Physical examination and patellofemoral pain syndrome. Am. J. Phys. Med. Rehabil. **85**(3), 234–243 (2006). https://doi.org/10.1097/01.phm.0000200390.67408.f0

Fry, A.C., Smith, J.C., Schilling, B.K.: Effect of knee position on hip and knee torques during the barbell squat. J. Strength Cond. Res. **17** (2003). https://doi.org/10.1519/1533-4287 (2003) 017<0629:EOKPOH>2.0.CO;2

Herrington, L., Al-Sherhi, A.: A controlled trial of weight-bearing versus non-weight-bearing exercises for patellofemoral pain. J. Orthop. Sport. Phys. Ther. **37**(4), 155–160 (2007). https://doi.org/10.2519/jospt.2007.2433

Hignett, S., McAtamney, L.: Rapid entire body assessment (REBA). Appl. Ergon. **31**(2), 201–205 (2000). https://doi.org/10.1016/S0003-6870(99)00039-3

Hita-Gutiérrez, M., Gómez-Galán, M., Díaz-Pérez, M., Callejón-Ferre, Á. J.: An overview of reba method applications in the world. Int. J. Environ. Res. Public Health. MDPI AG (2020). https://doi.org/10.3390/ijerph17082635

Karhu, O., Härkönen, R., Sorvali, P., Vepsäläinen, P.: Observing working postures in industry: examples of OWAS application. Appl. Ergon. **12**(1), 13–17 (1981). https://doi.org/10.1016/0003-6870(81)90088-0

Karhu, O., Kansi, P., Kuorinka, I.: Correcting working postures in industry: a practical method for analysis. Appl. Ergon. **8**(4), 199–201 (1977). https://doi.org/10.1016/0003-6870(77)90164-8

Kee, D.: An empirical comparison of OWAS, RULA and REBA based on self-reported discomfort. Int. J. Occup. Saf. Ergon. **26**(2), 285–295 (2020). https://doi.org/10.1080/10803548.2019.1710933

Khayambashi, K., Fallah, A., Movahedi, A., Bagwell, J., Powers, C.: Posterolateral hip muscle strengthening versus quadriceps strengthening for patellofemoral pain: a comparative control trial. Arch. Phys. Med. Rehabil. **95**(5), 900–907 (2014). https://doi.org/10.1016/j.apmr.2013.12.022

Lankhorst, N.E., Bierma-Zeinstra, S.M.A., Van Middelkoop, M.: Risk factors for patellofemoral pain syndrome: a systematic review. J. Orthop. Sport. Phys. Ther. **42**(2) (2012). https://doi.org/10.2519/jospt.2012.3803

Lee, S.J., Jin, D.Y., No, H.J., Kwon, S.J., Yoon, M.H., Jung, Y.J., Lee, D.Y.: The effects of squat exercises on the space between the knees of persons with genu-varum. Indian J. Sci. Technol. **9**(25) (2016). https://doi.org/10.17485/ijst/2016/v9i25/97206

Maclachlan, L.R., Collins, N.J., Matthews, M.L.G., Hodges, P.W., Vicenzino, B.: The psychological features of patellofemoral pain: a systematic review. Br. J. Sport. Med. **51**(9), 732–742 (2017). https://doi.org/10.1136/bjsports-2016-096705

Mølgaard, C., Rathleff, M.S., Simonsen, O.: Patellofemoral pain syndrome and its association with hip, ankle, and foot function in 16- to 18-year-old high school students. J. Am. Podiatr. Med. Assoc. **101**(3), 215–222 (2011). https://doi.org/10.7547/1010215

Neal, B.S., Lack, S.D., Lankhorst, N.E., Raye, A., Morrissey, D., Van Middelkoop, M.: Risk factors for patellofemoral pain: a systematic review and meta-analysis. Br. J. Sport. Med. BMJ Publishing Group (2019). https://doi.org/10.1136/bjsports-2017-098890

NP EN ISO 14122-3. Norma Portuguesa para Seguranąa de Máquinas: Meios de acesso permanentes as máquinas PARTE 3: Escadas , Escadotes, Guarda-Corpo, Pub. L. No. 1514/2001, 27 (2001). Lisboa, Portugal: Instituto Português da Qualidade, Ministério da Indústria e Energia

Papadopoulos, K., Stasinopoulos, D., Ganchev, D.: A systematic review of reviews in patellofemoral pain syndrome. exploring the risk factors, diagnostic tests, outcome measurements and exercise treatment. Open Sport. Med. J. **9**(1), 7–17 (2015). https://doi.org/10.2174/1874387001509010007

Pereira, P.M., Reis, J., Duarte, J., Santos Baptista, J., Torres Costa, J., Conceição, F.: Application of bodybuilding for correction of musculoskeletal disease in patellofemoral pain syndrome-a case report. Int. J. Occup. Environ. Saf. **4**(1), 82–88 (2020). https://doi.org/10.24840/2184-0954_004.001.0007

Piazza, L., Lisboa, A.C.A., Costa, V.D., Brinhosa, G.C.D.S., Vidmar, M.F., Oliveira, L.F.B.D., Santos, G.M.: Sintomas e limitações funcionais de pacientes com síndrome da dor patelofemoral. Revista Dor **13** (2012). https://doi.org/10.1590/s1806-00132012000100009

Powers, C.M., Witvrouw, E., Davis, I.S., Crossley, K.M.: Evidence-based framework for a pathomechanical model of patellofemoral pain: 2017 patellofemoral pain consensus statement from the 4th international patellofemoral pain research retreat, Manchester, UK: part 3. Br. J. Sport. Med. **51**(24), 1713–1723 (2017). https://doi.org/10.1136/bjsports-2017-098717

Sadler, E.M., Graham, R.B., Stevenson, J.M.: Gender difference and lifting technique under light load conditions: a principal component analysis. Theor. Issues Ergon. Sci. **14**(2), 159–174 (2013). https://doi.org/10.1080/1463922X.2011.611264

Santos, M.: Métodos para detetar o Risco de surgirem Lesões Músculo-Esqueléticas relacionadas com o Trabalho- sabemos o suficiente? - RPSO - Revista Portuguesa de Saúde Ocupacional. Revista Portuguesa de Saúde Ocupacional on line **10** (2020). https://doi.org/10.31252/RPSO.18.07.2020

Smith, B.E., Selfe, J., Thacker, D., Hendrick, P., Bateman, M., Moffatt, F., Logan, P.: Incidence and prevalence of patellofemoral pain: a systematic review and meta-analysis. PLoS ONE. Public Library of Science (2018). https://doi.org/10.1371/journal.pone.0190892

Weiss, B.D.: Nontraumatic injuries in amateur long distance bicyclists. Am. J. Sport. Med. **13**(3), 187–192 (1985). https://doi.org/10.1177/036354658501300308

Willy, R.W., Hoglund, L.T., Barton, C.J., Bolgla, L.A., Scalzitti, D.A., Logerstedt, D.S., McDonough, C.M.: Patellofemoral pain clinical practice guidelines linked to the international classification of functioning, disability and health from the academy of orthopaedic physical therapy of the American physical therapy association. J. Orthop. Sport. Phys. Ther. **49**(9), CPG1–CPG95 (2019). https://doi.org/10.2519/jospt.2019.0302

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J. Duarte Associated Laboratory for Energy, Transports and Aeronautics-LAETA (PROA), Faculty of Engineering, University of Porto, Portugal, Master (2016), Faculty of Engineering, University of Porto.

J. Santos Baptista Associated Laboratory for Energy, Transports and Aeronautics-LAETA (PROA), Faculty of Engineering, University of Porto, Portugal, Ph.D. (1998).

J. Torres Costa Associated Laboratory for Energy, Transports and Aeronautics (PROA/LAETA), Faculty of Medicine, University of Porto, Portugal, Ph.D.(2004).

Simulating Human-Robot Collaboration for Improving Ergonomics and Productivity in an Assembly Workstation: A Case Study

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Abstract Objective: To simulate the interaction human-robot regarding productivity, physical and mental workload, involving the worker in the process of implementing a new Human-Robot Collaboration (HRC) system. Background: The guidelines for designing ergonomic and management of work systems are key to ensure worker safety, health, and wellbeing. It considers physical and mental workloads, including worker in the process of implementation. Method: Consists of comparing two workstations regarding physical demand, mental demand, and productivity with a sample size of 6 subjects. First workstation is a replica of a current situation, in which it is intended to implement an industrial HRC system. Second workstation is a human-robot simulated scenario, in which a human hand simulates the tasks being performed by a robot arm. Results: Robot-simulated scenario resulted in: 24.3% increase in productivity; posture exposure time reduced from 33.5% to 22.0%; overall workload felt by workers decreased from 44/100 to 38/100; and participatory ergonomics provided meaningful insights for better understanding the whole system. Conclusion: Robot-simulated improved ergonomic conditions and productivity compared to the replica-workstation and it is important to involve the worker in the implementation of a HRC system. Application: Assembly task workstations considering the inclusion of an industrial collaborative robot to perform tasks and lighten the burden on humans.

Keywords Human factors · Participatory ergonomics · Workload

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1 Introduction

Machines have been introduced to industrial environments in order to improve productivity, quality, cost, and ergonomics (Gualtieri et al. 2020). Recently this interactions between human and machines advanced to collaborative robots (cobots) that allows human to work alongside them without barriers, aimed at achieving a common goal (Gervasi et al. 2020). According to IEA and ILO (2020), there are six guidelines for designing ergonomics and management of work systems to ensure worker safety, health, and wellbeing. These guidelines should be adapted to each situation, especially when emerging new technologies and new forms of work. First, ergonomics has to be seen as a system. Both physical and cognitive domains are equally important, as workers' capabilities and limitations prevail when designing a workplace. It can be accomplished by giving appropriate tools, training, and continuous learning, as well as by not allowing the robots or machines dictate matters. Participatory ergonomics is also relevant as experienced workers in a task have many ideas of how to improve the workplace, and also because workers need to know the system they are working in. Finally, the design of a work system has to be safe, healthy, promote wellbeing, and be sustainable. Figure 1 shows the main guidelines:

The design and implementation of HRC systems is complex. As stated by Charalambous et al. (2015, 2016a), to ensure acceptance and for a successful implementation of an industrial HRC system it is crucial to understand ergonomics (physical, cognitive, and organizational). Several studies consider the three dimensions, for example in Ender et al. (2019) where the design aims at optimizing workplaces for manual production and maintenance processes; and in Changizi et al. (2019) where the concept design considers human mental and physical viewpoints at the same time by proposing a hand-guiding on the robot in order to make the workers fell having control over the system, with the robot as a helper instead of a robot giving an object.

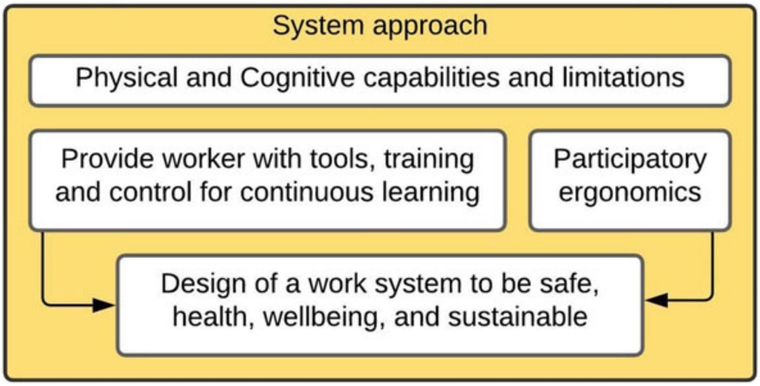

Fig. 1 Guidelines for ergonomic design and management in work systems. *Source* Adapted from IEA and ILO (2020)

However, it is not easy to quantify the benefits in terms of ergonomics and productivity, at the same time that considers the guidelines above mentioned. Therefore, this work aims at simulating the interaction human-robot regarding productivity, physical and mental workload, as well as involving the worker in the process of implementing a new HRC system.

2 Materials and Methods

The workstation selected for this study is a manual assembly of seven work pieces (P1–P7). The method consists of comparing two situations regarding physical demand, mental demand, and productivity with 6 workers. A replica-workstation (Fig. 2a) was built maintaining the same dimensions as the real workstation, imposing on the worker the same postures to reach the components to be assembled. While the robot-simulated scenario is presented in Fig. 2b, in which a human hand works simulating a robot arm to deliver the four largest components (P1, P4, P5, and P6), one at a time, and the remaining three components are placed next to the worker (P2, P3, and P7). Under this study the assembly table remains at the same place regardless the scenario.

2.1 Productivity

Cycle time is the variable chosen to measure productivity. Workers were asked to perform twenty minutes of task execution, in which the cycle times were measured by using a digital stopwatch. They were not allowed to stop working during this period of time. However, in both scenarios the pace was dictated by each worker, according to their individual abilities and motivation.

Fig. 2 Simulation scenarios: **a** Replica-workstation; **b** Robot-simulated

2.2 Physical Demand

Workers were chosen by gender and classes of percentiles in order to obtain data from a larger range following the anthropometric database for Portuguese adult workers (Barroso et al. 2005). For this study it means one woman and one man in between the percentiles 5–35, 35–65 and 65–95 using stature as the dimension of reference (Qutubuddin et al. 2012). The motions were captured during six cycle times by using Xsens MVN software, in which the Xsens Rapid Upper Limb Assessment (RULA) algorithm was applied. RULA (Middlesworth 2019) is a method that considers biomechanics and postures to assess physical workload. The output is a percentage of time the worker was under each of the four risk levels (negligible, low, medium, high).

2.3 Mental Demand

The ergonomic method NASA Task Load Index (NASA-TLX) (Hart and Staveland 1988) was applied after workers performed the task. This questionnaire is divided in two parts.

First, workers choose in a scale of 21 graduations their own perception on the task.

- Mental Demand—How mentally demanding was the task? (thinking, deciding, calculating, remembering, looking, searching);
- Physical Demand—How physically demanding was the task? (pushing, pulling, turning, controlling, activating) Was the task easy and restful or demanding and laborious?
- Temporal Demand—How hurried or rushed was the pace of the task? Was the task slow and leisurely or rapid and frantic?
- Performance—How successful were you in accomplishing what you were asked to do? How satisfied were you with your performance?
- Effort—How hard did you have to work to accomplish your level of performance?
- Frustration—How frustrated were you during the task? Were you insecure, discouraged, irritated, stressed, and annoyed or secure, gratified, content, relaxed and complacent?

Second, they were asked to choose between two items (fifteen pairs) which one represents the more important contributor to workload for the task performed. The rating of the first part combined with the weight of the second part gives the overall workload of the task for an individual.

Table 1 Cycle time for replica-workstation and robot-simulated scenarios

	Worker 1		Worker 2		Worker 3		Worker 4		Worker 5		Worker 6	
	RW	RS	RW	RS	RW	RS	RW	RS	RW	RS	RW	RS
Cycle Time (s)	23.02	18.15	21.46	17.87	24.68	16.81	29.63	25.96	22.11	17.54	17.71	15.23
Standard Deviation (s)	1.78	1.68	1.22	1.61	2.23	1.56	2.87	2.39	1.47	1.33	1.52	1.53

RW Replica-workstation, *RS* Robot-simulated

3 Results

Productivity was measured during 20 min of the assembly task. The average cycle time in the replica-workstation was 23.10 s and in the robot-simulated 18.59 s (−19.5% Cycle Time) which means 24.3% increase in productivity. The standard deviation in the robot-simulated is lower, in general, which is beneficial in terms of production line stocks. The results are presented in Table 1.

Physical demand was evaluated through RULA risks calculated by Xsens in percentage time of exposure to medium and high risks. The medium and high risks are presented in Fig. 3 for each percentile in both replica-workstation and robot-simulated scenarios. It shows that exposure decreases in all cases, as in the robot-simulated the workers movements are less painful. Especially smaller workers (percentile 5–35) felt the benefits by reducing their exposure time from 27.0% (medium risk) + 6.5% (high risk) to 21.5% (medium risk) + 0.5% (high risk).

Figure 4 shows that implementing a helper to deliver work pieces decreased the overall workload felt by workers from 44 to 38. However, temporal demand, performance and frustration results indicate that workers felt more uncomfortable performing the task even having control over the pace of work.

In summary, results corroborate with Turk et al. (2021), in which the redesign of an assembly workstation improved ergonomics and productivity time and errors.

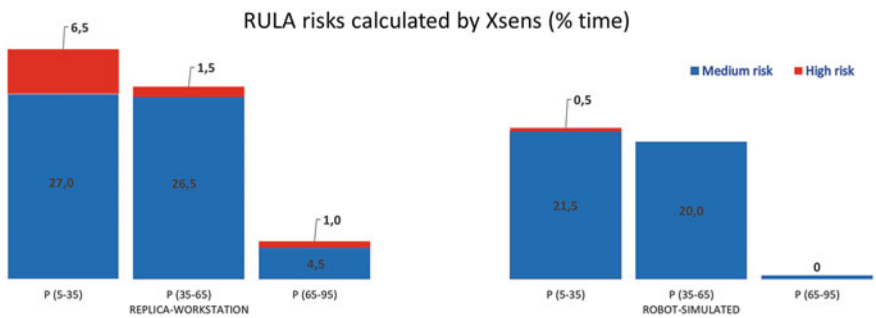

Fig. 3 RULA risk level calculated by Xsens in percentage time of exposure in replica-workstation and robot-simulated scenarios for different percentiles

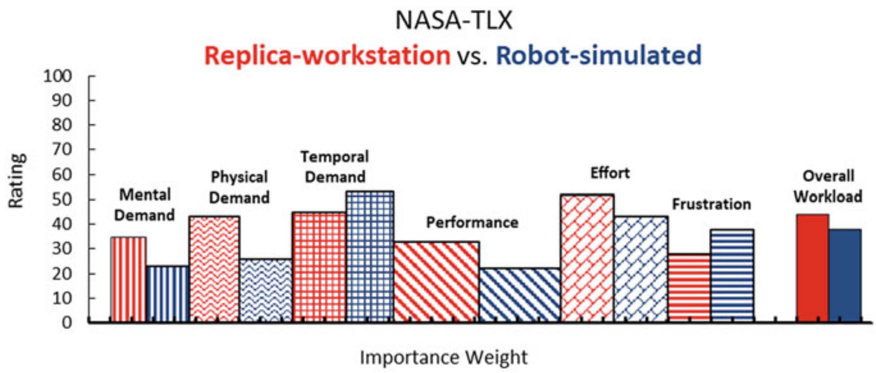

Fig. 4 NASA-TLX ratings and overall workload for replica-workstation and robot-simulated scenarios

4 Discussion

This case study compared two workstations regarding ergonomics and productivity, by involving six workers from different anthropometric percentiles, genders, and letting them work on their own preferences. This is according to Stoehr et al. (2018), which pointed that work instructions should be individual and user oriented, involving each user no matter limitations or disabilities. Otherwise, as stated by Green et al. (2008), by not reasoning ergonomics, the HRC system may present undesired effects, such as fatigue, monotony, and performance decrements. Regarding posture, Sanders and McCormick (1987) advises that the workstation should provide several working positions since there is no ideal posture that can be selected for the long term. Therefore, the most efficient work position during an assembly task with a robot, which requires continue operation, is the worker choose between standing and sitting positions. In this study only the standing position was considered in order to replicate the original workstation and make them comparable. Also the percentiles chosen are related to static dimensions and, according to Changizi et al. (2019), standard anthropometric data only presents information about static or fundamental features in usual postures. In summary, risky postures and overall physical workload were reduced by including a helper delivering components in front of the worker, which is expected to follow the same pattern with an industrial HRC system.

Regarding the cognitive aspect, Ogorodnikova (2008) proposed a framework that highlights workforce training and empowerment as cognitive important features when planning and designing an HRC workplace. In order to emphasize this topic, Busch et al. (2018) said that optimizing simultaneously task allocation while taking into account ergonomic aspects improves acceptance. In this study the work pieces were arranged to optimize both robot and human tasks. Results showed that mental demand was reduced, however other psychological factors increased. This aspect should be considered more seriously when planning the robot motion control, as advised in Sadrfaridpour et al. (2016). Instead of NASA-TLX, a possible cognitive assessment might be useful in the presence of a robot by applying the Trust Scale Questionnaire presented in Charalambous et al. (2016b).

Productivity increased as a consequence of having a teammate performing the task. In this regard, considering human and robot as teammates in HRC systems, an interesting comparison was done by Lindblom and Wang (2018): "To keep track of the environment the robot uses cameras and sensors, when humans use several senses; to safeguard the human the robot is equipped with artificial intelligence, as well as the worker must have knowledge of the robots, human-robot interactions and the assembly process."

Finally, in order to decide which level of collaboration to implement, considering the cobot capabilities suggestions in Cohen et al. (2021), and the results obtained in this study, the competence Level 3 is adequate. It means the cobot: gets information from sensors and cameras; follows preprogrammed schedule to move between stations; is responsive to human gestures and speech; and brings tools next to the operator.

By involving the operator in the process, it was possible to identify improvements when implementing the HRC system:

- A robot is only capable of delivering work pieces as in the case study, not assembling pieces itself due to restricted space;
- Even with the pace of work given to the human, psychological aspects still need to be better addressed;
- The assembly table could be lower in order to balance the physical demand of the three defined percentiles in the robot-simulated scenario.
- A sitting position is an option to be considered in such workstations, probably with adjustable assembly table height.

It would be more precise to consider ranges in defining percentiles, instead of static anthropometric dimensions.

5 Conclusions

As a conclusion, it has been noticed an improvement on ergonomic conditions by using a robot-simulated compared to the replica-workstation. Xsens showed that postures were improved, NASA-TLX showed a decreased in the overall workload perceived, and productivity increased 24% on average when compared to the workstation without aid. Moreover, involving the worker in the process was key to understand important features to be considered when including a real robot. Future work intends to implement a cobot to compare manual assembly with an industrial HRC in terms of ergonomics and productivity.

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References

Barroso, M.P., Arezes, P.M., da Costa, L.G., Miguel, A.S.: Anthropometric study of Portuguese workers. Int. J. Ind. Ergon. **35**(5), 401–410 (2005). https://doi.org/10.1016/j.ergon.2004.10.005

Busch, B., Toussaint, M., Lopes, M.: Planning Ergonomic Sequences of Actions in Human-Robot Interaction. In: IEEE International Conference on Robotics and Automation, pp. 1916–1923 (2018)

Changizi, A., Dianatfar, M., Lanz, M.: Comfort design in human robot cooperative tasks. In: A. T., T. R., K. W. (eds.) 1st International Conference on Human Systems Engineering and Design, vol. 876, pp. 521–526 (2019). https://doi.org/10.1007/978-3-030-02053-8_79

Charalambous, G., Fletcher, S., Webb, P.: Identifying the key organisational human factors for introducing human-robot collaboration in industry: an exploratory study. Int. J. Adv. Manuf. Technol. **81**(9–12), 2143–2155 (2015). https://doi.org/10.1007/s00170-015-7335-4

Charalambous, G., Fletcher, S., Webb, P.: Development of a Human Factors Roadmap for the Successful Implementation of Industrial Human-Robot Collaboration. In: AHFE International Conference on Human Aspects of Advanced Manufacturing, pp. 195–206 (2016a)

Charalambous, G., Fletcher, S., Webb, P.: The Development of a Scale to Evaluate Trust in Industrial Human-robot Collaboration. Int. J. Soc. Robot. **8**(2), 193–209 (2016). https://doi.org/10.1007/s12369-015-0333-8

Cohen, Y., Shoval, S., Faccio, M., Minto, R.: Deploying cobots in collaborative systems: major considerations and productivity analysis. Int. J. Product. Res. **1–17**,(2021). https://doi.org/10.1080/00207543.2020.1870758

Ender, J., Wagner, J.C., Kunert, G., Larek, R., Pawletta, T., Guo, F.B.: Design of an Assisting Workplace Cell for Human-Robot Collaboration. In: International Interdisciplinary Ph.D. Workshop, IIPhDW, pp. 51–56 (2019). https://doi.org/10.1109/IIPHDW.2019.8755412

Gervasi, R., Mastrogiacomo, L., Franceschini, F.: A conceptual framework to evaluate human-robot collaboration. Int. J. Adv. Manuf. Technol. **108**, 841–865 (2020)

Green, S.A., Billinghurst, M., Chen, X., Chase, J.G.: Human-robot collaboration: a literature review and augmented reality approach in design. Int. J. Adv. Rob. Syst. **5**(1), 1–18 (2008)

Gualtieri, L., Rojas, R.A., Garcia, M.A.R., Rauch, E., Vidoni, R.: Implementation of a Laboratory Case Study for Intuitive Collaboration Between Man and Machine in SME Assembly. In Industry 4.0 for SMEs, pp. 335–382 (2020)

Hart, S.G., Staveland, L.E.: Development of NASA-TLX (task load index): results of empirical and theoretical research. Adv. Psychol. **52**, 139–183 (1988)

IEA, ILO: Principles and Guidelines for Human Factors/Ergonomics (HF/E) Design and Management of Work Systems (2020)

Lindblom, J., Wang, W.: Towards an evaluation framework of safety, trust, and operator experience in different demonstrators of human-robot collaboration. In: C.K., T. P. (eds.), 16th International Conference on Manufacturing Research, vol. 8, pp. 145–150 (2018). https://doi.org/10.3233/978-1-61499-902-7-145

Middlesworth, M.: A Step-by-Step Guide Rapid Upper Limb Assessment (RULA), pp. 1–13 (2019)

Ogorodnikova, O.: Human Weaknesses and strengths in collaboration with robots. Periodica Polytechnica **1**, 25–33 (2008)

Qutubuddin, S.M., Hebbal, S.S., Kumar, A.C.S.: Significance of anthropometric data for the manufacturing organizations. Int. J. Bioinform. Res. Appl. **5**, 111–126 (2012)

Sadrfaridpour, B., Saeidi, H., Burke, J., Madathil, K., Wang, Y.: Modeling and control of trust in human-robot collaborative manufacturing. In: Robust Intelligence and Trust in Autonomous Systems, pp. 115–142 (2016)

Sanders, M.S., McCormick, E.J.: Human Factors in Engineering and Design (1987)

Stoehr, M., Schneider, M., & Henkel, C. (2018). Adaptive Work Instructions for People with Disabilities in the Context of Human Robot Collaboration. 2018 IEEE 16TH International Conference on Industrial Informatics (INDIN), pp. 295–308. 345 E 47TH ST, NEW YORK, NY 10017. IEEE, USA

Turk, M., Resman, M., Herakovič, N. : The impact of smart technologies: a case study on the efficiency of the manual assembly process. Proc. CIRP **97**, 412–417 (2021)

Guilherme Deola Borges University of Minho, MSc. Eng. (2018), UFSC.

Diego Luiz de Mattos University of Minho, Dr. Eng. (2020), UFSC.

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Musculoskeletal Disorders Investigation Among Workers that Operate with Brush Cutter in Vegetal Maintenance Tasks

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Abstract Objective: The main objectives were to assess the real working conditions and the complaints reported by workers using brush cutters and characterize the tasks' risk of developing musculoskeletal disorders (MSDs), aiming at implementing preventive measures. Background: The main tasks accomplished by brush cutter operators may be liable for increasing of chronic pain syndromes. Estimating the prevalence of self-reported musculoskeletal complaints among brush cutter operators and identifying possible associations with their real working conditions were the purpose of this study. Therefore, an Ergonomic Work Analysis was performed to evaluate and assess the working conditions of brush cutter operators during vegetal maintenance tasks. Method: To quantify the risk associated to the development of MSDs, Quick Exposure Check-QEC and Rapid Entire Body Assessment-REBA were applied for two tasks. A questionnaire aiming at characterizing MSDs symptoms and individual and work characteristics was filled by nineteen workers. Results: The results showed that the highest percentage of complaints were present in lumbar spine, feet, dorsal spine, right-wrist/hand, cervical spine and right-thigh. The risk of developing WRMSD was present in all tasks. Conclusion: This study has shown that several occupational risk factors trigger the development of MSDs among these operators.

Keywords Ergonomic Work Analysis · Quick Exposure Check (QEC) · Work-related Musculoskeletal Disorders symptoms (WRMSDs) · Nordic Musculoskeletal Questionnaire (NMQ) · Rapid Entire Body Assessment (REBA)

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1 Introduction

The tasks performed by brush cutter operators can be compared to those of forestry occupations which are recognized as physically demanding (Toupin et al. 2007). In 2015, according to the 6th European Working Conditions Survey, nearly 25% of the workers in Europe reported that their work affects their health, and 32% out of these correspond of the Agricultural workers. Plus, back pain was reported by 43% of the European workers daily. As for the muscular pain, the situation is similar, as around 42% of the respondents considered that working conditions origin muscular pain (upper limbs or neck). This result is greater among workers in forestry sector with 57% and 55%, respectively (Eurofound 2017; Sabino et al. 2019).

Musculoskeletal disorders occur in all activities sectors in European Union being the most frequent work-related disease (Park et al. 2017). Vegetation managing tasks usually require the adoption of uncomfortable and difficult postures for long periods of time, which may weakness and strain associate tendons and muscles, inducing the development of Work-related Musculoskeletal Disorders Symptoms (WRMSDs) (Francisco 2019; Grzywiński et al. 2016; Sabino et al. 2019). Numerous studies exploring the workload within workers of the forestry and agriculture sector highlight that certain activities impose a high workload (Balimunsi et al. 2011; Çalişkan and Çağlar 2010; Sullman and Byers 2000). To evaluate and assess the working conditions amongst brush cutter operators during vegetation managing tasks, an Ergonomic Work Analysis (EWA) was done considering the following main objectives:

- to assess the real working conditions and the self-reported complaints by workers using brush cutters;
- to Characterize the WRMSD risk associated with tasks/subtasks;
- to propose some preventive measures.

2 Materials and Methods

2.1 Stage of the Study, Location and Participants

Data collection was done from July to November 2020, in a Private Portuguese Enterprise, which workers are responsible for road infrastructures' operation and maintenance. Nineteen male workers, from six concessions, accepted to participate and fulfilled the questionnaire. However, only seven (being part of the vegetal maintenance teams) out of these, belonging to the two concessions visited, participated in the WRMSD development risk assessment, authorizing image recording during the work activity, for further postural analysis. In both situations, an informed and written consent was given. Data confidentiality was ensured. The study was developed in three stages:

(1) Characterizing the Work Situations;
(2) Characterizing WRMSD development risk associated with tasks/subtasks;
(3) Risk Controlling.

In the First Stage, the prevalence of musculoskeletal complaints was obtained from a questionnaire, in which self-reported symptoms were organized by body regions. In the Second Stage, two observational methods—Quick Exposure Check (QEC) and Rapid Entire Body Assessment (REBA)—were applied, aiming at characterizing the risk for the development of WRMSD, in the tasks and subtasks, previously selected. Finally, in the Third Stage, some preventive measures (technical and organizational) were proposed.

2.2 *Tasks/Subtasks' Sample*

This study comprised two main tasks: Control of Vegetation Growth (T1) and Cleaning of Drainage Systems (T2). Each task was further divided in Subtasks (Fig. 1).

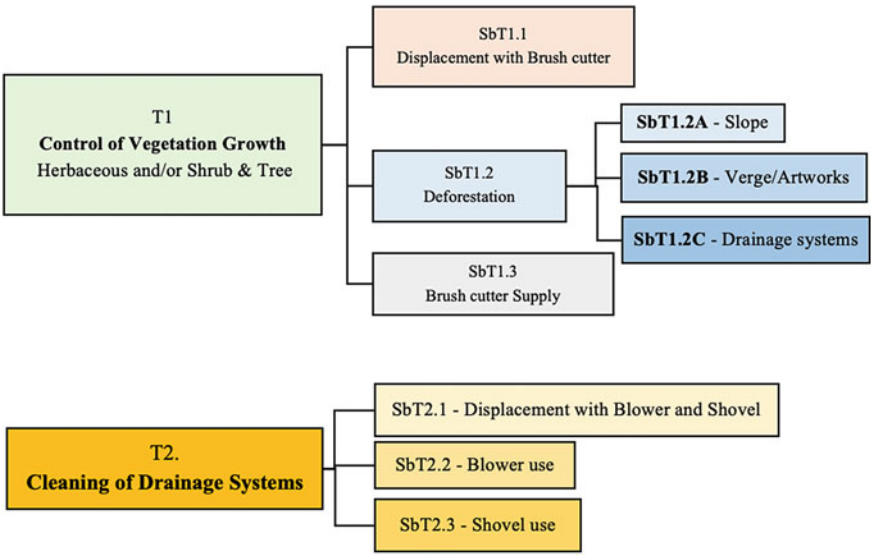

Fig. 1 Tasks and Subtasks assessed in the study

2.3 Data Collection and Procedures

For data collection diverse tools and methods were used: observations (free/systematized), non-structured interviews with workers, video/image recording and a Questionnaire (specifically developed for this purpose).

The questionnaire was created from the modified version of the Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al. 1987), used in previous studies (Francisco 2019; Sabino et al. 2019), and information collected in the company. The questionnaire, which was applied as an interview, aimed to identify important parameters for the workers' characterization, evaluate their perception of the real working conditions, and to identify self-reported symptoms related to discomfort, physical fatigue, or pain.

The questionnaire is organized in four sections. Section A included the workers' age, gender, anthropometric data (weight, height), dominant upper limb; organizational data (schedule type, number of hours worked per day/week, practice of work breaks, second job, seniority,…); the workers' health, smoking, alcoholic and caffeine habits, sport and physical activities, and the presence of chronic diseases. Section B incorporated items related to the occurrence of musculoskeletal symptoms, over the last 12 months and the last seven days. At the end of this section, the workers were inquired to identify possible relationships between characteristics of work and aforementioned WRMSDs. Section C included items to characterize the workers' perception about Work Activity and Conditions of Realization. This section also integrates the characterization of the general fatigue perception of workers. At the end, workers were asked to propose modifications to optimize their working conditions. Section D integrates QEC-Worker's Assessment Checklist, for further application of the method. The working postures were recorded with a Go Pro Hero 8 Black digital camera (with 12 megapixel and 1080 × 1920 HD/30 fps resolution).

WRMSD risk assessment relied on two observational methods: REBA (McAtamney and Hignett 2005) and QEC (David et al. 2008). The most harmful postures for the worker (such as: posture known to cause discomfort; the most frequently repeated posture; unstable, extreme, or awkward posture, especially when force is exerted; posture requiring the higher muscular activity or the greatest force) were always selected, as suggested by the authors of the methods.

Both methods were applied according to Sabino et al. (2019). Therefore, the videos were observed, and the worst posture was selected for assessment with QEC. For the application of REBA, several frames were selected from each video for further assessment. One single researcher analyzed 1378 postures with REBA and 129 postures with QEC.

As a reference, in both methods (REBA and QEC) low Scores represent acceptable work posture, whereas higher scores require an action. As both methods incorporate different Score level scales, REBA Scores were modified (the 2 first levels were merged in one) to simplify the association between both results. The QEC/REBA Risk Level and respective Action Level are shown in Table 1.

Table 1 Correspondence between QEC/REBA Risk level and action level

Risk level	Action level
1 - Low (or color green)	Acceptable
2 - Moderate (or color yellow)	Investigate further
3 - High (or color orange)	Investigate further and change soon
4 - Very high (or color red)	Investigate and change immediately

Source Adapted from Sabino et al. (2019)

3 Data Analysis

The Statistical Package for the Social Sciences (SPSS ©) software was used (version 26), for data processing.

To summarize socio-demographic data, job characteristics, prevalence of complaints and Risk Level obtained by each method descriptive analyses were performed using dispersion (standard deviation and ranges) and location (Frequency, Percentiles, Mean and Median) parameters. The non-parametric Wilcoxon test was used to compare the results obtained with both methods (REBA and QEC) whereas subtasks' Risk Levels were compared using the non-parametric Kruskal–Wallis test. In both cases the median value was considered. To make the comparison process feasible, the number of REBA analyzes was previously adjusted to the number of QEC analyzes (N = 129).

As criterion to reject the null hypothesis, a significance level of 0.05, was considered, in all cases.

Action Level two was considered the first one involving risk for WRMSD development according to both methods (REBA and QEC). Posture Score A and Posture Score B were additionally contemplated, for REBA method. Posture Score A evaluates the biomechanical load considering the use of "neck+trunk+legs" set and Posture Score B evaluates the biomechanical load considering how much the "upper arm+lower arm+wrist" segment set is involved in the task. As for the QEC method, the Risk level for each body region (QECNeck, QECBack, QECShoulder, QECWrist/Hand) was also considered. The working postures and the working conditions (frequency, held loads and movements' amplitude) were contemplated in the analysis.

4 Results and Discussion

Table 2 summarizes the principal socio-demographic data of the participants. Fifty-eight percent of the operators were over-weighted. Thirty-eight percent out of the 32% of the chronic health problems were related to musculoskeletal disorders. High school level was accomplished by 53% of the participants. Regarding Job, the majority of

Table 2 Main characteristics of the participants (N=19)

Variables	Average	Sd	Min.	Max.	Variables	Yes (%)	No (%)
Age (years)	35.8	8.45	24	53	Right-handed	95	5
Seniority (years)	3.3	3.93	0.58	15	Medical history of chronic illnesses	32	68
Height (cm)	174	6	160	187	Regular physical activity	53	47
Weight (Kg)	80.89	12.27	55	100	Smoking Habits	53	47
BMI (Kg/m2)	26.88	4.72	20.02	35.94	Caffeine daily habits	89	11
					Second Job	89	11

the workers were conservation assistants (84.2%) and the rest were conservation officers (15.8%).

Regarding working time organization: workers should complete eight hours daily; 95% of them stated that normally they took between one to six rest breaks (5–10 min each) per day. Only two participants were involved workplace accidents, in the last two years.

The highest percentages of complaints were identified for six body regions: lumbar spine (95%), feet—right (79%) and left (74%), dorsal spine (58%), right-wrist/hand (58%), cervical spine (53%) and right-thigh (53%). These results are in accordance with other studies, that reported lumbar spine as the region presenting higher prevalence of complaints (Francisco 2019; Gallis 2006; Lachowski et al. 2017). Workers who operate on sloped surfaces also reported complaints in the knees and feet (Breloff et al. 2019; Choi 2008).

Considering the intensity of complaints, the highest level of the scale (very high) was marked in the most affected regions in a proportion that varied between seven to 36%. It is important to highlight that some regions, despite not showing high prevalence of complaints (<50%), presented very high intensity (with records $\geq$ 50% of cases), such as the left hand/wrist and the knees.

For the thighs, feet and lumbar region, many of the complaints were related to working on the Slope. Therefore, the low percentage ($\leq$50%) of complaints reported in the last seven days, for the abovementioned regions, can explain the results, since the workers were not involved in these tasks in the past few weeks. The reported pain level was associated by the workers with some working conditions such as the rotation and flexion of the trunk, the repetition of hands/fingers and arms' movements, the standing posture, and the sloped surfaces.

Considering REBA and QEC results, the risk for the development of WRMSD (Risk Level ≥ 2) is present for 99% and 94% of the assessed postures and, for most of them, the risk level for the development of MSD is between High (39.9% and 34.9%) and Very High (37.8% and 45%) for both methods, respectively. These results indicate that further investigation and adjustments in the work situation are necessary.

Considering the Wilcoxon test, statistically significant differences were not found between the results obtained with both methods ($Z = -3.48$; $p = 0.728$). Only 33% of the postural rating obtained similar classification. Overestimation was registered in 36% and 31% of the cases (postures) assessed with QEC and REBA, respectively.

Considering the REBA results, the Biomechanical loading at the "neck + trunk + legs" segment set was the most contributing to the overall result of the Reba Risk Level (Posture Score A = 6), whereas according to QEC results, only the Neck region seems to be the region with higher contribution (QECNeck = 4).

Figure 2 shows the results by Task and Subtask when evaluated with REBA and QEC methods.

The results reveal that one Task (T2) and five out of eight Subtasks reveal different results, when assessed with both methods. The subtask Slope revealed to be the worst with both methods.

Additionally, considering the Kruskal–Wallis test, there were statistically significant differences between the results obtained by task when assessed with the same method (REBA or QEC) ($p < 0.05$). A careful analysis of the data suggests that the differences found are more related to the nature of the Subtasks in which each operator was evaluated. It should be noted that it was not possible to observe all operators performing all Subtasks. This disparity justifies the results found. Finally, the use of the Bruch cutter proved to be more demanding than the use of the Blower, with both methods.

4.1 Proposed Solutions

A few technical and organizational solutions were recommended to minimize the risk of developing WRMSD and the complaints presented by workers.

In terms of technical solutions, whenever new tools are purchased (Blowers, Brush cutters, etc.), special attention must be driven to the following characteristics: vibration levels; weight of the tool and adjustment possibilities; Equip each team with a "Green Climber" robot ensuring that they have the necessary means to reduce the effort associated with the use of the Brush cutter.

Concerning the organizational measures, increasing workers' awareness about their posture and the risk factors for the development of WRMSDs should be pursued. Whenever possible, pauses should be taken or rotation among tasks (such as: use of Bruch cutter vs use of Blower; Deforestation in Slope vs Verge/Artworks) should be promoted; Improve work planning before moving on to work fronts, ensuring that workers have the most appropriate tools and the right machines; Develop

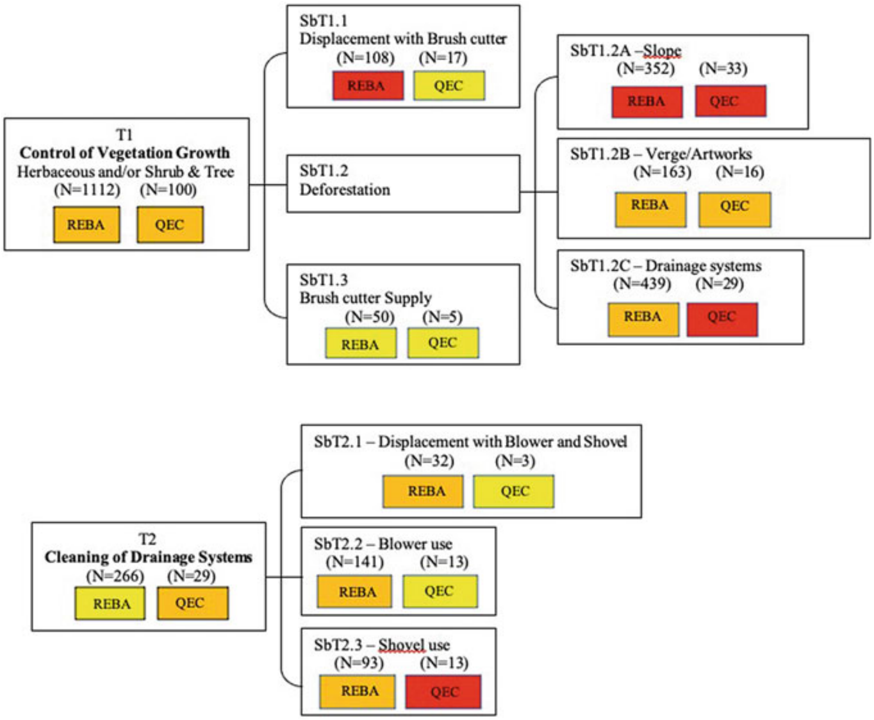

Fig. 2 Comparation between QEC Scores and REBA Scores results, by tasks and subtasks

the skills among the elements of the team, providing an effective rotation between control tasks (maneuvering machines) and execution tasks (use of hand tools such as Bruch cutter and Blowers); Bearing in mind the high prevalence of musculoskeletal symptoms among the respondents, and the risk of worsening due to the workers' aging, it is essential to reinforce the Health Promotion Program, already existing in the organization.

4.2 Limitations

The cross-sectional design of the study and the sample dimension may have influenced the results.

5 Conclusions

This study was carried out in a Private Portuguese Enterprise, who's main task is to ensure the operation and maintenance of road infrastructures. The intensity of WRMSDs was rated as high or very high, highlighting the need of ergonomic interventions for improving the working conditions. The obtained results agree with other studies (Breloff et al. 2019; Choi 2008; Francisco 2019; Gallis 2006; Lachowski et al. 2017). For all assessed regions, a minimum of four complaints/year in a proportion equal or higher then 50% were presented. It was also shown that most participants did not experience WRMSDs over the last seven days at the thighs, feet, and lumbar spine level, which could be due to the fact that workers did not work on the Slope in the previous weeks.

The QEC and REBA scores revealed that the risk for the development of WRMSD ($RL \leq 2$) is present in most evaluated postures, which requires further investigation and adjustments to be made in the work situation. The use of the Bruch cutter proved to be more demanding than the use of the Blower.

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References

Balimunsi, H.K., Kaboggoza, J.R.S., Abeli, S.W., Cavalli, R., Agea, J.G.: Working conditions and productivity of logging companies in Mafuga forest plantation, western Uganda. J. Trop. For. Sci. **23**(3), 232–238 (2011)

Breloff, S.P., Wade, C., Waddell, D.E.: Lower extremity kinematics of cross-slope roof walking. Appl. Ergon. **75**, 134–142 (2019). https://doi.org/10.1016/j.apergo.2018.09.013

Çalişkan, E., Çağlar, S.: An assessment of physiological workload of forest workers in felling operations. Afr. J. Biotech. **9**(35), 5651–5658 (2010). https://doi.org/10.5897/AJB10.294

Choi, S.D.: Postural balance and adaptations in transitioning sloped surfaces. Int. J. Constr. Educ. Res. **4**(3), 189–199 (2008). https://doi.org/10.1080/15578770802494581

David, G., Woods, V., Li, G., Buckle, P.: The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. Appl. Ergon. **39**(1), 57–69 (2008). https://doi.org/10.1016/j.apergo.2007.03.002

Eurofound: In: 6th European Working Conditions Survey - Overview report (2017 update). Publications Office of the European Union (2017)

Francisco, M.: Análise Ergonómica do trabalho realizado por operadores florestais [Dissertação elaborada com vista á obtenção do Grau Mestre em Ergonomia. Faculdade de Motricidade Humana - Universidade de Lisboa] (2019). https://www.repository.utl.pt/handle/10400.5/18928?mode=full

Gallis, C.: Work-related prevalence of musculoskeletal symptoms among Greek forest workers. Int. J. Ind. Ergon. **36**(8), 731–736 (2006). https://doi.org/10.1016/j.ergon.2006.05.007

Grzywiński, W., Wandycz, A., Tomczak, A., Jelonek, T.: The prevalence of self-reported musculoskeletal symptoms among loggers in Poland. Int. J. Ind. Ergon. **52**, 12–17 (2016). https://doi.org/10.1016/j.ergon.2015.07.003

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K.: Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl. Ergon. **18**, 233–237 (1987)

Lachowski, S., Choina, P., Florek-Łuszczki, M., Goździewska, M., Jezior, J.: Dissatisfaction with work as a risk factor of musculoskeletal complaints among foresters in Poland. Ann. Agric. Environ. Med. AAEM **24**(4), 706–711 (2017). https://doi.org/10.26444/aaem/80985

McAtamney, L., Hignett, S.: Rapid entire body assessment. In: Stanton, N., Hedge, A., Brookhuis, K., Salas, E., Hendrick, H. (eds.) Handbook of Human Factors and Ergonomics Methods, pp. 8-1–8-11. CRC Press, Boca Raton (2005)

Park, J., Kim, Y., Han, B.: Work Sectors with High Risk for Work-Related Musculoskeletal Disorders in Korean Men and Women. Safety and Health at Work, pp. 4–7 (2017). https://doi.org/10.1016/j.shaw.2017.06.005

Sabino, L., Melo, R.B., Carvalho, F.: Ergonomic work analysis at plant nurseries of a portuguese municipality. In: Goonetilleke, R., Karwowski, W. (eds.) Advances in Physical Ergonomics and Human Factors. AHFE 2018. Advances in Intelligent Systems and Computing, vol. 789, pp. 273–285. Springer International Publishing AG (2019). https://doi.org/10.1007/978-3-319-94484-5_29

Sullman, M.J.M., Byers, J.: An ergonomic assessment of manual planting pinus radiata seedlings. J. For. Eng. **11**(1), 53–62 (2000). https://doi.org/10.1080/08435243.2000.10702744

Toupin, D., LeBel, L., Dubeau, D., Imbeau, D., Bouthillier, L.: Measuring the productivity and physical workload of brushcutters within the context of a production-based pay system. For. Policy Econ. **9**(8), 1046–1055 (2007). https://doi.org/10.1016/j.forpol.2006.10.001

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Application of ErgoVSM to Improve Performance and Occupational Health and Safety Conditions in a Medication Dispensing System

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Abstract Objective: Use the ErgoVSM tool in a medication dispensing system inside the central pharmacy of a public hospital in the southern region of Brazil. Background: Looking to offer better services and more efficiently, techniques such as lean healthcare are growing in the healthcare sector and the ergonomics view of activities. Although the objective of both is the continuous improvement of the work and place, their approach is sometimes conflicting. To make them closer, the ErgoVSM seeks to analyze workplaces under both perspectives, conjunctly contributing to better work conditions. Method: This study occurred during 2020, in two phases, that contemplates the diagnosis of the current situation of the studied environment under both perspectives, using ErgoVSM as the primary tool to search for improvement opportunities. Results: Using ErgoVSM helped understand ergonomics and performance issues in the analyzed environment by identifying them and elaborating improvement 7 suggestions anchored in both perspectives. Conclusion: ErgoVSM demonstrated to be a helpful tool in various aspects, although it could be improved somehow. Application: Different economic sectors can be used the ErgoVSM tool to diagnose and monitor their activities, aiming at the continuous improvement of working conditions and productivity.

Keywords Ergonomics · Lean healthcare · Hospital pharmacy · Health workers

1 Introduction

To make processes lean usually means to rationalize them somehow, which can lead to unfavorable ergonomic conditions. In industry, engineers' actions, seeking performance, usually conflict with ergonomists' actions, seeking better work and health conditions (Wells et al. 2007). Therefore, lean manufacturing practices, although positives, could also lead to difficulties, as the relation of productive systems char-

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acteristics and their effects on worker's health is not always clear (Hasle 2016; Silva and Amaral 2019). For example, reducing the number of workers is not always ideal for improving the system, as it can increase the workload of others. Actions like this can make the environment less ergonomic (i.e., biomechanical, repetitiveness) (Silva and Amaral 2019; Kester 2013). In contrast, improvements in physical and organizational ergonomics can reduce absenteeism caused by these harmful factors (Westgaard and Winkel 2011), showing that it is essential to think about ergonomics when thinking about efficiency.

In the healthcare sector, lean practices are becoming more frequent and are called "lean healthcare". Techniques such as Value Stream Mapping (VSM), used to identify and reduce processes waste (Keyte 2004), are a good starting point. The VSM consists of a participative tool. Those involved in the process analyze the flow of materials and information to identify which activities add value (or not) to the product or service provided (Westgaard and Winkel 2011). This information is then used to suggest improvements.

Ergonomics seeks to guarantee the efficiency of processes and human resources, ensuring safety and minimizing worker's exposure to risk factors (Smyth 2003). However, value streams usually present manual activities (Koukolaki 2014) and, in general, do not consider worker's expectations for productivity. In this context, using a combined approach of lean and ergonomics might suffice ergonomic requirements and improve the environment (Adler et al. 1997).

A technique that seeks to analyze productive environments under both perspectives is the ErgoVSM (Jarebrandt et al. 2016). Based on VSM, descriptions of ergonomic conditions of the environment are added, providing a combined analysis. ErgoVSM allows visualizing and evaluating ergonomic risks that tend to appear when efficiency improvement actions are taken (Jarebrandt et al. 2016). When the objective is to improve the system's performance, eliminating waste is reduces activities that do not add value. Still, the individual risks to which workers are exposed are not considered (Silva and Amaral 2019). And there is where ErgoVSM makes its main contribution.

Using ErgoVSM in a medium hospital, Silva and Amaral (2019) mapped the value stream of serum, revealing that the stocks received were beyond what was necessary, requiring great physical effort to transport the materials. This physical load proved to be associated with low back pain, radiculopathy, joint pain, among others, demonstrating that inadequate inventory management is harmful to workers. Edwards (2014) applied ErgoVSM in the orthopedics section of a hospital, allowing improvements in physical workload by 40%, mental workload by 35%, increasing efficiency by 60%, and reducing the length of hospital stay for surgical patients from 5 to 4.5 days.

Supported by this context, the present study aimed to use ErgoVSM to evaluate the medication dispensing process in the central pharmacy of a public hospital, seeking to comprehend how a combined analysis of productive and ergonomic aspects could contribute to the healthcare sector.

Fig. 1 Variables for parts A and B of ErgoVSM (Jarebrandt et al. 2016)

Part A	Work Posture (WP)
	Weight/Force (WF)
	Calculation of Physical Ergonomics (PE)
	Mental Demand (time pressure) (MD)
	Control/Influence (CI)
Part B	Average Physical Ergonomics (APE)
	Physical Ergonomics Potential (PEP)
	Work Content Potential (WCP)
	Physical Porosity (PP)
	Mental Porosity (MP)
	Comunication (CO)

1.1 Research Method

This study presents an applied nature, combined approach, and solving specific problems (Kauark et al. 2010). It was conducted in a public hospital in the southern region of Brazil, in the central pharmacy, which meets the demands of medical prescriptions of inpatients (400 beds). The sector team comprises pharmacists and pharmacy technicians, divided into 6, 8, and 12-h shifts. Some scholarship holders and general assistants work transporting materials, managing inventories, and as receptionists. The Ethics Committee approved the research of the responsible institution.

The research was divided into two phases: (i) sector reconnaissance, non-interactive observations, interviews, and document analysis; (ii) the second phase was the application of ErgoVSM, which is divided into three parts: A, B, and C. Part A consists of analyzing each operation inside a value stream, part B is the analysis of the value stream itself, and part C consists of elaborating improvement suggestions. As ErgoVSM is based on traditional VSM, parts A and B comprehend the current state of the system, and part C, the future state. ErgoVSM evaluates different aspects, and in parts A and B, the variables represented by the denominations and acronyms presented in Fig. 1 receive a score that ranges from 1 to 10 based on work conditions, 1 being the best for that environment and 10 being the worst. Due to spatial restrictions in this paper, it is suggested to consult Jarebrandt et al. (2016) for more information regarding each step.

2 Results

2.1 Process Description Parsed

The initial phase of the study comprises the description of the primary process the pharmacy is responsible, the medication dispensing, which involves four macro steps: (1) reception and screening, (2) separation, (3) control, and (4) prescription dispens-

Fig. 2 The four main workplaces of each macro step (Author, 2020)

ing (Fig. 2). First, the prescription registered by the physician is received digitally in the pharmacy and automatically printed. In reception and screening, worker A takes the prescription from the printer, confers the medication, manually adds information about the destination, and places it on a shelf whose dividers correspond to the hospital sectors.

In separation, worker B takes from the shelf in room 1 a set of prescriptions (batch), usually from the sector that contains the most accumulated prescriptions. Then, he moves to room 2, makes a copy of the batch in another printer, and proceeds to separate the medication in each prescription, always finishing one before starting another. The medicines are arranged on shelves around the space and divided between controlled and uncontrolled, then by functional group, which is the chemical compound that gives the medication the desired characteristic, and within the functional group in alphabetical order. Worker B walks around the space, collecting the desired amount of each medication and placing them in a plastic bag. When finished, inserts the prescription in the bag, forming a complete kit, and sends the copy to be archived. Then, the kits are placed on a table in the center of the room.

In control, worker C, who is positioned sitting, takes a kit, removes all medications from the bag, scans each barcode, rebuilds the kit, and places it on a table on the opposite side. Finally, worker D takes the kits and places them in a container in room 4 corresponding to the destination sector of that prescription. Each container is transported to its sector at specific times of the day, finishing the dispensing process.

2.2 ErgoVSM—Part A

In the evaluation of operations (part A), the reception and screening are performed chiefly seated and have an average operation time of 1 min and 50 s. The task shows some inadequate posture conditions, high cognitive demands, and needs concentration, although there is no physical effort required to perform the task. In the current state, the result for each variable is: Work Posture (WP) = 7; Weight/Force (WF) = 1; Physical Ergonomics (PE) = 12.83 sc-min; Mental Demand (MD) = 6; and Control/Influence (CI) = 4.

The separation is performed on foot, and worker B walk around the place collecting medications and forming kits. Although some containers are at the proper heights, most still require inappropriate postures for access. The task has a high physical demand and a medium mental demand. The average operation time is 1 min and 58 s, therefore: WP = 8; WF = 4; PE = 62.93 sc-min; MD = 6; and CI = 4.

The control is similar to reception and screening, and the task is performed sitting, with generally unfavorable postures, with no need for physical effort, but with high mental demand. However, this operation is characterized by repetitiveness. Worker C does not influence the task and cannot control sub-steps. The average time is 1 min and 41 s and the results are: WP = 7; WF = 3; PE = 35.35 sc-min; MD = 6; and CI = 8.

The dispensing is a simple task, with an average time of 21 s, so: WP = 7; WF = 5; PE = 12.25 sc-min; MD = 5; and CI = 7.

2.3 ErgoVSM—Part B

In part B, the value stream is evaluated, and the first variable is the Average Physical Ergonomics (APE) of the stream, which is calculated in a specific equation and depends on the Physical Ergonomics (PE) of each operation and the total processing time (Jarebrandt et al. 2016). Using =12.83 sc-min, =62.93 sc-min, =35.35 sc-min, =12.25 sc min, and t = 5.83 min, APE resulted in 4.6. This result indicates that the process presents a medium physical risk and, although the value is below 5, it is still necessary to take measures to prevent these risks. The next step, to determine the Physical Ergonomics Potential (PEP) of the stream, is necessary to decide on the PEP of each operation, represented by PEPt, and compare with Fig. 3. In the given context, PEP was evaluated as 7, as there are no operations rated A. Two operations ranked B, and two ordered D. This result indicates a significant difference between the physical load of operations, which the individual results of PE can verify.

Group	Description
A	Easy and varied work, i.e. a mix of standing, walking and sitting work, no significant manual handling.
B	Sitting work, no significant manual handling. E.g. admission talks, computer work, administrative tasks, talking on the phone.
C	Standing and/or walking work, no significant manual handling. E.g. "run", alarm, get/leave materials, distributing medicines.
D	Mainly standing work with manual handling. E.g. distributing medicine or food.
E	Moving, standing and walking work with some weight. E.g. wheelchair transport, easy cleaning, delivery of drip racks, carts, blood pressure monitor.
F	Heavy work, standing and walking. E.g. moving a patient, delivery of food cart, pushing bed or gurney, manual handling of supplies.

Fig. 3 Group references to compare PEPt (Jarebrandt et al. 2016)

The estimative of the Work Content Potential (WCP) of the process uses the results of Mental Demand (MD) and Control/Influence (CI) of each operation, represented by WCPt, and the process was evaluated as WCP = 7. This result of WCP indicates that the process inflicts above-average mental demands, being it time pressure, the need for concentration, and constant distractions, but does not provide the workers enough control and influence measures to mitigate or avoid these effects. For example, in reception and screening, the rate prescriptions arrive is outside the control of worker A. When the dispensing hour of a sector approaches, remaining prescriptions are sent urgently by the physicians. These prescriptions receive priority and therefore put worker A under time pressure.

Physical Porosity (PP) refers to the moments during the workday that workers can recover from the physical demands. This analysis is made for the entire stream. The current condition of the process shows varied contexts but usually allows freedom of movement for workers. However, in times of higher demand, more workers perform tasks and share the space, hindering the move around the environment. As demand decreases, it is possible to take short breaks, but the environmental conditions do not allow adequate recovery. Therefore PP was evaluated as 5.

Mental Porosity (MP) refers to the moments during the workday that workers can recover from the cognitive demands. The current conditions offer few opportunities for cognitive recovery, as when there is an opportunity for a specific worker to rest, their surroundings are active, providing cognitive stimuli and distractions. There are already scheduled breaks, i.e., for lunch, however, the environment is shared by multiple workers, and even during rest periods, there are constant cognitive stimuli and distractions. In this context, MP was evaluated as 7.

The last variable is Communication (CO), representing the potential to dialogue with colleagues or ask for help or opinions. The current condition favors communication. The friendly and relaxed environment allows workers at any stage to communicate with others in casual or professional manners. Contact with colleagues to request help occurs frequently, and there are no impediments to this. Therefore, CO was evaluated as 3.

2.4 ErgoVSM—Part C

As demonstrated by Average Physical Ergonomics (APE) and Physical Ergonomics Potential (PEP), the operations have different physical requirements, emphasizing reception and screening and control, which are performed chiefly sitting and characterized by repetitiveness. The separation also has some characteristics of repetitiveness, but it is an operation with a longer cycle time than the mentioned above and allows for different movement patterns. On the other hand, separation presents a greater risk of musculoskeletal disorders since it is the operation with the most unfavorable postures, often exceeding the limits recommended by the legislation.

Regarding cognitive aspects, reception and screening and separation stand out, as the two require the most concentration to perform. Distractions surround both workers moving or noise from the conversation and other tasks being performed. Given their complexity, they also offer their workers greater autonomy, allowing adaptation if necessary, while the other two operations are more restricted.

In this context, the suggestions for improvement must consider how many people are involved, the complexity to implement, and the impact on ergonomics and process performance. Thus, a total of 7 recommendations of a low, medium and high complexity were elaborated. Low complexity is understood as the few need for people and technical knowledge for implementation, in which workers themselves can act on the process. Medium complexity requires more people involved and monitoring of people with technical expertise in the field. Finally, high complexity indicates the involvement of sectors other than the hospital pharmacy and requires planning and specialized personnel involvement.

For example, a low-complexity suggestion for the separation is to remove the sectors trays. Prescriptions leave reception and screening with an indication, added by worker A, to which sector they belong. During the break, they are redundantly grouped in trays labeled for each sector. When there is no tray on the table, worker B searches the corresponding tray on a shelf. When the tray is empty, they must store it, performing two sub-steps that add no value, while the benefit of performing them provides redundancy regarding the destination. The shelf stores tray too high or too low, and eliminating this sub-step would bring immediate ergonomic benefits and reduce processing time.

A medium complexity suggestion involves changing how operations are performed and requiring all workers' collaboration in all operations. The proposition is to replace the processing of prescriptions in batches by processing them in a unitary way, which would improve performance without compromising ergonomic conditions. Currently, workers in all operations wait for prescriptions to accumulate, forming batches. Therefore, the first prescription has to wait until the last one enters the batch to be processed, which indicates "waiting", one of the wastes of lean thinking. The average processing time is 5 min and 50 s, while the average waiting time adds up to 13 min and 24 s, more than twice the processing time. The suggestion is to process the prescriptions as they are printed, reducing the waiting time.

The following recommendation does not require a simple change but to restructure the process. Most tasks are performed manually and require a series of information being exchanged verbally, which is very common in non-automated environments. The suggestion is to implement visual management tools and process automation technologies. There is no visual information between operations to indicate whether or not prescriptions are waiting for processing. An alternative is to use screens at strategic locations to display data. To a certain degree, this can be automated. Still, ideally, at each operation, workers could manually update the information so others could see and even verify what has already been processed and what is still waiting. The immediate benefit is a better flow of information and more control over each prescription.

While being processed, to quickly identify the destination of each prescription, a color-coded system could be implemented. Each hospital sector receives a unique color to be marked on a specific spot in the prescription. It can be quickly identified, reducing questions asked and eliminating the sector trays.

The control is currently responsible for updating inventories by scanning. Still, to do so, it is required to disassemble the kits, scan all medications and reassemble the kits, which is highly manual and repetitive. With barcodes on each prescription and portable scanners on strategic points, worker B could update inventories while separating the kits, removing the need for the control step. Still, with this resource is possible to integrate worker C in separation, giving each worker more time to perform tasks and rest. This last suggestion portrays an environment that is substantially more efficient and more ergonomically adequate. However, it is highly complex to implement, requires investments in various ways, involves multiple sectors, and mobilizes multiple resources.

3 Discussion

The search for analysis methods and tools that reflect the actual context of situations, providing increasingly assertive improvements, is a constant in all areas of knowledge. The combined approach of the ErgoVSM allowed a different analysis than other methods that focus only on productive performance or ergonomics aspects, using the under both perspectives. In addition, combining quantitative and qualitative research was beneficial for the critical evaluation of each operation.

ErgoVSM proved to be an effective guide to the observer, dedicating some space for each analyzed part of the environment, including operation time and the impact in both physical and cognitive aspects. In this regard, it was superior in its approach compared to other specific methods, considering ergonomics factors often neglected in the lean production approach and lean factors not addressed by ergonomics.

However, some subjective aspects could lead the observer to different interpretations based on previous knowledge for each analysis topic. Although the process to describe each variable is explicit, the limits 1 and 10 are subjective matters, and the decision on each of them depends on the previous knowledge of the observer. The method, by itself, does not offer sufficient resources for its application and requires the observer has prior knowledge both in ergonomics and in lean practices to understand which aspects of the environment should be observed. In addition, the method is relatively difficult to apply in the routine of labor environments, with some difficulties transposing analyzed domains to local realities.

As mentioned by Edwards (2014), the scoring part of ErgoVSM was quite tedious for the team and the group was losing energy, requiring extra effort from the lean consultant. Silva and Amaral (2019), however, worked with a more engaged group, which shows that the applicability of ErgoVSM could depend both of team energy as well as team knowledge.

4 Conclusions

This study aimed to use ErgoVSM to seek improvement opportunities in performance and ergonomic conditions in a specific context of the central pharmacy. The results indicate multiple improvement opportunities, both in performance and ergonomics. For example, some sub-steps in operations do not add value, such as the sector separation in the shelf during reception and screening and during control, requiring disassembling and reassembling the kits. Others only delay the tasks, such as separating the prescriptions in trays.

In conclusion, the combined approach of a method like ErgoVSM is beneficial. The improvement suggestions reveal essential information about the real work performed. Workers do not always perceive that during the workday. Presenting recommendations that could be carried out at different organizational levels was a challenge and an inspiration, as it is a healthcare environment and under public administration, with limited human and material resources.

Finally, it is suggested that further work should be carried out in contexts similar to the one presented here. The application of ErgoVSM in different contexts is fundamental for it to mature, generating more and better ways to analyze the work environment.

Acknowledgements The present study is dedicated to all healthcare sector workers working harder than ever during this global pandemic and deserves a more humane analysis to improve their work environment conditions.

References

Adler, P.S., et al.: Ergonomics, employee involvement and the Toyota production system: a case study of Nummi's 1993 model introduction. Ind. Labor Relat. Rev. (1997)

Edwards, K.: Ergonomic value stream mapping - can lean and ergonomics go hand in hand? Human Factor in Organizational Design and Management. In: Nordic Ergonomics Society Annual Conference (2014). https://doi.org/10.4122/dtu:2130

Hasle, P., et al.: Value stream mapping as a tool for systematic employee based improvement of the psychosocial work environment in hospitals. In: Euroma Conference Interactions (2016). https://vbn.aau.dk/ws/portalfiles/portal/236827414/Hasle_2016_Value_stream_mapping_in_hospitals.pdf

Jarebrandt, C., et al.: ErgoVSM: a tool for integrating value stream mapping and ergonomics in manufacturing. Hum. Factor Ergon. Manuf. Serv. Ind. (2016)

Kauark, F.S., Manhães, F.C., Medeiros, C.H.: Metodologia da pesquisa: um guia prático. Via Litteratum (2010). http://www.pgcl.uenf.br/arquivos/livrodemetodologiadapesquisa2010_011120181549.pdf

Kester. J.: A lean look at ergonomics. Industrial Engineer, Peachtree Corners, vol. 45 (2013)

Keyte, B.: The Complete Lean Enterprise: Value Stream Mapping for Administrative and Office Processes, 1st edn. Productivity Press, New York (2004)

Koukolaki, T.: The impact of lean production on musculoskeletal and psychosocial risks: an examination of sociotechnical trends over 20 years. Appl, Ergon. **45** (2014)

Silva, M.P., Amaral, F.G.: Mapeamento de perdas e absenteísmo em fluxo de valor do soro hospitalar. Brazilian Congress of Ergonomics (2019)

Smyth, J.: Work smarter not harder: Ergonomics in a lean business environment. In: Annual Conference of the Ergonomics Society (2003)

Wells, S.D., et al.: Time: a key issue for musculoskeletal health and manufacturing. Appl. Ergon. **38** (2007). https://doi.org/10.1016/j.apergo.2006.12.003

Westgaard, R.H., Winkel, J.: Occupational musculoskeletal and mental health: significnce of rationalization and opportunities to create sustainable production systems - a systematic review. Appl. Ergon. **42** (2011). https://doi.org/10.1016/j.apergo.2010.07.002

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How Ergonomic Evaluations Influence the Risk of Musculoskeletal Disorders in the Industrial Context? A Brief Literature Review

A. Pimparel, S. Madaleno, C. Ollay, and A. T. Gabriel

Abstract Ergonomic risk factors are present in many industrial environments. They include posture, repetitive tasks, vibration, physical workloads, among others. Long-term exposure to these factors may lead to musculoskeletal injuries. Risk analysis allows the identification and elimination/reduction of the causes. This research reviews briefly the connection between ergonomic evaluations and the chance of developing musculoskeletal injuries in the industrial environment. Namely, it aims to understand the impact of risk analysis and ergonomic interventions on musculoskeletal disorders and workers' well-being. To pursue the brief literature review, the authors defined the inclusion criteria and extracted the data. It led to 53 studies collected from Taylor and Francis, Elsevier, and Springer. Of these, five articles published after 2015 were considered relevant for the purpose. A summary table was created to resume the objective and the main findings of each study. Results evidenced a positive correlation between ergonomic interventions and musculoskeletal injuries. Overall, the review points out that musculoskeletal disorders are less frequent when there is an ergonomic risk analysis that leads to implementing measures and solutions.

Keywords Ergonomics · Risk analysis · Risk factors · Musculoskeletal injuries

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1 Introduction

According to the International Ergonomics Association (IEA), Ergonomics is the scientific discipline concerned with the interaction between humans and other elements inside a system. It brings together knowledge from many subjects such as anthropometry, biomechanics, physics, and psychology to ensure that user needs and limitations are respected. This way, uncomfortable and stressful activities can be avoided. It is only possible by recognizing the variability of several attributes such as age, gender, strength, cognitive ability, experience, and cultural aspects to create a safe, comfortable, and productive work environment and also to minimize the risk of injury or harm (Klussmann et al. 2017a, b).

Ergonomic risk factors are a reality in all types of workplaces. They include working posture, repetitive tasks, exposure to vibration, physical workloads, and manual material handling (MMH). Long-term exposure to risk factors can lead to musculoskeletal disorders (Union 2016). These injuries can affect many parts of the human body, such as the back, shoulders, hands, wrists, and structural anatomical elements (Cheung et al. 2007; Yahya and Zahid 2018).

Musculoskeletal disorders represent one of the most common causes of work absence, affecting millions of European workers and costing billions of euros for employers (Bevan 2015). The health problems can vary, from milder cases to more worrying situations where there are suffering and prolonged pain, which requires time off work or long medical treatment processes (Lesões 2021).

Ergonomic risk assessment could be the key to prevention. Identifying existing or even potential risks that can cause musculoskeletal disorders is part of the risk analysis process (Buckle 2005). As soon as the risk factors are identified, interventions are imposed to eliminate or reduce them (Grooten and Johansson 2018). Specific methodologies have been developed for this purpose. They consider biomechanical, physiological, psychophysical, and epidemiological aspects to evaluate the working environment. The methodologies are designed to evaluate a specific risk factor. For example, some methodologies are recommended to evaluate postures, while others are indicated to study MMH activities (de Miranda Prottes et al. 2012; Berlin and Adams 2017).

As so, the objective of this paper is to identify if the application of ergonomic studies can be associated with a positive impact on the incidence of musculoskeletal disorders and the workers' well-being so that it can improve their overall comfort and productivity.

2 Methodology

This brief literature review of the literature followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses 2009 (PRISMA) (Liberati et al. 2009) statement. The main steps that guided the work are shown in Fig. 1.

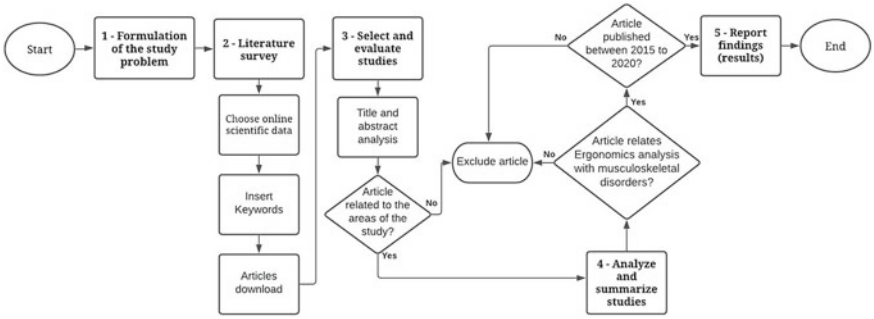

Fig. 1 Flowchart of the methodology

The first step regards the research objective, which can be resumed into the question: "Is the evaluation of ergonomic risk factors connected to the decrease of musculoskeletal injuries in the industry?". Thus, as previously mentioned, the aim of this paper is a brief literature review of the relation between ergonomic interventions and the incidence of musculoskeletal disorders. The focus is on the industrial environment since many industrial workstations present ergonomic risk factors. Thus, the following points were defined as inclusion criteria:

1. Studies that used one or more ergonomic tools for risk evaluation;
2. Studies focusing on the before and after a risk assessment;
3. Studies that reported the impact of the ergonomic intervention after the risk evaluation;
4. Studies performed in an industrial environment.

The bibliographic research process was restricted to articles published in English after 2015.

Online scientific data sites were used to perform the survey, such as Taylor and Francis, Elsevier, and Springer. The following combinations of Keywords were used: ("Manual Material Handling"), ("ergonomics" OR "risk factors"), ("ergonomics in industry"), ("MMH analysis"), ("risk analysis"), ("MMH risk assessment"), ("posture risk analysis" OR "ergonomic implementation").

As a result, 53 articles were reached.

3 Results

Initially, all the articles that did not follow the inclusion criteria based on their titles and abstracts were excluded. With the conclusion of this stage, the first set of 46 articles was reached. Then, a new analysis was carried out, this time based on the full article. From this analysis, 17 articles were excluded for deviating from the subject, 10 for not responding to the problem in question. Finally, 14 articles were excluded since they did not demonstrate a clear impact of the ergonomic risk analysis in their studies. In the end, 5 articles were selected.

The last step comprised gathering the selected articles and understanding how they answer the formulated problem.

The present review focused on the selected publications, from which the respective aims, methodologies, and main findings were extracted and reported here.

Table 1 synthesizes the 5 articles, reporting relevant information primarily concerned with ergonomic risk evaluations in industrial contexts and the impact of adequate ergonomic interventions on MSDs and workers' well-being. All articles evidence the differences between before and after risk assessment to evaluate the effectiveness of the ergonomic interventions. In addition, some articles used tools of time study to assess the effect on the organizations' productivity. The 5 articles reported case studies that were performed since 2015. They represent data from manufacturing and assembly industries from several parts of the world, giving evidence that concerns are worldwide.

There are several risk factors related to the development of musculoskeletal disorders, especially in manufacturing industries. The 5 articles reviewed for risk assessment applied specific ergonomic methodologies as Questionnaires, RULA, REBA, NIOSH, and NBD. They verified that most operators felt discomfort or pain during the execution of their tasks. Throughout the case studies, measures were taken based on a first evaluation. They included ergonomic education, the introduction of mechanical and automatic tools, shift rotation, and redesign of the workstations. In general, the studies reviewed highlight the importance of adapting the working environment for the workers' well-being and company performance. They demonstrated that the ergonomic interventions contributed to reducing the ergonomic risk level while productivity and the well-being of workers increased.

4 Discussion

The 5 articles analyzed revealed a pre-post study regarding the impact of ergonomic interventions in specific industrial contexts. This brief review confirmed that ergonomic risk factors are identified in many types of industries worldwide. It is noteworthy that the time between the ergonomic intervention and the second evaluation can be crucial to the results. This information would be relevant to this review, but it was not mentioned in most studies. In addition, this search also revealed a lack of comparative studies about the practical impact of ergonomic interventions on workers and organizations.

Nevertheless, the analyzed articles used several ergonomic methodologies to assess the risk that workers were exposed to their daily work and understand the adequate solutions.

In this brief review, the most common methodology was the NIOSH Lifting Equation. It is an observational method used to study MMH activities and find the recommended weight limit (RWL) and lifting Index (LI) (Cheung et al. 2007; Setyanto

Table 1 Summary of published Work on the pre and post ergonomic risk evaluation in industrial contexts

Article [reference]	Working context	Methodologies	Ergonomic risk factors	Causes of risk factors	Consequences of risk factors	Ergonomic interventions	Impact of interventions
Article #1	Standing job in a selected manufacturing plant in Malaysia	• Direct observation • Unstructured interview; Questionnaire	• Standing position • Static posture	• Job demands • Vibrating tools	• Aching feet • Low back pain	• Redesign of the workstation • Job rotation	• Less fatigue and stress • Reduction of medical leaves
Mas'aud and Abdullah (2021)	Sample: 56 workers	• RULA	• Repetitive movements • Vibration • Uncomfortable working environment • Work 2h overtime (every day)		• Swollen ankles • Calves • Hip pain • Fatigue • High number of medical leaves • Low productivity	• Anti-fatigue mat	• Higher productivity • Improved workers satisfaction

Table 1 (continued)

References	Objective	Cortisol Levels	Main Results				
Article #2	Woodworking department from a musical instruments production company	• NBM • REBA	• Awkward posture • Load	Not identified	Worker: • Musculoskeletal complaint	Implementation of new tools: • Automatic hand lift	• Low level of musculoskeletal disorders (NBM decreased) • Low-risk level for posture (REBA score decreased)
Suryoputro et al. (2018)	Sample: 2 workers	• Recommended Weight Limit (RWL) • Maximum Permissible Limit (MPL) • Time study • Productivity measurement	• Lifting		Organization • High number of injuries • Low performance (standard time and productivity)	• Manual hand lift	• Reduction in the application of force (MPL results) • Low-risk level for lifting (RWL findings) • Lower complaints rate • Reduction of the standard time • Productivity improvement
Article #3	Truck manufacturing plant	• Questionnaire • In-house ergonomic observational method	• Repetitive tasks • Force	Not identified	• Pain • Discomfort	• Redesign of the workstation • Redistribution of tasks (balancing)	• Fewer reports of MSDs symptoms • Cycle time was reduced (11 to 8 min)

Table 1 (continued)

References	Objective	Cortisol Levels	Main Results				
Zare et al. (2020)	Sample: 15 workers before and 21 after the intervention	• NIOSH lifting equation	• Awkward posture • Lifting • Load • Vibration • Un-balanced workstations • Inadequate recovery time			• Repeated actions were eliminated • Implementation of specific tools to make the job easier (lifting tools, gripping tools, and an embedded camera on the hand-held screwdriver machine) • Information and education implementation • Participatory approach and involvement of stakeholders	
Article #4	Rice milling industry in Indonesia	• Direct observation in the floor plant • NBM	• Awkward posture • Repetitive tasks	• Rudimentary working techniques	• Worker • Pain	• Redesign of a filtering rice appliance • Addiction of an extra tools cart	• Complaints reduction • Working posture improvement (REBA score decreased)

Table 1 (continued)

References	Objective	Cortisol Levels	Main Results				
Astuti et al. (2017)	Sample: 5 workers	• REBA	• Load • Manual material handling		• Tiredness • Overstress • Discomfort		• Overall job quality improvement
Article #5	Italian company in the industrial processing wool industry	• National Aeronautics and Space Administration Task Load Index (NASA TLX); • NIOSH lifting equation	• Uncomfortable postures • Load (dynamic and static)	• Lack of adequate equipment and tools • Shortcomings in the availability of adequate staff	• Fatigue • Increase of perceived workload	Supply of electric or ergonomic tools to replace hand tools: • Trolley with adjustable load support	• Improvement of workers well-being • Productivity improvement
Capodaglio (2020)	Sample: 45 workers	• OCRA checklist • TACOS (Time-based Assessment Computerized Strategy) • Snook and Ciriello tables	• Repetitive movements • Unbalanced design of machinery • Production processes • Environmental characteristics	• Difficulty to organize teamwork	• Stress • Costs for the company • Low quality of the product	• Mobile electric winches • Hydraulic lifting	

et al. 2015). It suggests that MMH activities, especially lifting or lowering loads, are frequent in industrial atmospheres despite technological evolution.

Additionally, the Nordic Body Map and REBA methodologies are also a standard in some articles. Their application is justified for also being observational methods to identify physical effort by posture, force, and static or repetitive load. REBA was primarily used to analyze posture and muscle activity caused by static, dynamic, rapid changing, or unstable postures. This was presented to the different parts of the body that include upper arms, lower arms, wrist, trunk, neck, and legs (Kee 2021; Hignett and McAtamney 2000). On the other hand, Nordic Body Map was used to analyze each body part directly, according to a scale that goes from uncomfortable feeling to high pain (Setyanto et al. 2015).

Several solutions were found to respond to the level and severity of the risk encountered. No authors reported indifference to the risks; solutions were found and applied in all studies. According to most articles, essential measures include, for instance, organizational interventions, redesign of the workplace, and even tool design.

After the ergonomic intervention, the methodologies previously used by the authors were once again applied. The second risk analysis process aimed to guarantee the effectiveness of measures (Grooten and Johansson 2018). In all articles, the authors reported that the main objective was accomplished, which means the risk level decreased. The differences were more notable in some articles than others, but there was always a significant difference. It can be highlighted that the workers reported fewer symptoms of musculoskeletal disorders and appeared to be more motivated and happier with the performance of their tasks.

Consequently, the results evidenced the possible positive impact of reasonable ergonomic interventions. When correctly implemented, these interventions drastically reduce musculoskeletal injuries and significantly increase the company's productivity. Ergonomics must be seen as a philosophy in which all parties involved (operators, safety, and health professional's management) actively participate.

5 Conclusion

This review covered the analysis of five articles that portray operators' exposure to musculoskeletal injuries in the industrial context. Several scientific databases, such as Taylor and Francis, Elsevier, and Springer, were used to find the articles that report the effects of ergonomic interventions in different industries and work contexts. This detailed analysis recognized the relationship between ergonomic risk analysis and musculoskeletal injuries.

Before implementing the improvements, the authors highlighted a high number of musculoskeletal disorders, low productivity, and low performance.

After the interventions, most companies experience higher productivity levels compared to previous data.

Considering the articles presented, the authors verified that ergonomic interventions tend to positively impact organizations, both for workers' performance and the quality of work. Thus, and as concluded in the articles presented, it suggests that with the committed involvement of all company employees, it is possible to achieve ergonomic solutions that positively impact the working environment.

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References

Astuti, R.D., Susmartini, S., Kinanthi, A.P.: Improving the work position of worker based on manual material handling in rice mill industry. AIP Conf. Proc. **1902**(1), 020043 (2017). https://doi.org/10.1063/1.5010660

Berlin, C., Adams, C.: Production Ergonomics: Designing Work Systems to Support Optimal Human Performance - Ergonomics Evaluation Methods, pp. 139–160. Ubiquity Press, London (2017)

Bevan, S.: Economic impact of musculoskeletal disorders (MSDs) on work in Europe. Best Pract. Res. Clin. Rheumatol. **29**(3), 356–373 (2015). https://doi.org/10.1016/j.berh.2015.08.002

Buckle, P.: Ergonomics and musculoskeletal disorders: overview. Occup. Med. **55**(3), 164–167 (2005). https://doi.org/10.1093/occmed/kqi081

Capodaglio, E.M.: Participatory ergonomics for the reduction of musculoskeletal exposure of maintenance workers. Int. J. Occup. Saf. Ergon. 1–11 (2020). https://doi.org/10.1080/10803548.2020.1761670

Cheung, Z., Feletto, M., Galante, J., Waters, T.: Ergonomic Guidelines for Manual Material Handling. Faye Ong - CDE Press, California Department of Education - Sacramento, CA (2007)

de Miranda Prottes, V., Oliveira, N.C., de Oliveira Andrade, A.B.: Ergonomic work analysis as a tool of prevention for the occupational safety and health management system. Work **41**(Supplement 1), 3301–3307 (2012). https://doi.org/10.3233/WOR-2012-0597-3301

Grooten, W.J.A., Johansson, E.: Observational methods for assessing Ergonomic risks for work-related musculoskeletal disorders. A scoping review. Rev. Cienc. Salud **16**, 8–38 (2018). https://doi.org/10.12804/revistas.urosario.edu.co/revsalud/a.6840

Hignett, S., McAtamney, L.: Rapid entire body assessment (REBA). Appl. Ergon. **31**(2), 201–205 (2000). https://doi.org/10.1016/S0003-6870(99)00039-3

Kee, D.: Comparison of OWAS, RULA and REBA for assessing potential work-related musculoskeletal disorders. Int. J. Ind. Ergon. **83**, 103140 (2021). https://doi.org/10.1016/j.ergon.2021.103140

Klussmann, A., Liebers, F., Gebhardt, H., Rieger, M.A., Latza, U., Steinberg, U.: Risk assessment of manual handling operations at work with the key indicator method (KIM-MHO) - determination of criterion validity regarding the prevalence of musculoskeletal symptoms and clinical conditions within a cross-sectional study. BMC Musculoskelet. Disord. **18**(1), 184 (2017a). https://doi.org/10.1186/s12891-017-1542-0

Klussmann, A., et al.: Validation of newly developed and redesigned key indicator methods for assessment of different working conditions with physical workloads based on mixed-methods design: a study protocol. BMJ Open **7**(8), e015412 (2017b). https://doi.org/10.1136/bmjopen-2016-015412

Lesões musculoesqueléticas - Segurança e saúde no trabalho - EU-OSHA. https://osha.europa.eu/pt/themes/musculoskeletal-disorders. Accessed 01 May 2021

Liberati, A., et al.: The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. **6**(7) (2009). https://doi.org/10.1371/journal.pmed.1000100

Mas'aud, N.H., Abdullah, B.: Evaluating the performance of ergonomic working environment in assembly line, undefined (2016). [Em linha]. Disponível em: https://www.semanticscholar.org/paper/Evaluating-the-performance-of-ergonomic-working-in-Mas'aud-Abdullah/200d2c339300cca8dd5a4fec124c7cedd1e8a02b. Accessed 01 May 2021

P. O. of the E. Union, Safer and healthier work at any age: review of resources for workplaces (2016). http://op.europa.eu/en/publication-detail/-/publication/d4b4a442-f7ce-11e5-b1f9-01aa75ed71a1/language-en. Accessed 01 May 01 2021

Setyanto, N., Efranto, R., Prasetyo, R., Dirawidya, A.: Ergonomics analysis in the scarfing process by OWAS, NIOSH and nordic body map's method at slab steel plant's division (2015). https://doi.org/10.15680/IJIRSET.2015.0403060

Suryoputro, M.R., Wildani, K., Sari, A.D.: Analysis of manual material handling activity to increase work productivity (Case study: manufacturing company). MATEC Web Conf. **154**, 01085 (2018). https://doi.org/10.1051/matecconf/201815401085

Yahya, N.M., Zahid, M.N.O.: Work-related musculoskeletal disorders (WMDs) risk assessment at core assembly production of electronic components manufacturing company. IOP Conf. Ser. Mater. Sci. Eng. **319**, 012036 (2018). https://doi.org/10.1088/1757-899X/319/1/012036

Zare, M., Black, N., Sagot, J.-C., Hunault, G., Roquelaure, Y.: Ergonomics interventions to reduce musculoskeletal risk factors in a truck manufacturing plant. Int. J. Ind. Ergon. **75**, 102896 (2020). https://doi.org/10.1016/j.ergon.2019.102896

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Ergonomic Assessment on a Twisting Workstation in a Textile Industry

José Barbosa, Paula Carneiro, and Ana Colim

Abstract Background: In textile industries, the workers of twisting workstations are exposed to several risk factors that may contribute to the increasing of Work-related Musculoskeletal Disorders (WMSD) risk. However, the information about twisting' working conditions is limited. Objective: This study aims to identify and quantify the main risk factors associated with WMSD that workers of a twisting workstation are exposed. Method: Data of 20 workers were collected through self-report questionnaire. This questionnaire was structured into three categories based on published methods/techniques, namely: (i) Ergonomic Workplace Analysis (EWA) method; (ii) a checklist for manual handling tasks developed by the Portuguese Authority for Working Conditions; (iii) and Nordic Musculoskeletal Questionnaire (NMQ). It was also applied the Rapid Upper Limb Assessment (RULA) method and the NIOSH Lifting Equation to quantify the risk of the tasks and prioritize the ergonomic interventions. Results: The questionnaire results highlighted that the highest occurrence of musculoskeletal complaints was in the lumbar region and shoulders, while through RULA assessment the upper limbs were the most critical body regions. Furthermore, RULA and NIOSH Equation application indicated that there is WMSD risk associated to the evaluated tasks, being necessary to investigate and, for the most critical tasks, make changes immediately. Application: The participatory ergonomics promotes the identification of risks and the contribution to improvement suggestions between workers. This multi-method approach to achieve a comprehensive assessment of problematic tasks comproved the need of an ergonomic intervention.

Keywords Human factors · WMSD · Risk assessment · Workers' participation · Textile industry

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1 Introduction

In industrial contexts, workers are often subject to non-neutral postures (Yoon et al. 2016), repetitive tasks (Zare et al. 2018), and material handling (Ramadan and Alkahtani 2017), being exposed to different risk factors associated with development of Work-related Musculoskeletal Disorders (WMSD).

WMSD are a problem with a significant impact on organizations around the world, corresponding to the most frequent work-related illness in the European Union (Bevan 2015). The consequences of this problem are severe and reflected in high levels of absenteeism (Bevan 2015), reduction of productivity and competitiveness (Widanarko et al. 2014), decreases in products' quality and time available in the training of new workers (Caroly et al. 2010). There are several factors that contribute to the WMSD occurrence (Colim et al. 2020), and Bevan (2015) considers that many of them are present in the work environment, aggravating the incidence of these disorders. For this reason, Ergonomics focuses on understanding the causal relationship between WMSD and risk factors, in order to prevent its prevalence (Petit et al. 2014; Yoon et al. 2016).

Organizations have continuously taken an active and multifaceted position focusing efforts on reducing and eliminating WMSD risks (Widanarko et al. 2014), investing in the risk assessment and posteriorly in ergonomic interventions. For that, there are several validated methods for WMSD risk assessment that are divided into the following categories:

(i) checklists and self-assessment questionnaires;
(ii) observational methods;
(iii) direct measurements (David 2005).

Despite the limited studies about ergonomic conditions on twisting workstations, these work tasks are characterized by a higher utilization of upper limbs, involving adoption of painful postures and manual handling with an excessive physical load. The statistical data provided by the company regarding the number of the last incidents occurred at the company indicated that 44 of 100 incidents occurred on the twisting workstation. Therefore, the current study had the purpose to analyze a specific twisting workstation in a Portuguese textile industry where most of the workers are expose to WMSD risk factors, particularly related to the upper limbs. In this way, this study corresponds to an initial moment of musculoskeletal risk assessment, considering an active participation of the workers to justify the respective ergonomic intervention.

2 Materials and Methods

From observation of the work activity during two weeks and conversation with workers and supervisors, the main tasks were identified, considering the following criteria:

(i) the most frequent;
(ii) the higher duration;
(iii) complexity;
(iv) adoption of awkward postures.

A twisting machine is composed of sixty eight spindles being each of them constituted by one creel with two positions (lower and upper) and one spindle pot. Therefore, the work activity was subdivided into the following manual tasks:

(i) lowering the creel;
(ii) lifting the creel;
(iii) supply the upper position of the creel;
(iv) supply the lower position of the creel;
(v) carry the spindle pot;
(vi) perform air splice between yarn ends;
(vii) remove the twisted cord bobbin from the conveyor belt;
(viii) insert a new tube to restart the twisting process.

2.1 Ergonomic Assessment by Collecting Workers' Perceptions About Workplace Conditions and Musculoskeletal Symptoms

In a first phase of the study, a questionnaire was developed in order to collect the workers' opinions about ergonomic conditions and musculoskeletal symptomology perceived. It was based on other validated methods and checklists, namely: Ergonomic Workplace Analysis (EWA) (Ahonen et al. 1989); a checklist for manual handling developed by the Portuguese Authority for Working Conditions (ACT 2014); and the Nordic Musculoskeletal Questionnaire (NMQ) in the Portuguese version (Mesquita et al. 2010).

EWA method was developed by the Finnish Institute of Occupational Health (FIOH) to adapt the working conditions to the specific workers' needs, based on observation of the workplace and workers' interviews. It aims to identify existing risks and outline improvement proposals, addressing and discussing the strengths and weaknesses of the workplace with the workers (Chiasson et al. 2015). Likewise, the expert in ergonomics evaluated all parameters on a scale of 4–5 levels. Higher scores mean higher dissatisfaction by workers and higher risk assessed by analyst.

Relatively to the Nordic Musculoskeletal Questionnaire (NMQ), this is a self-assessment method regarding musculoskeletal complaints. This tool consists of three questions related to nine anatomical regions: neck, shoulders, upper back, lower back, elbows, wrists/hands, hips/thighs, knees, ankles/feet. Each worker should report if, in the last 12 months, and in the last 7 days, presented any musculoskeletal symptoms at the referred regions and evaluate the pain intensity according to a numerical scale (Visual Analogical Scale—VAS), with values ranging from 0 (no pain) to 10 (maximum pain).

It also analyzed the technical aids used in the workstation and it had an open-question to collect workers' opinions for possible workpace improvements. The questionnaire structured in different sections, aimed to collect the perception of workers for a set of factors responsible for the risk they are exposed.

A pilot test was carried out with three workers randomly selected leading to minimal changes. The questionnaire was applied during the workers' breaks in the form of an interview along two weeks. The answers collection was random and anonymous.

2.2 Ergonomic Assessment by RULA and NIOSH Lifting Equation

There are several methods available for the risk assessment, but observational ones are the most used in the practice (Takala et al. 2010). These methods perform risk assessment through direct observation, considering risk factors such as frequency and duration of the tasks (Colim et al. 2020). To assess the WMSD risk, it was selected the Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett 1993). It is an observational and quantitative assessment method that allows a more detailed analysis at level of the upper limbs (Takala et al. 2010). RULA prioritizes ergonomic interventions identifying the risk associated and the respective actions to be taken through four action levels.

Additionally, for the lifting/lowering material tasks, the NIOSH Lifting Equation (Waters et al. 1993) was also applied. This equation allows the calculation of the Recommended Limit Weight (RLW) and also provides the Lifting Index (LI), corresponding to an indicator of physical stress in lifting tasks. According to the LI value three risk levels are defined: (i) $LI \leq 1$ means no risk associated; (ii) LI = 1, 1–2, 9 means risk for some workers; and (iii) $LI \geq 3$ means risk for the most of workers.

3 Results and Discussion

3.1 Collection of Workers' Perceptions About Working Conditions and Musculoskeletal Complaints

The questionnaire was applied to 20 workers, corresponding to five workers in each of the four rotation shifts, 80% of them were male and 20% female, with an average age of 29.9 (±6.3) years old and average seniority at the workstation of:

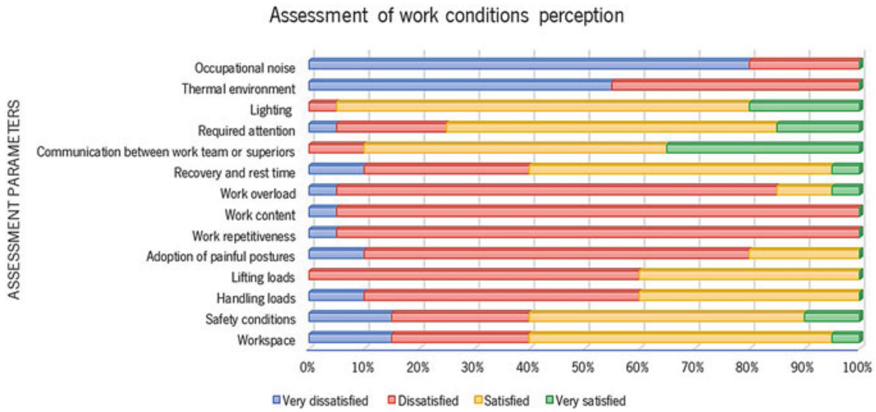

Fig. 1 Workers' perceptions about the working conditions

(i) less than 5 years (30%);
(ii) between 5 and 10 years (55%);
(iii) between 10 and 15 years (10%);
(iv) more than 15 years (5%).

The results obtained through the subjective evaluation of the 14 parameters (Fig. 1) demonstrated an evident dissatisfaction with certain parameters. These results highlight that more than 50% of the workers considered to be very dissatisfied or dissatisfied about the following factors: occupational noise, thermal environment, work content, work repetitiveness, work overload, adoption of painful postures, lifting and handling loads.

Considering the parameters directly associated with the performance of work tasks, 80% of workers attributed a negative score to the adoption of painful postures and 100% to the work repetitiveness. The workers' perceptions reinforced the need to deeper evaluate the workstation, namely through the NMQ and the application of observational assessment methods. Figure 2 shows that more than 50% of workers reported musculoskeletal complaints in at least 3 body regions in the last 12 months and 7 days, being the lumbar region (n = 19 workers) and the shoulders (n = 19) the regions most affected. Workers also rated the perceived pain intensity using a VAS scale, highlighting that the highest score is also attributed to the lumbar region and shoulders.

Finally, in the section for improvement suggestions, the questionnaire reinforced that all workers consider that there are opportunities for improvement in the workplace. Regarding the possibility of introducing new technical aids, workers are receptive to experimental tests with collaborative robotics and exoskeletons, with 80% and 70% of workers considering that these technologies could produce a positive impact, respectively (Colim et al. 2021).

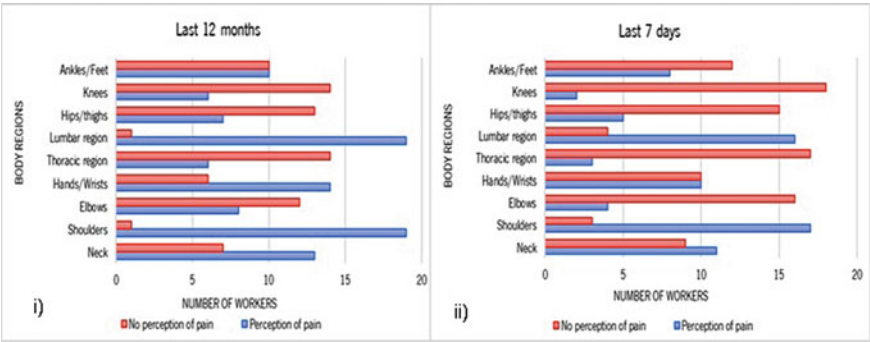

Fig. 2 Workers musculoskeletal symptoms: (i) last 12 months; (ii) last 7 days

3.2 RULA and NIOSH Lifting Equation Assessment

For the application of RULA method, the most frequently performed tasks were selected. For each task, from the video-records observation of several work cycles, the most critical posture was selected and the RULA score was calculated (Table 1). The tasks of lowering and lifting the creel, and supply the lower position have a higher RULA score, which means that these tasks are associated with a greater musculoskeletal risk compared to the others. It is important to clarify that the task of supply the lower position of the creel is carried out with a full yarn bobbin, while supply the upper position is performed with a half bobbin making this task less painful. For the seven tasks analyzed, the upper limb region is the most affected due to the adopted posture (Fig. 3).

In order to ensure a more sustained and complete assessment as well as to understand the variation of the musculoskeletal risk in the load placement between the two positions of the creel, the NIOSH Lifting Equation was applied for the tasks "supply the creel" . The results agree with those obtained by RULA, indicating that the supply of the creel in a lower position has more associated musculoskeletal risk because it has a higher LI compared to upper position. However, it's important to note that both tasks represent a significant musculoskeletal risk for most workers, being the LI = 3, 14 for the task 3 (supply the upper position) and LI = 3, 19 for the task 4 (supply the lower position).

The findings based on the observational assessment methods are aligned with the perceptions of workers. In this way, the musculoskeletal complaints perceived in the shoulders and lumbar region may be the result of the adopted postures in the execution of the tasks. The final RULA score divided the task analyzed into three action levels, with the task of lowering and lifting of the creel, and supply the lower position indicating the need of an immediate ergonomic investigation and intervention. Therefore, the participatory ergonomics combined with a multi-method approach can be used to achieve a more detailed assessment and, subsequently, a

Table 1 Assessment of the tasks—RULA method

Task assessed	Body regions more affected	RULA upper limb score	RULA neck, trunk and lower limb score	RULA final score	Action level
1-Lowering the creel	Arm, neck and trunk	8	6	7	D: Investigation and ergonomic intervention are needed immediately
2-Lifting the creel	Arm, neck and trunk	6	6	7	D: Investigation and ergonomic intervention are needed immediately
3-Supply the upper position of the creel	Arm and neck	5	4	5	C: Investigation and ergonomic intervention are needed shortly
4-Supply the lower position of the creel	Arm, neck and trunk	8	7	7	D: Investigation and ergonomic intervention are needed immediately
5-Carry the spindle pot	Lower arm and trunk	3	2	3	B: Further investigation is needed
6-Air splice between yarn ends	Arm and neck	4	3	3	B: Further investigation is needed
7-Insert a new tube	Arm and wrist	6	1	4	B: Further investigation is needed

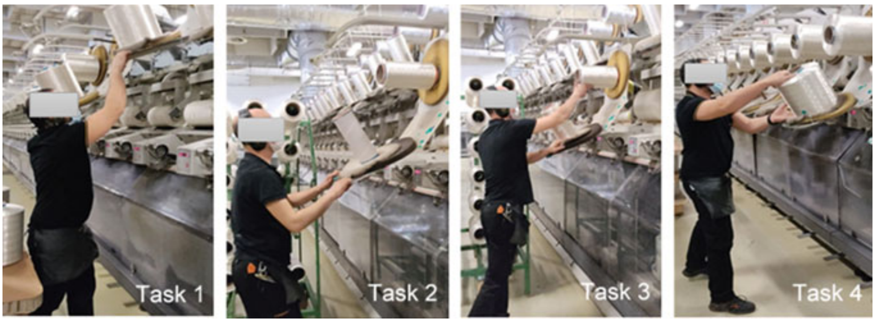

Fig. 3 Most critical posture: task 1, task 2, task 3 and task 4

successful ergonomic intervention to reduce risks to safety and health (Burgess-Limerick 2018; Colim et al. 2021).

In this sense, as future work it's expected a prioritization of the suggestions in order to proceed to the test in the workplace. For example, through the introduction of technical aids such as collaborative robotics or implementation of job rotation. Human-robot collaboration is considered one of the major milestones of the Industry of future, eliminating monotonous, repetitive and hazardous tasks, potentiating the human (D'Souza et al. 2020). In addition, job rotation models has been one of the organizational measures frequently adopted in the prevention of WRMSD (Boenzi et al. 2016; Leider et al. 2015; Mehdizadeh et al. 2020). It is a strategy to alternate workers between tasks with different exposure level to risk factors, avoiding overload in specific body regions (Leider et al. 2015), reducing the monotony of repetitive individual tasks, and increasing the workers' satisfaction (Yoon et al. 2016).

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References

ACT: Lista de Verificação das Condições de Trabalho: Movimentação Manual de Cargas, pp. 1–4. Autoridade para as Condições do Trabalho (2014). https://www.act.gov.pt/(pt-PT)/CentroInformacao/ListasVerificacao/Paginas/default.aspx

Ahonen, M., Launis, M., Kuorinka, T.: Ergonomic Workplace Analysis. Finnish Institute of Occupational Health, Ergonomics Section (1989)

Bevan, S.: Economic impact of musculoskeletal disorders (MSDs) on work in Europe. Best Pract. Res. Clin. Rheumatol. **29**(3), 356–373 (2015). https://doi.org/10.1016/j.berh.2015.08.002

Boenzi, F., Digiesi, S., Facchini, F., Mummolo, G.: Ergonomic improvement through job rotations in repetitive manual tasks in case of limited specialization and differentiated ergonomic requirements. IFAC-PapersOnLine **49**(12), 1667–1672 (2016). https://doi.org/10.1016/j.ifacol.2016.07.820

Burgess-Limerick, R.: Participatory ergonomics: Evidence and implementation lessons. Appl. Ergon. **68**(December 2017), 289–293 (2018). https://doi.org/10.1016/j.apergo.2017.12.009

Caroly, S., Coutarel, F., Landry, A., Mary-Cheray, I.: Sustainable MSD prevention: management for continuous improvement between prevention and production. Ergonomic intervention in two assembly line companies. Appl. Ergon. **41**(4), 591–599 (2010). https://doi.org/10.1016/j.apergo.2009.12.016

Chiasson, M.E., Imbeau, D., Major, J., Aubry, K., Delisle, A. : Influence of musculoskeletal pain on workers' ergonomic risk-factor assessments. Appl. Ergon. **49**, 1–7 (2015). https://doi.org/10.1016/j.apergo.2014.12.011

Colim, A., Faria, C., Braga, A. C., Sousa, N., Rocha, L., Carneiro, P., Costa, N., Arezes, P.: Towards an ergonomic assessment framework for industrial assembly workstations - A case study. Appl. Sci. (Switzerland), **10**(9) (2020). https://doi.org/10.3390/app10093048

Colim, A., Morgado, R., Carneiro, P., Costa, N., Faria, C., Sousa, N., Rocha, L.A., Arezes, P.: Lean manufacturing and ergonomics integration: Defining productivity and wellbeing indicators in a human-robot workstation. Sustainability (Switzerland) **13**(4), 1–21 (2021). https://doi.org/10.3390/su13041931

D'Souza, F., Costa, J., Pires, J.N.: Development of a solution for adding a collaborative robot to an industrial AGV. Ind. Robot. **47**(5), 723–735 (2020). https://doi.org/10.1108/IR-01-2020-0004

David, G.C.: Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occup. Med. **55**(3), 190–199 (2005). https://doi.org/10.1093/occmed/kqi082
Leider, P.C., Boschman, J.S., Frings-Dresen, M.H.W., van der Molen, H.F.: Effects of job rotation on musculoskeletal complaints and related work exposures: a systematic literature review. Ergonomics **58**(1), 18–32 (2015). https://doi.org/10.1080/00140139.2014.961566
McAtamney, L., Nigel Corlett, E.: RULA: a survey method for the investigation of work-related upper limb disorders. Appl. Ergon. **24**(2), 91–99 (1993). https://doi.org/10.1016/0003-6870(93)90080-S
Mehdizadeh, A., Vinel, A., Hu, Q., Schall, M.C., Gallagher, S., Sesek, R.F.: Job rotation and work-related musculoskeletal disorders: a fatigue-failure perspective. Ergonomics **63**(4), 461–476 (2020). https://doi.org/10.1080/00140139.2020.1717644
Mesquita, C.C., Ribeiro, J.C., Moreira, P.: Portuguese version of the standardized Nordic musculoskeletal questionnaire: cross cultural and reliability. J. Public Health **18**(5), 461–466 (2010). https://doi.org/10.1007/s10389-010-0331-0
Petit, A., Ha, C., Bodin, J., Parot-Schinkel, E., Ramond, A., Leclerc, A., Imbernon, E., Roquelaure, Y.: Personal, biomechanical, organizational and psychosocial risk factors for neck disorders in a working population. J. Occup. Health **56**(2), 134–140 (2014). https://doi.org/10.1539/joh.13-0186-OA
Ramadan, M.Z., Alkahtani, M.: Development of a device to reduce the risk of injury in handling unstable loads. Work **58**(3), 349–359 (2017). https://doi.org/10.3233/WOR-172627
Takala, E.P., Pehkonen, I., Forsman, M., Hansson, G.Å., Mathiassen, S.E., Neumann, W.P., Sjøgaard, G., Veiersted, K.B., Westgaard, R.H., Winkel, J.: Systematic evaluation of observational methods assessing biomechanical exposures at work. Scand. J. Work Environ. Health **36**(1), 3–24 (2010). https://doi.org/10.5271/sjweh.2876
Waters, T., Putz-Anderson, V., Garg, A., Fine, L.J.: Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics **36**(7), 749–776 (1993). https://doi.org/10.1080/00140139308967940
Widanarko, B., Legg, S., Devereux, J., Stevenson, M.: The combined effect of physical, psychosocial/organisational and/or environmental risk factors on the presence of work-related musculoskeletal symptoms and its consequences. Appl. Ergon. **45**(6), 1610–1621 (2014). https://doi.org/10.1016/j.apergo.2014.05.018
Yoon, S.Y., Ko, J., Jung, M.C.: A model for developing job rotation schedules that eliminate sequential high workloads and minimize between-worker variability in cumulative daily workloads: Application to automotive assembly lines. Appl. Ergon. **55**, 8–15 (2016). https://doi.org/10.1016/j.apergo.2016.01.011
Zare, M., Sagot, J.C., Roquelaure, Y.: Within and between individual variability of exposure to work-related musculoskeletal disorder risk factors. Int. J. Environ. Res. Public Health **15**(5) (2018). https://doi.org/10.3390/ijerph15051003

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Evaluation of Ergonomic Risk of Warehouse Activities in a Telecommunications Sector Company

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Abstract Work-related Musculoskeletal Disorders (WMSDs) are a worldwide problem, both in terms of health and socioeconomic level. WMSDs are one of the main concerns of ergonomics, since they have been identified as being associated with occupational activities that expose employees to a high biomechanical and physiological load. In view of the above, it is necessary to assess risk in real work contexts. The present study was developed in a company in the telecommunications sector with the aim of assessing the risk of developing WMSDs to which employees are subject in carrying out their activities in the warehouse. The tasks analyzed were carry task, manual load lifting task and logistical work. For this purpose, the NIOSH Equation, Key Indicator Method and Rapid Upper Limb Assessment will be applied. It is intended to identify whether these tasks developed constitute risk for employees, to allow the presentation of measures that can minimize the effort required during the activity and, consequently, reduce the risk to which employees are exposed. The results show that the risk of low back pain and the development of WMSDs is increased, so there is a need for an ergonomic intervention in terms of technical and organizational measures in this activity.

Keywords Ergonomics · Key Indicator Method · Manual handling of loads · Niosh Equation · Work-related Musculoskeletal Disorders · Rapid Upper Limb Assessment

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1 Introduction

Ergonomics aims to achieve improvements in the work context and in the task performed (ACT n.d.). It is therefore necessary to carry out an ergonomic risk assessment and to identify the associated hazards in order to implement the most appropriate preventive and corrective measures (ACT n.d.). Manual handling of loads in occupational contexts is one of the most frequent tasks and result in a high risk for the development of Work-related Musculoskeletal Disorders (WMSDs) (Hoe et al. 2012; Mattos et al. 2015; Mital et al. 1997). In these types of tasks, the skeletal and muscular systems of employees are the most affected and can cause WMSDs, namely at the level of the upper limbs, neck, back and lower limbs. These types of disorders have consequences for the employees themselves and cause high costs for employers and society (EU-OSHA 2019; Fontes et al. 2017). Decree—Law No. 330/93, of 25 September, seeks to transpose into domestic law Directive No. 90/269/EEC, of the Council, of 29 May, on the minimum health and safety requirements in manual handling of loads, defines the general preventive measures to be considered in manual handling of loads works, as well as some recommendations that the employer should consider in the risk assessment. There are still a high number of jobs where manual handling represents a worrying risk factor. In view of the above, numerous methods have been developed over the years to allow the identification and assessment of the risk of WMSDs inherent to manual handling tasks. The National Institute for Occupational Safety and Health (NIOSH) has developed a practical analysis tool that is called the NIOSH Equation (Waters et al. 1994). This tool allows the risk assessment of tasks involving manual handling of loads (Waters et al. 1994). Bearing in mind that interventions at the level of risk assessment and control in manual handling are not limited to lifting tasks, but also tasks such as pulling and pushing, these can also be critical situations from the point of view of risk of occurrence of WMSDs. Thus, the Key Indicator Method (KIM) which is a method that includes a description of the requirements and conditions of work with the objective of assessing the risk of physical overload to which employees are exposed when performing tasks to lift /lowering, holding and transporting, pushing and pulling loads, adopting strange body postures and body movement, meeting biomechanical, physiological and psychophysical criteria (BAuA 2019; Steinberg et al. 2006, 2007). The Rapid Upper Limb Assessment (RULA) in turn is an observational method of workstations which aims to assess employee's exposure to adopted postures, muscular effort, repetition, and strength exerted to performing the task that contribute to the development of WMSDs (Másculo and Vidal 2011; McAtamney and Corlett 1993; Serranheira et al. 2008). It is based on the recording of the different postures adopted during the execution of the task, regarding the upper limbs (arm, forearm, and hands), neck, trunk and legs. This method allows to select the posture that occurs most frequently or where the highest load value occurs (Másculo and Vidal 2011). The present work was developed in a company in the telecommunications sector with the aim of assessing the risk of developing WMSDs to which employees are subject in carrying out their activities in the warehouse. For this purpose, the following two specific objec-

Table 1 Description of employees

	Age	Gender	Seniority in the company	Tasks developed	Personal protective equipment
ID1	26	Male	2 months	Carry and manual load lifting tasks	Footwear and protective gloves
ID2	24	Male	6 months	Logistical work	Footwear and protective gloves

tives were defined: apply an ergonomic tool, namely the NIOSH Equation, KIM and RULA to characterize the conditions of employees in relation to the work; define and propose preventive strategies that can be adopted and contribute to risk mitigation. Thus, it is expected to contribute to the definition of healthier work practices that contribute to the prevention of WMSDs.

2 Methodology

In order to assess the ergonomic risk, a visit to the workplace was carried out with the support of a questionnaire, a stopwatch and a measuring tape, to survey the sociodemographic characteristics of the employees and the characteristics of the tasks under analysis.

2.1 Characterization of the Sample

The present study was developed in a company in the telecommunications sector that provides services to the main national operators, namely in terms of fiber optic infrastructures and next generation networks. The study counted on the presence of the two employees who perform functions in the warehouse. Information about employees was collected, namely age, gender, seniority in the company and personal protective equipment. The information collected is described in the Table 1.

2.2 Characterization of Tasks

The tasks analyzed were: (1) carry task; (2) manual load lifting task; (3) logistical work (outbound and inbound management of warehouse material, warehouse management and stock control). Employee ID1 spend about 6 h per day in carry tasks and manual load lifting tasks. Employee ID2 spend about 4 h in logistical work. However, the time spent varies depending on the workload. In the first task the load is carried

Table 2 Description of the variables for the application of the NIOSH Equation

Subtasks	H (cm)	L (kg)	V (cm)	D (cm)	A (°)	P	F
1	52.5	55	15	165	0	Good	0, 5
2	60	70	15	105	0	Good	2
3	55	60	15	105	0	Good	1

with the aid of a pallet truck to the warehouse. The distance covered is approximately 150 m and takes about 5 min to complete the route. The pavement of the route is in parallel with some irregularity. In the second task, employees lift the boxes, from the pallet truck to the rack shelves, until everything is packed. The employees were observed during several work cycles, allowing the identification of the tasks of manual lifting/lowering of loads and the postures adopted during their performance. The loads consist of telecommunication material that is packed in boxes of different dimensions and weights. For this purpose, three subtasks were considered depending on the weight of the load (L) to be handled. By monitoring the execution of the tasks, the following variables associated with each subtask were measured: Vertical Location (V), distance of the hands above the floor; Vertical Travel Distance (D), absolute value of the difference between the vertical heights at the destination and origin of the lift; Asymmetry Angle (A), angular measure of how far the object is displaced from the front (mid-sagittal plane) of employees, there was no trunk rotation in the three subtasks. The lifting of the loads was done by the base of boxes. With the stopwatch it was possible to determine the Lifting Frequency (F). The values of the variables for the application of the NIOSH Equation are described in Table 2.

Finally, in the third task, the employee organizes the orders records and stock control through the computer. The employee to perform this task is sitting in a chair in front of a desk. The chair is adjustable in height; however, it does not allow the employee feet to rest on the floor. The top of the computer monitor is below the eye line, causing the employee neck to be slightly bent.

2.3 Evaluation Methods

Although there are several methods to assess ergonomic risk, NIOSH Equation, KIM and RULA methods were selected for this study. The NIOSH equation allows to assess risks based on the load used in manual handling tasks and to assess in detail individual lifting situations (Herzog and Buchmeister 2020). The RULA method assesses postural risk, focusing on the most relevant body segments for the development of musculoskeletal disorders (Herzog and Buchmeister 2020). Finally, KIM, push and pull, during its application considers the important factors that influence working conditions (Schaefer et al. 2007).

NIOSH Equation. Prior to the evaluation and after verifying the applicability of the NIOSH Equation, it was considered that the work performed should be analyzed as multitasking. The multitasking analysis consisted of tree fundamental points (Waters et al. 1994):

1. Calculate the Frequency-Independent Recommended Weight Limit (FIRWL) and Single-Task Recommended Weight Limit (STRWL) for each task;
2. Calculate the Frequency-Independent Lifting Index (FILI) and Single-Task Lifting Index (STLI) for each task;
3. Calculate the Composite Lifting Index (CLI) for the overall job through Eqs. 1 and 2.

$$CLI = STLI_j + \sum \Lambda LI \tag{1}$$

$$\sum \Lambda LI = STLI_2 \left(\frac{1}{MF_{1,2}} - \frac{1}{MF_1} \right) + STLI_3 \left(\frac{1}{MF_{1,2,3}} - \frac{1}{MF_{1,2}} \right) + \cdots \tag{2}$$

KIM. The method is a risk assessment method related to manual handling of loads (BAuA 2019). In this study, the pull and push task were evaluated. The key indicators for the evaluation of this type of tasks are time, weight of the load, unfavourable working conditions, driveway conditions, unfavourable properties of the transport device, body posture, work organization/temporal distribution (BAuA 2019). These indicators are quantified using what is described in the respective tables for each one (BAuA 2019). Initially a score for the time is assigned. Then, the score for the key indicators is determined. Finally, the sum of the key indicators is performed where the total score is obtained. The time factor is multiplied to the total score and the final result is obtained, which is compared with the established evaluation criteria.

RULA. The application of the method consists of recording different observed work postures, classified through a scoring system, using diagrams of body postures and tables that assess the risk of exposure to external load factors to identify the muscular effort, which is associated with work posture, analyzing posture and dividing the body into two groups (McAtamney and Corlett 1993):

- Group A—Upper limbs (arms, forearms and hands).
- Group B—The legs, trunk and neck.

2.4 Assessment Criteria

NIOSH Equation. Through the application of the NIOSH Equation, the CLI value is obtained, which provides a relative estimate of the level of physical stress associated with a given manual load lifting task (Másculo and Vidal 2011; Waters et al. 1994).

Table 3 Development risk classification of WMSDs, according to CLI (Adapted from Waters et al. 1994)

CLI	Risk of low back pain and development of WMSDs
≤1	Absence of risk
]1 – 3[	Risk for some employees
≥3	Risk for most of employees

Table 4 Risk level and type of intervention

Risk range	Score	Measure
1	>20	Physical overload is unlikely. No health risk is to be expected
2	20–50	Physical overload is possible for less resilient persons. For less resilient persons, workplace redesign and other prevention measures may be helpful
3	50–100	Physical overload is also possible for normally resilient persons. Workplace redesign and other prevention measures should be considered
4	≥100	Physical overload is likely. Workplace redesign measures are necessary. Other prevention measures should be considered

The value of this index should be less than 1 and not exceed the value of 3. It is defined by Eq. 1 in the case of multitasking and its relationship with the risk of developing WMSDs is described in Table 3.

KIM. Based on the total score obtained from the task, it is possible to classify it in one of the 4 levels of risk. This scale indicates whether low exposure situations are present where physical overload is unlikely even situations of high physical overload in the musculoskeletal system where it is necessary to intervene in the workplace (BAuA 2019) (Table 4).

RULA. The RULA method determines 4 levels of action according to the values (points) that are obtained from the evaluation of each exposure factor (arm, forearm, wrist, neck, trunk, and legs) (McAtamney and Corlett 1993). The first level states that the posture is acceptable if it is not repeated or maintained for long periods. Level four, on the other hand, states that immediate changes in the workplace are necessary (Table 5).

3 Results

Through the monitoring of the execution of the tasks in the warehouse, it was found that there were differences in the variables associated with the different subtasks which led to the adoption of a multitasking analysis. The value of 2.82 for the CLI

Table 5 RULA action levels

Risk range	Score	Measure
1	1–2	Acceptable posture
2	3–4	Further investigation, change may be needed
3	5–6	Further investigation, change soon
4	+7	Investigate and change immediately

Table 6 Results of the NIOSH Equation for the manual load lifting task

Subtasks	FIRWL	STRWL	FILI	STLI	ORDER	CLI
1	7.59	6.15	0.53	0.65	3	2.82
2	6.81	4.43	1.17	1.81	2	
3	7.29	5.47	1.37	1.83	1	

Table 7 Results of the KIM method for the carry task

Time rating	Load weight/ transport device	Driveway conditions	Unfavourable working conditions	Unfavourable properties of the transport device	Body posture	Work organisa-tion	Total of indicator rating points	Risk level
2.5	1.5	6	3	0	5	2	43.75	2

Table 8 Results of the RULA method for the logistic work task

	Score	Muscle use	Force/load	Group score	Final score
Group A (upper limbs)	3	1	0	4	5
Group B (legs, trunk and neck)	4	1	0	5	

was obtained, which represents that there is a risk for some employees. The values obtained that resulted from the application of the NIOSH Equation are described in Table 6.

With regard to the result of the application of the KIM method through Table 7 it can be seen that a final result of approximately 44 was obtained, corresponding to a level of risk 2, which indicates an increased load situation where physical overload is possible for less resilient employees (BAuA 2019). It is important to intervene in workstations for these employees (BAuA 2019). The key indicators relating to driveway conditions and body postures were the most penalizing.

Regarding the application of the RULA method through the analysis of Table 8, it was found that the analyzed task had a final score of 5 which corresponds to a level of risk 3, this means that it is necessary to investigate and immediately requires changes (McAtamney and Corlett 1993). In this task it was found that employees are exposed to continuous and static muscular work at the level of the neck, back, forearms and arms.

4 Discussion

The FIRWL value obtained reflects the global requirement of each subtask, thus does not reflect the contribution of the other subtasks performed. This calculation is useful in assessing physical stress for an individual task (Waters et al. 1994). The results obtained for the NIOSH Equation demonstrate that subtasks 2 and 3 present FILI and STILI values higher than 1, which indicates that there will be a need for an ergonomic intervention to decrease the overall physiological requirements of the task and reduce the risk of occurrence of fatigue (Waters et al. 1994). At the end, a CLI value of 2.82 was obtained. Therefore, the purpose is to design all lifting jobs to accomplish an LI of 1 or less. In order to minimize the risk to which employees are exposed when carrying out the task of lifting loads, the vertical location from the hands above the floor has been increased (V = 75 cm), the value for which the CLI was calculated, obtaining the value of 1.65. Thus, there is a significant decrease in the risk value, however the CLI remains higher than 1. Regarding the characteristics of the load to be lifted, namely the weight and length, it’s not possible to make changes due to the material being supplied by customers. Storage is a fundamental task in a warehouse and is responsible for organizing the material in order to make good use of available space and efficient handling (Gu et al. 2007). Thus, it is necessary to redefining how the materials will be stored in view of their specific characteristics and having considered the risk of WMSDs for carrying out this task. It should be noted that NIOSH Equation is a tool for assessing the physical stress of two-handed manual lifting tasks, however its application is limited to those conditions for which it was designed (Waters et al. 1994). The Equation assumes that lifting and lowering tasks have the same level of risk for low back disorders, but this assumption may not be true if the employee drops the box rather than lowering it all the way to the destination (Waters et al. 1994).

In view of the results obtained from the application of the NIOSH Equation and KIM, the technical measure that is considered appropriate is the acquisition of a stacker with lifting forks, thus reducing the employee’s physical effort in both, the transport and manual load lifting task.

The modification of the floor will make it possible to smooth the passage of the pallet truck, which in turn may reduce the risk, as well as reduce the number of boxes transported, decreasing the weight of the total loads. Regarding the task of logistical work, the preventive and corrective measures that must be applied include the acquisition of the following equipment: a chair with adjustable height and a backrest adjustable in height, a footrest, a keyboard with ergonomic support for the wrists and a mouse pad with wrist support (EHS 2002; Pheasant 2002). It is also needed to adjust the height of the monitor so that the top of the screen is about 10º to 20º below the horizontal line of sight and tilt it about 10º to 20º so that the screen remains perpendicular to the eyes of employee (EHS 2002; Pheasant 2002). In terms of general organizational measures, task rotation should be considered, thus allowing the effort exerted by employees throughout the day to affect different muscle groups (EHS 2002; Pheasant 2002). There is no model of turnover in the warehouse’s workstations, employees move from one station to another, but both perform the same tasks with the same postures. Alternating manual load lifting task with carry tasks and logistic work tasks, as well as switching between different workstations would be a possibility to break the repetition of tasks (EHS 2002; Pheasant 2002). The training and information of employees on ergonomics and manual handling of loads will be essential for the reduction of WMSDs, as it allows the employee to be an active agent in prevention (ACT n.d.; DGS 2008). The existence of an active medical surveillance program is also important to detect symptoms and early signs of WMSDs (DGS 2008).

4.1 Limitations

One of the limitations of the present study is the short duration which implied the selection of certain tasks in detriment of others. It should also be noted that psychosocial and individual factors were not assessed in this study and, as such may have an influence on the development of WMSDs. However, the diagnosis of risk situations of WMSDs is the first step towards the definition of a strategy to improve working conditions.

For future research, the proposal will be based on the extension of risk assessment of the development of WMSDs for other workstations in the warehouse. It would be important to develop a rotation model according to risk factors related to work activity, organizational and individual factors, with a view to reducing the risk of developing WMSDs. In addition, there is a need for an ergonomic assessment in terms of material transport tasks from the vans to the rooftops of the building where the work is carried out, which implies that all material be transported manually to the site.

5 Conclusions

The overall objective of the study was achieved, giving insights about the risk of developing WMSDs on the tasks performed in the warehouse. Results showed that both in the task of carry and manual load lifting task, and logistical work, employees are exposed to considerable levels of developing WMSDs. Thus, prevention and correction measures were suggested for each specific task. The adoption of the measures will be reflected in improvements that will contribute to the reduction of employee's fatigue and, consequently an increase in productivity.

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References

ACT: Prevenir riscos ergonómicos (n.d.). https://www.act.gov.pt/(ptPT)/Publicacoes/Documents/AF_ergonomicos.pdf

BAuA: Key Indicator Method for assessing and designing physical workloads with respect to manual Pushing and Pulling of loads KIM-PP (2019). https://www.baua.de/EN/Topics/Work-design/Physical-workload/Keyindicator-method/pdf/KIM-PP-Pushing-Pulling.pdf?__blob=publicationFile&v=4

Decreto Lei n^o 330/93 Ministério do Emprego e da Segurança Social: Diário da República: Série I-A, n^o 226 (1993)

DGS: Guia de Orientação para a Prevenção de Lesões Musculoesqueléticas Relacionadas com o Trabalho (2008). http://www.dgs.pt/?cr=12830

EHS: Office Ergonomics pratical solutions for a safer workplace (2002). https://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/ergo/wa_office_ergonomics.pdf

EU-OSHA: Report of Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. Publications Office of the European Union (2019)

Fontes, A., Alves, A., Ribeiro, H.: Instrumento Breve para Rastreio de Perturbações MúsculoEsqueléticas relacionadas com o Trabalho (LMERT). Revista Portuguesa de Saúde Ocupacional online - RPSO **3**, 1–7 (2017)

Gu, J., Goetschalckx, M., McGinnis, L.F.: Research on warehouse operation: a comprehensive review. Eur. J. Oper. Res. **177**, 1–21 (2007)

Herzog, N.V., Buchmeister, B.: Workplace design and ergonomic analysis for workers with disabilities. In: International Conference on Applied Human Factors and Ergonomics, pp. 127–134. Springer, Cham (2020)

Hoe, V.C., Urquhart, D.M., Kelsall, H.L., Sim, M.R.: Ergonomic design and training for preventing work-related musculoskeletal disorders of the upper limb and neck in adults. Cochrane Database Systematic Rev. **2012**(8) (2012)

Másculo, F.S., Vidal, M.C.: Ergonomia: Trabalho adequado e eficiente. Elsevier, Amsterdam (2011)

Mattos, D.L., Merino, E.A.D., Pinto, A.C.C.S., Moro, A.R.P., Moraes, A.S.P.: Ergonomics and lean manufacturing: a case study of A3 as visual management tool for ergonomics in a Brazilian paper and pulp industry. In: Proceedings from 19th Triennial Congress of the IEA. Melbourne (2015)

McAtamney, L., Corlett, E.N.: RULA: a survey method for the investigation of work-related upper limb disorders. Appl. Ergon. **24**(2), 91–99 (1993)

Mital, A., Nicholson, A., Ayoub, M.: A Guide to Manual Materials Handling, 2nd edn. Taylor & Francis, Milton Park (1997)

Pheasant, S.: Bodyspace: Anthropometry, Ergonomics and the Design of Work, 2nd ed. CRC Press, Boca Raton (2002)

Serranheira, F., Uva, A.S., Lopes, F.: Lesões músculo-esqueléticas e trabalho: Alguns métodos de avaliação do risco. Sociedade Portuguesa de Medicina do Trabalho (2008)

Schaefer, P., Boocock, M., Rosenberg, S., Jäger, M., Schaub, Kh.: A target-based population approach for determining the risk of injury associated with manual pushing and pulling. Int. J. Ind. Ergon. **37**, 893–904 (2007)

Steinberg, U., Behrendt, S., Caffier, G., Schultz, K., Jakob, M.: Key indicator method manual handling 7 operations - Design and testing of a practical aid for assessing working conditions, 1st edn. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (2007)

Steinberg, U., Caffier, G., Liebers, F.: Assessment of Manual Material Handling based on Key Indicators - German Guidelines. Handbook of Standards in Ergonomics and Human Factors. Lawrenz Erlbaum Associates (2006)

Waters, T.R., Baron, S.L., Piacitelli, L.A., Anderson, V.P., Skov, T., Haring-Sweeney, M., Fine, L.J.: Evaluation of the revised niosh lifting equation: a cross-sectional epidemiologic study. Spine **24**(4), 386 (1999)

Waters, T., Putz-Anderson, V., Garg, A.: Applications manual for the revised NIOSH lifting equation. NIOSH (1994)

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Ergonomic Study of a Support Interface for the Therapheet Device in the Rehabilitation of the Tibiotarsal Joint

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Abstract Objective: To analyzed and verify the usability and ergonomic adaptability of a medical device, as well assess its functionality for the purposes of tibiotarsal rehabilitation. Background: Therapheet is a device that uses pneumatic technology to perform tibiotarsal joint rehabilitation exercises in passive mode. This device still has many limitations, has it does not have a suitable chair, nor a proper foot and knee fixation system. Its high mechanical complexity and oversized components make it difficult to perform a functional rehabilitation, moreover pneumatic technology does not seem to be the most suitable for continuous and precise movements. Method: XSens® MTw Awinda technology was used to analyze the movements made by the volunteers. The kinematic analysis kit made it possible to measure the angles and accelerations performed by the dominant foot. Results: There is no combination of the knee and back angle that favors all rehabilitation exercises, so an adjustment adapted to each exercise and each patient will be the most appropriate. Conclusion: The application of ergonomics and anthropometry allowed to fill some gaps in the device, leading to the development of support for the patient's lower limb and servomotor implementation. Application: Design of a rehabilitation device for the tibiotarsal joint.

Keywords Ergonomics · Rehabilitation · Therapheet · Tibiotarsal joint · XSens®

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1 Introduction

Due to its location, the human ankle is often subjected to heavy loads that can exceed the body's own weight. Body weight, excessive activity, or declining physical function, lead to bone, muscle or ligaments injury, which eventually leads to the loss of some of the tibiotarsal joint functions (Chang and Zhang 2019). The tibiotarsal joint is the most injured body part in sports, constituting about 16–21% of sports injuries (Chang and Zhang 2019; Kulunkoglu and Celik 2019). The general goals of a rehabilitation program are to restore the adequate range of motion, the surrounding muscles strength through resistance training, proprioception, and balance, which leads to full function and reduction of the probability of chronic instability and recidivism.

The ankle is a complex anatomical joint that produces movement with 3 degrees of freedom (DoF). Its main movement is plantar flexion and dorsiflexion that occur in the sagittal plane, abduction, and adduction (external rotation and internal rotation, respectively) that occur in the transversal/axial plane, and inversion and eversion, which occur in the frontal/coronal plane (Brockett and Chapman 2016). The neutral or resting position occurs when the axis of the foot makes an angle of 90° as the axis of the leg (Racu Cazacu and Doroftei). The ankle's range of motion varies significantly between individuals due to geographical and cultural differences based on their daily activities, in addition to the method used to assess range of motion.

Robotic devices have a significant impact on health, functioning as a vital component to improve the quality of life, so their application in the rehabilitation of the tibiotarsal joint will be very beneficial in providing additional resources to facilitate the physiotherapy of patients suffering from injuries in this articulation. Devices with this functionality already exist on the market, however there is not one that is fully efficient (Tsoi 2011; Kulunkoglu and Celik 2019).

Nowadays, the biggest concerns in the development of medical devices are improving patient safety and improving medical performance. Health professionals recognize that a care approach must be centered in the user and that a biomedical perspective alone can't generate good levels of care (Boute et al. 2018). For this reason, it is crucial that ergonomic principles and criteria are considered in the development of medical devices.

In the article by Boute et al. (2018) the commercial device AIO ™ Orfit, which is a table model used to support patients for breast radiotherapy, was analyzed (Boute et al. 2018).

The authors' objective was to search for a comfortable position for patients and create a device that is suitable for complete breast irradiation and irradiation of lymph nodes. They intended to specify the pain and pressure points on the currently used device (AIO ™ Orfit).

After each 10-min session, in which the volunteers were asked to remain steady, they completed a pain and comfort assessment questionnaire. Six regions can be assessed: neck, right shoulder, left shoulder, chest, right arm, left arm. A numerical pain rating scale, Numeric Rating Scale (NRS), from 0 to 10 was used, starting from no pain to unbearable pain, respectively. These types of scales are considered the most common and adaptable scales to assess pain intensity (Boute et al. 2018).

For each volunteer, the pain and comfort scores were observed in a female's body outline, where circles were represented, in which each circle represents a painful region reported by a volunteer. The size of the circles represents the pain score from 1 as a smaller circle to 10 as a larger circle. With these data it was possible to develop a new position for the females and create prototypes (Boute et al. 2018). In the study by DiGiovine et al. (2000), the purpose is to examine the comfort perceived by the user in the wheelchair during the impulse and to compare the ride comfort of ultra-light (high adjustment) and light (minimum adjustment) manual wheelchairs. For this study, the seven most used manual wheelchairs were compared (DiGiovine et al. 2000).

Classifications were made in terms of comfort perceived by users and basic ergonomics, while they performed some daily activities.

Ratings were written down for each wheelchair on individual tasks and for the overall course, this being defined by the authors (DiGiovine et al. 2000).

After three trials, each volunteer filled a questionnaire. Here, it was scored comfort for each of the tasks on the route and rated the basic ergonomics of the wheelchair. The comfort part, which assessed the driving tasks, used a 10 cm long visual analog scale. The scale ranged from extreme discomfort (0 cm) on the left to extreme comfort (10 cm) on the right. Volunteers needed to write an "X" on the visual analog scale to represent their comfort level for each task and each wheelchair. After that, one researcher, blinded to the type of chair, measured the distance from the left end of the scale to the nearest millimeter using a ruler (DiGiovine et al. 2000).

The wheelchair ergonomics part of the survey had four multiple-choice questions that were related to the stability, ease of use, hand comfort and overall ride comfort on the trail. For each ergonomic question, it was used five descriptors: Not at all (1), Reasonably (2), Moderately (3), Very (4), and Extremely (5). For the overall ride comfort question the descriptors were Poor (1), Reasonable (2), Moderate (3), Good (4), and Excellent (5) (DiGiovine et al. 2000).

The comfort section scores were analyzed using repeated measures of multiple variance analysis with Sheffe's post hoc analysis. The ergonomics and overall comfort scores were analyzed using the Kruskal–Wallis test. When designing a device, several factors such as usability, comfort, efficiency, safety, reliability, and anthropometrics must be considered. These "merge" into one word: Ergonomics (Silva 2008).

One of the existing barriers to achieving excellence in this area is due to the enormous physical variability that exists between people, because what may be suitable for one, is not for another. This is an aspect to take into consideration when designing this equipment (Silva 2008).

The sitting position requires constant back and belly muscle activity. If the seat is well dimensioned, this posture has advantages such as reducing the overload on the legs; possibility of avoiding forced positions of the body; energy consumption is reduced and blood circulation is improved (Silva 2008). To achieve this requires it would be necessary an ergonomics analysis with possible end users.

2 Material and Methods

The test, carried out in the automation laboratory of the University of Minho (UM), is called "test-retest" and counted on the participation of a heterogeneous population of healthy young adults of both genders, students at UM. Those who had recently injured their tibiotarsal joint and experienced pain while using the device, or those who were undergoing physical therapy were excluded from the study.

During the recruitment of the participants, a questionnaire was presented where information about the individuals was collected and from which, including the short adapted version of the International Physical Activity Questionnaire (IPAQ), conclusions were also drawn about the sedentary level of the individuals. Throw another questionary it was also collected information about the perception of comfort and other ergonomic questions about the device. There were 10 volunteers which 50% were males and 50% females to understand if the gender influenced the results. They had ages between 23 and 31 and an average BMI of 28,85. Only one volunteer had the left foot has the dominant one. None of the volunteers had recent injuries and 50% practice sports frequently, making them not sedentary.

For the rehabilitation movements were tested chair backrest angles of 110° and 140° and knee tilt angles of 90° and 130°.

Each level of the device is configured for two rehabilitation exercises, so the subjects performed one pair of movements at a time (dorsiflexion-plantar flexion (DF/PF), abduction-adduction (AB/AD), and inversion-eversion (I/E)), which were repeated for a period of 15 s.

The test was performed in one day and lasted a maximum of 30 min, and the retest was performed 1 week after the initial test so we could reassure that the obtained results were acceptable and were similar even days apart. At the end of the retest, the volunteers filled the Part II of the IPAQ questionnaire giving their perception of some functional and ergonomic aspects of the device, using a 5-point Likert scale, where 1 would be the least satisfactory value and 5 the top of the scale.

During each test, the XSens® kinematic analysis kit was used to measure the amplitude of the movements made by the volunteer's dominant foot. To do so, 7 sensors were used: 1 for the pelvis, 2 for the upper leg, 2 for the lower leg, and 2 for the feet (Fig. 1).

The collected values were subjected to statistical analysis using Microsoft Excel. Once the angle values were obtained for the various chair and knee movements and inclinations, outliers were excluded. To do so, values whose error between test and retest was greater than 30% were excluded and values that weren't between the maximum and minimum values found in literature. These outliers can be related to an inaccurate calibration, sudden movements derived from inertia of the device and foot or knee oscillation. The accelerations obtained are described in vectors decomposed in the x, y, and z axes, to make comparison between samples possible, the equivalent acceleration was calculated from its vector, which had the origin as reference. Once the acceleration values were obtained, it was necessary to exclude outliers. The largest acceleration value immediately below the upper limit was selected, which

Fig. 1 XSens® sensors placed on the foot and tibia of a volunteer during testing

corresponds to the maximum acceleration measured, the error between test and retest was calculated, calculating the minimum value of the difference, and the tests in which the error values between test and retest were greater than 25% were excluded.

3 Results

3.1 Kinematic Analysis (XSens®)

Taking as example a fixed back tilt of 110° for DF/PF (Fig. 2a), a knee tilt of 130° is the one that results in a greater range of motion (ROM) for all volunteers both in the test and retest, except for the test of volunteer number 10 ("Vol. 10"). The results per volunteer display individual variability and variances between volunteers. Here, the knee tilt significantly affected the results obtained.

For a 140° back tilt (Fig. 2b), better results are seen for the 130° knee tilt as compared to a 110° knee tilt. Figure 3 shows, within each cell, the values corresponding to the sum of the differences in amplitudes for each combination of movements. Here,

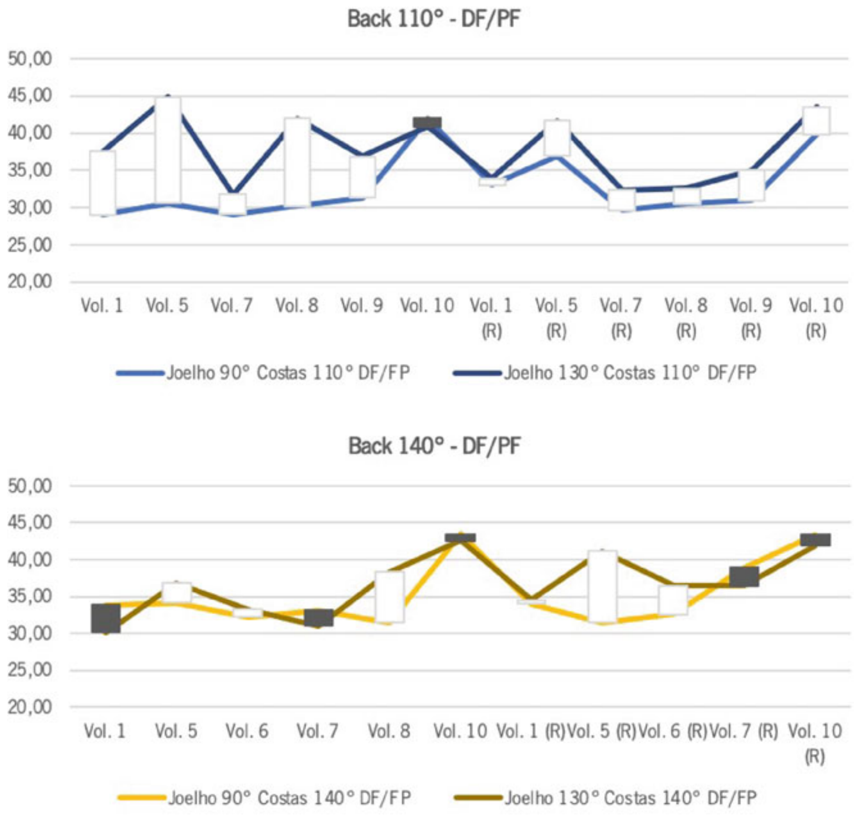

Fig. 2 Range of motion of dorsiflexion and plantar flexion, for back inclinations of **a** 110° and **b** 140°, varying the knee inclination to 90° and 130°. "Vol." represents the word "volunteer", corresponding to each of the 10 volunteers who performed the tests and retests ("R")

for each pair of movements and for each condition under study, only the same volunteers were accounted. The cells in green represent the best combinations between knee and back tilts, because they are the ones that produce the greatest amplitudes, which means they lead to a better rehabilitation.

All angles are given in degrees (°). Green is the combination of positions that produced the greatest amplitudes at the tibiotarsal joint, and red is the combination that produced the least amplitudes. The values represented within each cell represent the sum of the differences in amplitudes for each combination of movements.

All participants obtained maximum acceleration in the dorsiflexion/plantar flexion movements with an acceleration of 2.1 m/s^2, Fig. 4. In the inversion/eversion and adduction/abduction exercises, a maximum acceleration of 1.3 and 1.4 m/s^2 was verified respectively.

	Fixed condition											
	Back 110°			Back 140°			Knee 90°			Knee 130°		
	DF/PF	AB/AD	I/E	DF/PF	AB/AD	I/E	DF/PF	AB/AD	I/E	DF/PF	AB/AD	I/E
Knee 90°	1,12°	44,93°	8,35°	10,64°	29,68°	15,20°						
Knee 130°	49,23°	19,99°	1,91°	19,72°	15,89°	0°						
Back 110°							5,45°	15,95°	4,13°	21,86°	19,57°	8,79°
Back 140°							29,03°	7,69°	4,97°	6,43°	4,56°	0,87°

Fig. 3 Representative table of the best position to reach the highest amplitudes

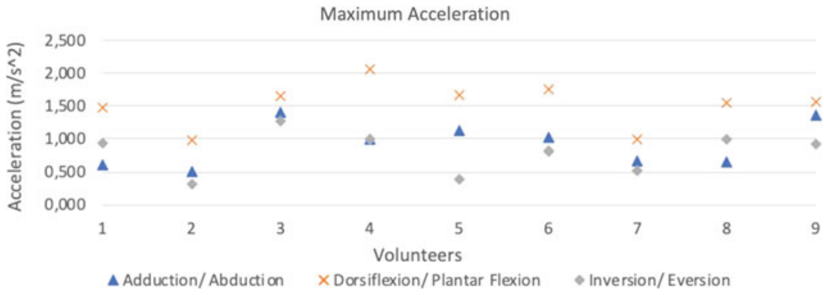

Fig. 4 Maximum joint accelerations for each volunteer per movement pai

3.2 *Volunteer Questionnaire*

The grouped column chart (Fig. 5) allows you to see which Likert scale value is dominant and what the average response is.

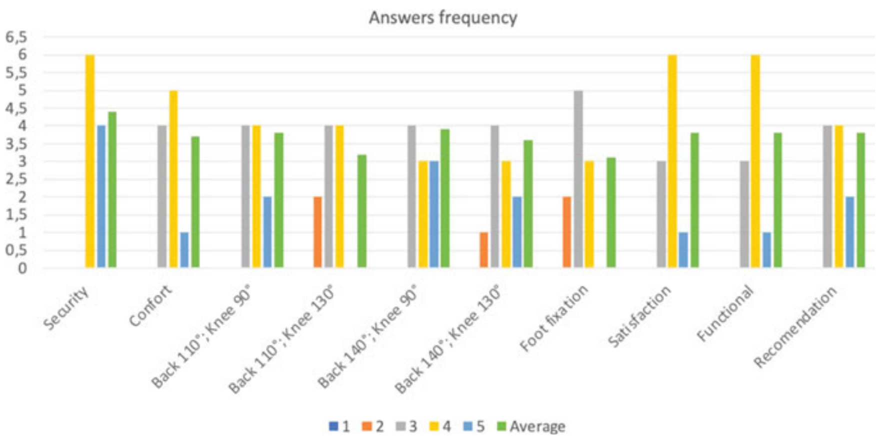

Fig. 5 Frequency and average of the volunteers' responses

The lowest comfort scores were registered for a knee position of 130°. For a knee position of 90°, a back angle of 110° provided the highest levels of comfort, coinciding with mode highest values.

According to the volunteers' perception, the foot anchorage system is not suitable, with a value of around 3 for both the mean and the mode.

4 Discussion

For the pair of AB/AD and I/E movements, for a back 110° back tilt a 90° knee angle is preferable than a 130° knee angle, and when the knee angle is fixed at 90°, a 110° back tilt is preferable rather than 140°. Regarding the DF/PF pair, opposite results were obtained. In the case of I/E for a fixed 90° knee tilt, the cells are blank, because it cannot be gauged which is the best back tilt for this case.

Almost all the volunteers felt safe and comfortable performing the movements in the 4 different positions, with the volunteers finding the 90° bent knee and 110° back angle the most comfortable. This goes according to the best solution found for 2 of the 3 pairs of movements by the analysis of the data obtained with XSens®. A knee position of 130° recorded the lowest comfort levels. For a knee position of 90°, it can be concluded that a back angle of 110° is more comfortable for the user, where the highest values recorded for fashion were also obtained.

The foot attachment system is a crucial point to change since if it does not hold the foot correctly, the foot will move on the support, which may result in ineffective rehabilitation.

All volunteers generally consider the device functional and suitable for the rehabilitation of ankle injuries and would recommend the use of the Therapheet in the future.

Thus, it can be concluded that there is no combination of the knee and back angle that favors all rehabilitation exercises, so an adjustment adapted to each exercise and each patient will be the most appropriate.

4.1 Limitations

The x-axis represented in the graphic may not correspond to the separation point between the movements, once an initial referential was not defined for all volunteers, thus not knowing at what point this change occurs.

It should be noted that the system for attaching the foot to the equipment is not adjustable to the width of the volunteer's foot, so there were lateral movements of the foot in the device, which could compromise the results obtained. Also, the leg support was not totally effective because its height adjustment was not enough to accommodate all the different individuals' dimensions, and this support also did not prevent the leg from sliding laterally. The equipment chair rotates, making it unstable to perform some exercises. In addition, the chair should be able to be adjusted so that the volunteer's leg is aligned with the device's footrest, whether the leg is right or left.

5 Conclusions

In this study it was visible the relationship between anthropometry, ergonomics and design. Applied anthropometry is one of the basic human sciences and it has contributed to ergonomics, which contributed with data, concepts and methodologies to the design process.

The device under study has several aspects that were changed/improved for its use in health care institutions and home environments. From the kinematic analysis results, it was possible to design a chair that is stable in height and distance according to each patient, so that the alignment of the hip with the knee and ankle to be rehabilitated was possible, as well as a variable angle of inclination of the back. The knee support was designed to adapt to the user's characteristics, thus supporting the weight of the patient's leg. The way the foot is attached to the support has been optimized to adjust to the different volumes and sizes of the feet so that the foot does not move. The inclination of the fixation site of the device was changed to a smaller angle. The main operational changes achieved were device's mass and size decrease, as well as less mechanical complexity. Servo motors allow more precise and controlled movement compared to pneumatic technology. Therefore allowing a more functional and safer rehabilitation.

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References

Boute, B., Veldeman, L., Speleers, B., Van Greveling, A., Van Hoof, T., Van de Velde, J., Detand, J.: The relation between patient discomfort and uncompensated forces of a patient support device for breast and regional lymph node radiotherapy. Appl. Ergon. **72**, 48–57 (2018). https://doi.org/10.1016/j.apergo.2018.05.002

Brockett, C.L., Chapman, G.J.: Biomechanics of the ankle. Orthop. Trauma **30**(3), 232–238 (2016). https://doi.org/10.1016/j.mporth.2016.04.015

Chang, T.C., Zhang, X.D.: Kinematics and reliable analysis of decoupled parallel mechanism for ankle rehabilitation. Microelectron. Reliab. **99**(June), 203–212 (2019). https://doi.org/10.1016/j.microrel.2019.05.016

Colim, A.: Algoritmi centre at University of Minho, Ph.D. (2017), University of Minho

DiGiovine, M.M., Cooper, R.A., Boninger, M.L., Lawrence, B.M., VanSickle, D.P., Rentschler, A.J.: User assessment of manual wheelchair ride comfort and ergonomics. Arch. Phys. Med. Rehabil. **81**(4), 490–494 (2000). https://doi.org/10.1053/mr.2000.3845

Kulunkoglu, B.A., Celik, D.: Reliability and validity of the Turkish version of foot and ankle ability measure for patients with chronic ankle disability. J. Foot Ankle Surg. **58**(1), 38–41 (2019). https://doi.org/10.1053/j.jfas.2018.07.007

Pereira, A.: Engineering School of Minho University, Master Degree (2021), University of Minho

Racu Cazacu, C.M., Doroftei, I.: Structural and kinematic aspects of a new ankle rehabilitation device. Appl. Mech. Mater. **658**(October), 507–512 (2014). https://doi.org/10.4028/www.scientific.net/AMM.658.507

Rodrigues, M.: Engineering School of Minho University, Master Degree (2021), University of Minho

Seabra, E.: Engineering School of Minho University, Ph.D. (2005), University of Minho

Silva, Â.: ERGONOMIA E ANTROPOMETRIA. DIMENSIONAMENTO DE POSTOS DE TRABALHO EM PÉ. Universidade de Aveiro (2008)

Tsoi, Y.H.: Modelling and adaptive interaction control of a parallel robot for ankle rehabilitation (The University of Auckland) (2011). https://researchspace.auckland.ac.nz/handle/2292/6756

Viana, R.: School of Health Sciences Fernando Pessoa - University of Fernando Pessoa, Ph.D. (2012), Faculty of Psychology and Educational Sciences of the University of Porto

Ana Pereira Engineering School of Minho University, Master Degree (2021), University of Minho.

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WIDEA: Waste Identification Diagram with Ergonomic Assessment—Towards the Integration of Lean and Ergonomics

A. C. Peixoto, J. Dinis-Carvalho, Ana Colim, N. Sousa, L. A. Rocha, and João Oliveira

Abstract Objective: Presentation of a tool capable of integrating Lean manufacturing with Ergonomics, aiming to assist the continuous improvement of production processes and the insurance of the well-being of employees. Background: To face the current markets' characteristics, industrial organizations need effective and efficient production systems. The key to achieve this efficiency and effectiveness is to fully understand the production process, and to identify its wastes. Foreseeing the continuous improvement of these processes, the integration of Lean manufacturing with Ergonomics potentiates productivity and enhances working conditions. Method: In this study, a new diagnostic tool is proposed—the WIDEA. It intends to combine the potential of Waste Identification Diagrams (WID) with the risk assessment method Key Indicator Method (KIM). Conclusion: WIDEA is a tool that allows us to quickly diagnose the main problems of a production process, combining the concerns of Lean manufacturing and Ergonomics. Application: The use of the WIDEA can assist the understanding of the production process, help identify wastes and assists the improvement of processes, towards a more efficient and effective production system, able to face the challenges the industry has come across.

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Keywords Waste · Lean manufacturing · Production systems · Musculoskeletal disorders · Diagnosis tool

1 Introduction

1.1 Challenges to the Industry

In full transition to the 4th Industrial Revolution, companies face the benefits and challenges of new technologies. Despite increasing the productivity and flexibility of industries, these technologies also make the market even more competitive. Emerging technological developments are likely to bring widespread automation and irreversible shifts in the structure of jobs, raising major challenges on labour markets (Kergroach 2017). In addition, the Covid-19 pandemic has brought even more challenges. Its financial impact has diminished people's purchasing power and has forced companies to review and eliminate their costs. With part of the world population at home, supply chains are under pressure, due to considerable increase in online purchases, and some products have their demand above the normal levels, forcing industries to adapt to these new circumstances. At the same time, needs prior to the start of the pandemic have taken a back seat, pressuring organizations to rethink their product or production process. To face this challenges, industrial organizations need effective and efficient production systems so they can deal with the current markets' characteristics (Dinis-Carvalho et al. 2015).

1.2 Waste

The key to achieve efficiency and effectiveness is to fully understand the production process, and to identify all types of waste. Waste is related to the concept of value, therefore to recognize the occurrence of waste, it is fundamental to identify the activities that add value to the product an eliminate the ones that don't (Dinis-Carvalho et al. 2019).

Ohno (1988) and Shingo and Dillon (1989) identified seven types of waste: Overproduction, Inventory, Waiting, Defects, Over-processing, Motion, Transportation. Relatively to Overproduction, it happens when a product is produced before it is required by the next process in sequence. It results in longer lead times and increasing costs; Inventory leads to high and unnecessary costs, masks defects and damages material that has been stored for a long time; Waiting is one of the easiest wastes to be detected, be it waiting for people, materials or machines that have not finished their work; Defects are any product characteristic that do not respect the previously defined standards. They can lead to excessive material and rework costs; Over-processing happens when the product has more features or functionalities than the customer is willing to pay. This implies that in the production process there are expenses with activities that do not add value to the product and, as such, carry unnecessary costs for the company. Motion concerns any unnecessary movement, which does not add value to the product, whether it be people, tools, machines or materials. Transportation, as well as the waste previously mentioned, does not add value to the product and can also damage it, affecting people, tools, machines or materials.

In addition to these seven wastes, Womack and Jones (1997) identified an eighth category: the Unused Talent, related to the failure to make fully use of the knowledge, skills and abilities of the people involved in the company.

1.3 Value Stream Mapping and Waste Identification Diagram

When looking at the definitions of each waste, it is easy to understand that these are related to the fact that no value is being added to the product. Understanding the customers' needs is then critical to eliminate them. Lean production is targeted at progressively aligning shop-floor operations with clients' requirements and for doing so it seeks to implement a culture of waste-elimination activities and continuous improvement of the processes (Dinis-Carvalho et al. 2015).

Womack and Jones (1997) defined five principles of the Lean Production: the creation of value, the identification of the value stream, the continuous production flow, the implementation of a pull system and the pursue of perfection.

However, concerning the second principle, to identify the value stream in an accurate way, it is necessary to have a powerful tool to represent the main aspects of a production system and to highlight its wastes. Several graphical tools are available to assist this process, but they are usually dedicated to specific aspects (Dinis-Carvalho et al. 2019). Some tools are mainly focused on representing the layout and production routes, while others are focused on the production flow of certain products (Dinis-Carvalho et al. 2014).

A tool that has been widely used is the Value Stream Mapping (VSM) (Rother and Shook 1999). VSM represents the value stream, material and information flows, wastes and key performance data. An important characteristic of the VSM is its visual nature, allowing for a quick assessment of the state of the production processes (Dinis-Carvalho et al. 2019). It has revolutionized the graphic representations of production systems (Sá et al. 2011).

Despite all the advantages that VSM has, some limitations were also spotted and thoroughly described by multiple report studies, starting from 1998 (Dinis-Carvalho et al. 2015). These limitations pointed out over the years by several authors were collected and synthesized by Dinis-Carvalho et al. (2019). Briefly, some of the main limitations of the tool are: the inability to represent layouts; the use of different symbols, which make its interpretation, at times, confusing; the inability to represent more than one family of products; the need for reading the written information, in order to understand important data, such as the amount of work in progress (WIP); and the lack of representation of transport and movement waste.

Towards the surpass of some VSM's limitations, a tool named Waste Identification Diagram (WID) was developed by the Department of Production and Systems, at the University of Minho (Sá et al. 2011). WID is able to represent entire production units; all production flows; deal with low-volume and high-variety industry; allow layout visualization; show and evaluate all types of wastes in a visual and intuitive way; and provide effective visual and performance information (Dinis-Carvalho et al. 2015). The data presented is clear, allowing an immediate perception of the number of workers, WIP, takt time, cycle time and setup time for each workstation. WID borrows the concept of visual control, one of the tools associated to Lean production, and provides immediate visual perception, when applied to waste identification (Sá et al. 2011).

The work presented in this document seeks to combine the WID with an ergonomic indicator, in order to introduce information related to the workers' well-being in its representation, as for them being a central point in any production system.

1.4 Key Indicator Method (KIM)

For Lean philosophy, the continuous improvement and process optimization must always be focused on the people involved in it. Thus, it is crucial to ensure their safety and well-being. Foreseeing the continuous improvement of production processes, the association of Lean manufacturing with Ergonomics potentiates productivity gains, enhances working conditions and reduces workers' absenteeism (Colim et al. 2021). According to the European Council Directive 89/391/EEC of 12th June 1989 (Conseil des Communautés Européennes 1989), the employer must perform an assessment of the risks to safety and health at work, which shows the importance of preserving the health and well-being of the workforce.

In 2015, approximately three out of every five workers in the EU-28 reported musculoskeletal disorders (MSD) and complaints in the back, upper limbs and/or lower limbs (de Kok et al. 2019). Therefore, an risk assessment is crucial to implement prevention strategies in the working area, to reduce exposure to unhealthy conditions (Klussmann et al. 2017a).

To examine the risk of MSD related to work, several assessments methods have been developed, such as the Rapid Upper Limb Assessment (RULA) (McAtamney and Nigel Corlett 1993), the Revised Strain Index (RSI) (Garg et al. 2017), and the Key Indicator Method (Röddecke and Schultz 2013). Bearing in mind the purpose of this article, the focus will be placed on the KIM method, as it being the one used by the industry that collaborated with this study. The KIM was developed by the Federal Institute for Occupational Safety and Health (BAuA) and the Committee of the German states for Occupational Safety and Health (LASI).

The KIM method allows to evaluate six types of activities, since new versions have been developed over the years. Each version corresponds to a type of activity that goes from pushing and pulling material to awkward body postures. Through an evaluation sheet, certain characteristics such as frequency of activity, load and posture are assessed. In the end, this evaluation results in a single score that represents the risk of exposure to physical overload, which can lead to MSD. Its risk score have a statistically significant correlation to the prevalence of MSD and clinical conditions in the shoulder, elbow and hand-wrist body regions (Klussmann et al. 2017b).

1.5 WIDEA—Waste Identification Diagram with Ergonomic Assessment

A tool that tries to integrate Ergonomics and Lean is the Ergonomic Value Stream Mapping (ErgoVSM) (Jarebrant et al. 2016a), based on the regular VSM methodology proposed by Rother and Shook (1999), but with work environment issues integrated in the method (Jarebrant et al. 2016b). This additional analysis might result in future savings for companies, since it takes into account ergonomic factors, before applying physical transformations in productive systems (Goossens 2018). Nagaraj et al. (2019) stated that this integrated approach reduces human factor risk levels and enhances lean performance. However, developing it might be time-consuming, since additional data is required, and can be more labour intensive compared to traditional VSM.

Taking into account the limitations already mentioned in the traditional VSM, this study proposes to combine Ergonomics and Lean via another tool—the WID (described previously).

As workers are involved in the production process, it is important to diagnose whether their well-being is ensured, or whether it is necessary to act towards it. Considering the WID method and its advantages regarding VSM, in addition to the information related to cycle time, takt time, WIP, and others, in this proposed version it is also possible to visualize the KIM risk level in the diagram. Thus, it is possible to perceive the physical load associated with each station. The main objectives of this study are then the presentation of this tool- the WIDEA- that seeks to add an ergonomic indicator to the existing WID and its application in a production process, to identify its main potentials and limitations.

2 Materials and Methods

2.1 WID—Waste Identification Diagram

This tool is composed by a series of blocks and arrows. Blocks represent (a group of) workstations, (a group of) machines or sections of the shop floor. Arrows represent the transportation effort. The dimensions of the icons give us information on certain parameters, since they are scaled with their values, giving immediate visual information (Fig. 1).

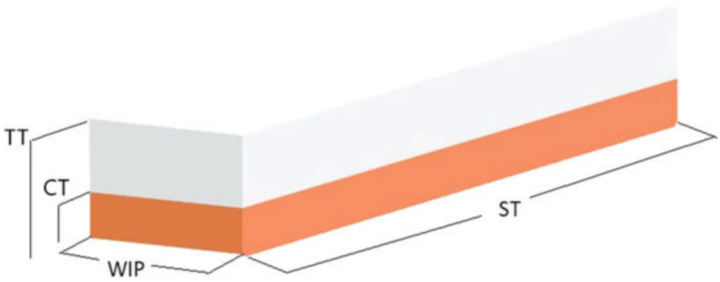

Fig. 1 A block representative of a workstation and its dimensions

The block dimensions include four types of information: the block length represents the amount of work in progress (WIP), waiting to be processed; The block height represents the takt time (TT); The height of the coloured part of the block represents the cycle time (CT); The block depth represents the setup time (ST) of the process. The frontal area of the block represents the throughput time of that station. Besides this, inside the block (or next to it when the scale requires so) the number of workers assigned to the station is represented.

The width of the arrows represents the transport effort. This value is achieved by multiplying the number of products transported from one station to another by the travelled distance between them. The length of the arrows has no meaning, to keep the interpretation simple, and it's the same for every arrow on the diagram.

By looking at the final drawing of this graphic tool we can come up with some conclusions. We can easily identify production routes, by looking at the arrows, and identify the longest path and see where the transport effort is higher, by searching for the widest arrows. We can see how WIP is distributed through the entire production system (or the section it represents) and focus the efforts in decreasing it on the right spots. We can see each station idle time, highlighted by the non-coloured part of the block (cycle time << takt time), check if they operate at their full capacity or identify the station with higher occupation. But the most powerful and immediate information that the WID can give is where waste is more evident, since larger blocks means larger waste (Dinis-Carvalho et al. 2015).

3 KIM—Key Indicator Method

As mentioned before there are six types of activities that the KIM method can evaluate. These are: KIM-Awkward Body Postures; KIM-Whole Body Forces; KIM-Body Movement; KIM-Lifting, Holding and Carrying; KIM-Manual Handling Operations and KIM-Pushing and Pulling (Klussmann et al. 2017a).

Each assessment sheet for these six types of activities starts with a small overview on the specific KIM, followed by a distinction from other KIMs, to make sure the

Table 1 KIM risk level

Risk	Risk range	Measures
1	<20 points	None
2	20–<50 points	Workplace redesign; other prevention measures may be helpful
3	50–< 100 points	Workplace redesign; other prevention measures should be considered
4	≥100 points	Workplace redesign necessary; other prevention measures to be considered

Fig. 2 Icons representing the number of workers coloured according to the risk level

user is choosing the right one. Sometimes, for certain activities, there might be the need to use more than one KIM. On this section we can check if that's the case. To start the evaluation, we first determine a time rating point, related to the frequency of the activity or to the amount of time spent on it in a working day. Secondly, we determine the rating points to other indicators, which vary depending on the KIM we are using, for example: type of force, load, posture, work organization, hand/arm position, among other. Finally, we get to the final score, by multiplying the time rating point by the sum of the points from the other indicators. This final scored gives us the risk level of exposure to physical overload, during the specific activity. The risk range goes from 1 to 4 and its meaning is briefly represented in Table 1.

WIDEA—Waste Identification Diagram with Ergonomic Assessment To combine the WID with the KIM method, in order to have an ergonomic indicator represented in the diagnosis diagram, it was chosen to assign colours to the icons that represent the number of workers per workstation. Since the KIM method was the ergonomic evaluation method chosen for this study, we decided that, if the risk level associated with the station is 1 or 2, the station's icons are represented in green; if the risk level is 3, they are represented in yellow and, finally, for risk levels of 4, the icons are represented in red, according to the original colours used by the ergonomic assessment method (Fig. 2).

By adding this variation to the diagram, we can also get immediate information on the physical workload related to each station, giving us insight on were efforts to improve the well-being of the workers need to be focused.

3.1 Data Collection

To labour the WIDEA to be presented on this paper, we had the collaboration of a furniture industry located in the North of Portugal. This work is then focused on a section of the company, responsible for producing wooden frames. To collect the necessary information, the site was visited during two weeks. Information concerning cycle times, takt times, setup times, and production routes was given by the production department personnel and shop floor workers. The information about WIP was given by the production department personnel and, when possible, collected by the authors. The travelling distances and quantities of material to be carried between stations was collected by the author. Concerning the ergonomic assessment, information on the characteristics of the activities associated with the workstations in study was collected in site. The execution of the activities was recorded on video. Adapted KIM sheets were used, provided by the company.

4 Results

The WIDEA developed in this work is represented in Fig. 3.

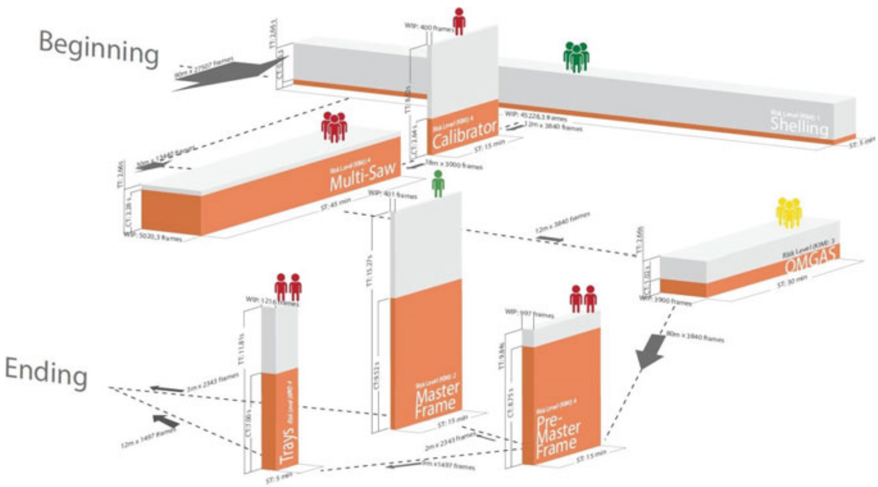

Fig. 3 WIDEA representing a section of the factory

We can verify that the station with more work in process is the Shelling and the one with less is the Calibrator. Any effort to reduce WIP should be focused on the Shelling station. The biggest transportation effort is between the beginning of the section and the Shelling station. This effort is related to the distance between the two spots (90 m) and the quantity of material that has to be transporter per shift. The station with higher throughput time is also the Shelling. The Multi-Saw station has the biggest setup time (45 min) and is the second one with higher level of WIP. The impact of the setup time on the WIP of this station should be studied. The station with higher idle time is the Calibrator and the stations with more occupation are the Multi-Saw and the Pre-Master Frame. The risk of physical overload is higher (level 4) on the Calibrator, Multi-Saw, Pre-Master Frame and Trays stations. This means that workplace redesign measures are necessary. The stations with lower risk are the Shelling and the Master Frame, meaning that no measures concerning the redesign of the workplace are necessary.

5 Discussion

The results presented allow us to understand where the actions to eliminate waste should be focused, both to reduce WIP and transport effort. It is also possible to immediately identify which workstations need to be redesigned, in order to reduce the risk associated with the workers' well-being. WIDEA is then a tool that allows us to quickly diagnose the main problems of a production process, combining the concerns of Lean manufacturing with the concerns of Ergonomics. The use of the WIDEA can assist the understanding of the value stream, help identify wastes and assist the improvement of processes, towards a more efficient and effective production system, able to face the challenges the industry has come across.

However, obtaining data and drawing the diagram are complicated processes. Getting access to the necessary information is dependent on what the company provides or on what we are able to observe and collect on the shop floor. The diagram design does not have any associated design software, making it difficult to elaborate.

Regarding the introduction of the ergonomic indicator, it should be subject of further studies, since there may occur some dubious interpretation of its information. At the same time, a station may have more than one associated activity, with different levels of risk, something that was not addressed in this study.

The use of WIDEA instead of ErgoVSM might be simpler, since the ergonomic indicator is also present in this tool and the limitations of VSM, summarized previously, are overcome thanks to the use of WID. Future studies will go through validating the tool, with experts in the area of Lean and Ergonomics, comparing it with other tools, collecting suggestions and evaluating it according to a set of criteria. It may also associate WID with other methods of ergonomic evaluation, such as RULA, as well as other indicators from other fields of study, since the diagram aspect and elaboration are quite flexible.

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References

Colim, A., Morgado, R., Carneiro, P., Costa, N., Faria, C., Sousa, N., Rocha, L.A., Arezes, P.: Lean manufacturing and ergonomics integration: defining productivity and wellbeing indicators in a human-robot workstation. Sustainability (Switzerland) **13**(4), 1–21 (2021). https://doi.org/10.3390/su13041931

Conseil des Communautés Européennes. Directive du Conseil 89/391/CEE. Journal Officiel Des Communautés Européennes **183**(29), 8 (1989). https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31989L0391

de Kok, J., Vroonhof, P., Snijders, J., Roullis, G., Clarke, M., Peereboom, K., van Dorst, P., Isusi, I., Observatory, E.R., Agency, E., Agency, E.: Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. In: European Agency for Safety and Health at Work (2019). https://doi.org/10.2802/66947

Dinis-Carvalho, J., Guimarães, L., Moreira, F., Rodrigues, J., Lima, R.M.: Waste identification diagrams with OEE data. In: XX International Conference on Industrial Engineering and Operations Management (ICIEOM 2014), 8th International Conference on Industrial Engineering and Industrial Management (CIO2014) and International IIE Conference 2014, pp. 313–320 (2014)

Dinis-Carvalho, J., Moreira, F., Bragança, S., Costa, E., Alves, A., Sousa, R.: Waste identification diagrams. Prod. Plan. Control **26**(3), 235–247 (2015). https://doi.org/10.1080/09537287.2014.891059

Dinis-Carvalho, J., Guimaraes, L., Sousa, R.M., Leao, C.P.: Waste identification diagram and value stream mapping: a comparative analysis. Int. J. Lean Six Sigma **10**(3), 767–783 (2019). https://doi.org/10.1108/IJLSS-04-2017-0030

Garg, A., Moore, J.S., Kapellusch, J.M.: The revised strain index: an improved upper extremity exposure assessment model. Ergonomics **60**(7), 912–922 (2017). https://doi.org/10.1080/00140139.2016.1237678

Goossens, R.H.M.: Preface. Adv. Intell. Syst. Comput. **605**(July), VII–VIII (2018). https://doi.org/10.1007/978-3-319-60828-0

Jarebrant, C., Winkel, J., Hanse, J.J., Mathiassen, S.E., Öjmertz, B.: ErgoVSM: a tool for integrating value stream mapping and ergonomics in manufacturing. Hum. Factors Ergon. Manuf. **26**(2), 191–204 (2016a). https://doi.org/10.1002/hfm.20622

Jarebrant, C., Hanse, J.J., Harlin, U., Ulin, K., Winkel, J., Edwards, K., Birgisdóttir, B.D., Gunnarsdóttir, S.: Ergonomic value stream mapping tool and user guide (2016b)

Kergroach, S.: Industry 4.0: new challenges and opportunities for the labour market. Foresight STI Gov. **11**(4), 6–8 (2017). https://doi.org/10.17323/2500-2597.2017.4.6.8

Klussmann, A., Liebers, F., Brandstädt, F., Schust, M., Serafin, P., Schäfer, A., Gebhardt, H., Hartmann, B., Steinberg, U.: Validation of newly developed and redesigned key indicator methods for assessment of different working conditions with physical workloads based on mixed-methods design: a study protocol. BMJ Open **7**, 15412 (2017a). https://doi.org/10.1136/bmjopen-2016-015412

Klussmann, A., Liebers, F., Gebhardt, H., Rieger, M.A., Latza, U., Steinberg, U.: Risk assessment of manual handling operations at work with the key indicator method (KIM-MHO) - determination of criterion validity regarding the prevalence of musculoskeletal symptoms and clinical conditions within a cross-sectional study. BMC Musculoskelet. Disord. **18**(1), 1–13 (2017b). https://doi.org/10.1186/s12891-017-1542-0

McAtamney, L., Nigel Corlett, E.: RULA: a survey method for the investigation of work-related upper limb disorders. Appl. Ergon. **24**(2), 91–99 (1993). https://doi.org/10.1016/0003-6870(93)90080-S

Nagaraj, T.S., Jeyapaul, R., Vimal, K.E.K., Mathiyazhagan, K.: Integration of human factors and ergonomics into lean implementation: ergonomic-value stream map approach in the textile industry. Prod. Plan. Control Manag. Oper. (2019). https://doi.org/10.1080/09537287.2019.1612109

Ohno, T.: Toyota Production System: Beyond Large Scale Production. Productivity Press, New York (1988)

Röddecke, S., Schultz, K.: Aus dem LASI: Handlungsanleitung zur Beurteilung der Arbeitsbedingungen bei manuellen Arbeitsprozessen LV 57. In Sicher Ist Sicher (Issue 7) (2013). https://doi.org/10.37307/j.2199-7349.2013.07.13

Rother, M., Shook, J.: In: Womack, J. (ed.) Learning to See: Value Stream Mapping to Create Value and Eliminate Muda. Lean Enterprise Institute (1999)

Sá, J.C., Dinis-Carvalho, J., Sousa, R.M.: Waste identification diagram 1–7 (2011)

Shingo, S., Dillon, A.P.: A Study of the Toyota Production System from an Industrial Engineering Viewpoint. Productivity Press, New York (1989)

Womack, J.P., Jones, D.T.: Lean thinking—Banish waste and create wealth in your corporation. J. Oper. Res. Soc. **48**(11), 1148–1148 (1997). https://doi.org/10.1038/sj.jors.2600967

A. C. Peixoto Integrated Master's in Industrial Management and Engineering, Degree in Industrial Management and Engineering (2019), University of Minho.

J. Dinis Carvalho Department of Production and Systems, University of Minho, Ph.D. Scheduling and Process Planning Integration (1997), University of Nottingham.

Ana Colim Dtx-Colab and ALGORITMI Center, University of Minho, Ph.D. in Industrial and Systems Engineering (2017), University of Minho.

N. Sousa Master's Degree in Human Factors, University of Minho, Degree in Chemical Engineering (1995), University of Porto.

L. A. Rocha DTx Colab, Ph.D. in Mechanical Engineering (1996), University of Minho.

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Assessment of Work-Related Musculoskeletal Disorders by Observational Methods in Repetitive Tasks—A Systematic Review

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Abstract Repetitive movements play an important role in the growing and aggravation of the discomforts related to the musculoskeletal system. There are many different observational methods for risk assessment for repeated movements in literature. The main objective of this review is to identify the observational methods that have been used to assess repetitive movements risk in previous studies. A systematic literature review was performed using the PRISMA protocol, in journal databases such as Taylor & Francis, Science Direct, and Scopus. We retrieved 322 articles and, after classification, 45 of them were selected for full analysis. Results showed that the most applied method was the OCRA method, especially by researchers from Italy and Brazil. Besides this, RULA (Rapid Upper Limb Assessment), QEC (Quick Exposure Check), and REBA (Rapid Entire Body Assessment) were also methods well-known and extensively applied to assess ergonomic repetitive working tasks.

Keywords Repeated work · Ergonomics · Musculoskeletal injuries · Risk assessment

1 Introduction

Ergonomics can be defined as the scientific field that concerns the interactions between humans and the elements of a working system. This scientific discipline applies theories, principles, data, and methods in to optimize human well-being and

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overall system performance. The musculoskeletal system includes the bones, muscles, ligaments and joints. The skeleton plays a supportive role in the body, while the muscles, ligaments and joints are involved in adopting a posture, carrying out a movement and applying a force (Bridger 2003). Poor posture and movements may cause mechanical stress on the musculoskeletal system. Even more, some movements also require an energy expenditure at the level of muscles, heart and lungs. The tasks performed in an occupational context often impose a posture. Sometimes the workers have to maintain a poor posture, which can lead to musculoskeletal complaints. Musculoskeletal disorders (MSD) are injuries or dysfunctions affecting muscles, bones, nerves, tendons, ligaments, joints, cartilages, and spinal discs. MSD include sprains, strains, tears, soreness, pain, hernias, and connective tissue injuries of the structures (Da Costa and Vieira 2010). If MSD are caused, or aggravated, primarily by work and by the effects of the immediate environment in which work is carried out, they are known as work-related musculoskeletal disorders (WMSD) (EU-OSHA 2019).

Repeated movements of the upper limbs are known to be hazardous for the working population. In manual handling operations, repetitive movement plays a role in the growing and aggravation of the musculoskeletal discomforts of hands, arms, and wrists. Repetitive movements are also tiring and can lead to musculoskeletal injuries. Workers' exposure to severe repetitive tasks induces lower productivity, decreased motivation to work, deterioration of life quality, and increases medical expenses, compensation problems and requirements for work environment improvement. It even leads to disputes between labour and management (Rebelo 2004).

In real-work scenarios, work postures, gestures or movements are frequently evaluated using observational methods. In this context, the evaluations are carried out with the workers in their workplaces through direct observation or through the analysis of video records. This type of techniques allows assessing the existence of risk factors for the occurrence of WMSD in an expeditious manner. In addition, they are holistic ergonomic methods that do not require the use of special equipment for their application. The literature proposes different observational methods for risk assessment due to repetitive movements of upper limbs (Colombini 1998).

As explained by Takala et al. (2010) there is no consensus in the literature of a specific method to be used to assess repetitive working tasks, and this issue remains a challenge for researchers. Therefore, this study will provide a systematic overview to observational ergonomic assessment techniques that analyze repetitive movements in literature.

2 Materials and Methods

In order to find observational methods, that has been applied to the risk assessment of repetitive movements, it was performed a systematic literature review (Tranfield et al. 2003). Preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Moher et al. 2009) checklist and diagram were used to conduct the systematic review to ensure complete, transparent, and unbiased reporting. These techniques were used aiming to make a literature overview about ergonomic assessment methods that analyze repetitive movements of workers. This meta-analysis study was performed according to PRISMA guideline. Science direct, Taylor & Francis online, and Scopus databases were used for finding relevant papers published in the field studies of ergonomic assessment methods that analyze repetitive movements. To avoid papers not falling into the topic under study, the search was performed using the Boolean operator "AND", together with the search term 'repetitive task'. Regarding the search criteria the following combination was used: "WMSDs" AND "risk assessments methods" AND "repetitive task".

Apart from the criteria mentioned above, the following additional inclusion criteria were also adopted:

- Original and review articles written in English published, or in press, in peer-reviewed journals;
- Published or in press between January 2014 and December 2020;
- Papers that considered the evaluation of repetitive working tasks by using WMSD observational risk assessment methods;
- Papers with an ergonomics research/application purpose.
  In the selection stage, the analysis was performed by one researcher; articles were selected based on two criteria: analysis of titles and abstracts. Initially, the analysis considers the title, and then the abstracts of the articles selected by the title. Then, the selected articles were entirely analyzed.

3 Results and Discussion

The search resulted in 322 potentially eligible studies, of which 38 were duplicates and 64 were excluded based on the review of the titles. An additional 175 studies were excluded after reviewing the abstracts, leaving at the final 45 studies (Fig. 1) for data collection.

Considering the 45 articles selected, Fig. 2 summarizes the observational methods applied across these studies. In 10 articles more than one observational method was applied to assess musculoskeletal risk related to repetitive handling tasks. Results showed that the most used observational methods to assess repetitive works risk are OCRA (The Occupational Repetitive Actions), RULA (Rapid Upper Limb Assessment), QEC (Quick Exposure Check), and REBA (Rapid Entire Body Assessment).

This review showed the diversity of observational methods assessing repetitive working tasks. As a most preferred, method OCRA was applied in 15 articles and 4 of those articles applied OCRA with other methods like ACGIH-HAL, SI, NIOSH, RULA (Intranuovo et al. 2019; Antonucci 2019; Ranavolo et al. 2017; Occhipinti and Colombini 2016). Three of those studies were about risk assessment in slaughterhouses in Brazil and they assessed upper limb repetitive movements risks during cutting tasks (Tirloni et al. 2020; Dias et al. 2020; Reis et al. 2015). Another study, about olive harvesting with hand-held beaters (described as a repetitive work, that

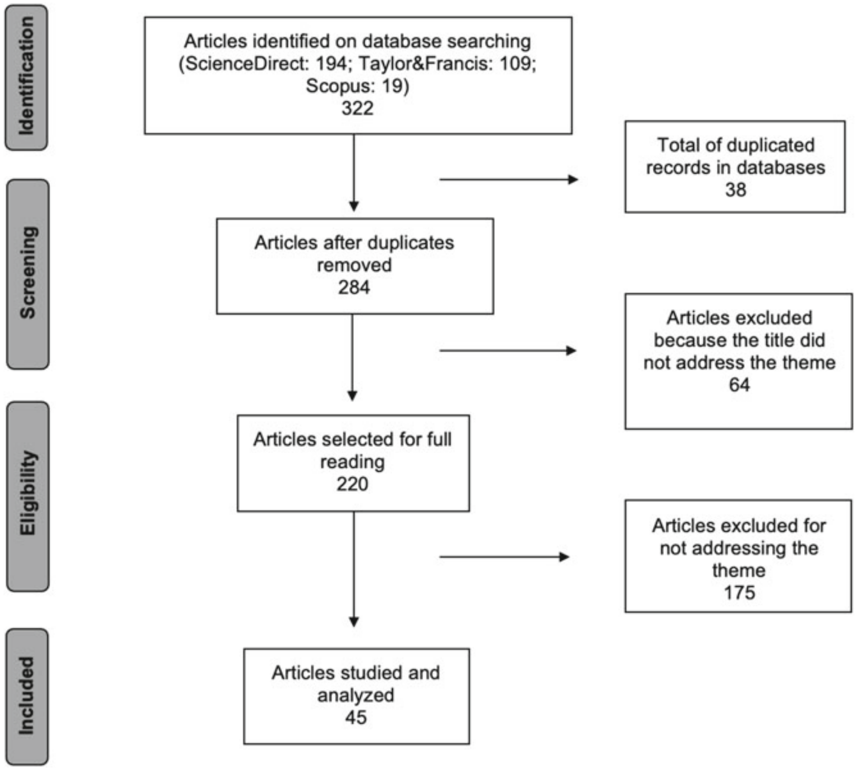

Fig. 1 Steps of the PRISMA protocol for the systematic literature review

tiring and time consuming), analyzed MSD risk in repetitive tasks for the upper limb using the OCRA checklist (Calvo et al. 2018).

Among the articles selected for analysis, 11 of them used RULA to analyze repetitive movements, 6 of these studies only applied RULA and 5 of these articles used the RULA method combining with other observational methods. The study carried out by Ab et al. (2020) aimed to analyze the repetitive movements of the operators in two harvester models, using RULA and REBA in order to propose ergonomic solutions. Two more studies carried out with construction workers (Li et al. 2018) and students (Kee 2020) also used RULA and REBA to analyze repetitive movements. Ghasemi and Mahdavi (2020), Khan and Singh (2018), Salmani Nodooshan et al. (2017) and Houshyar and Kim (2018) used REBA to assess musculoskeletal risk in repetitive tasks. The findings of Nino et al. (2020) indicate that increased REBA scores were associated with days and conditions with higher workloads.

Another preferred method for ergonomic assessment of repetitive working tasks was QEC. This method was applied in 6 articles: to assess the ergonomic risk level of office workers (Ozdemir and Toy 2020), agricultural workers (Momeni et al. 2020),

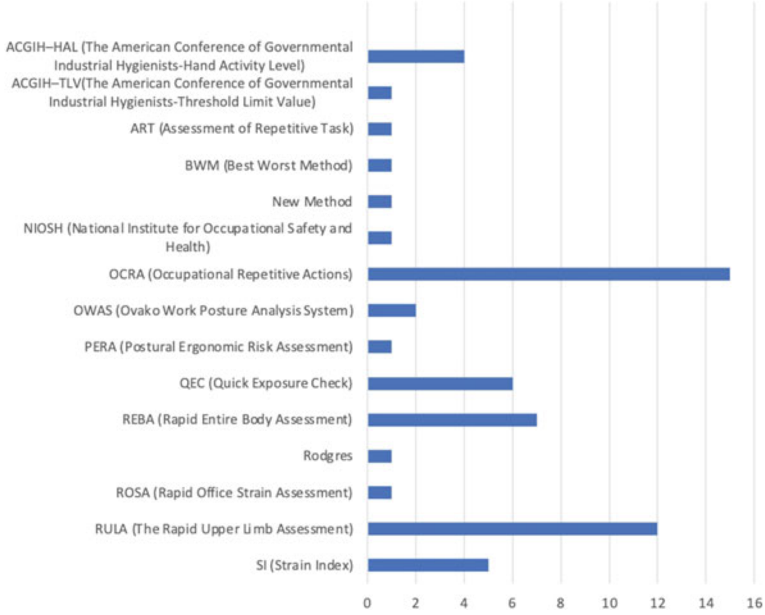

Fig. 2 The number of times each method has been applied

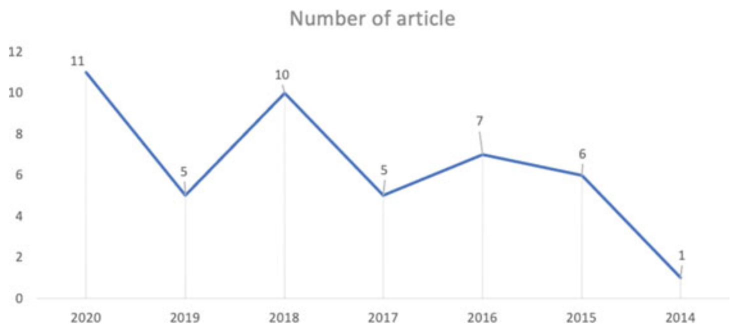

Fig. 3 Number of articles per year

sewing machine operators (Bulduk et al. 2016), factory workers, and taxi drivers (Abareshi et al. 2015; Bidiawati and Suryani 2015; Bulduk et al. 2014).

The year with the highest number of articles retrieved that applied observational methods was 2020 with 11 articles, followed by 2018 with 10 articles (Fig. 3 of Chap. "WIDEA: Waste Identification Diagram with Ergonomic Assessment—Towards the Integration of Lean and Ergonomics"). Moreover, Italy was the country of origin of 11 articles, followed by Brazil and Iran with 7 articles (Fig. 3).

Figure 4 represents the methods used and respective frequency across the countries of the authors' affiliation. According to these results, OCRA was the most selected

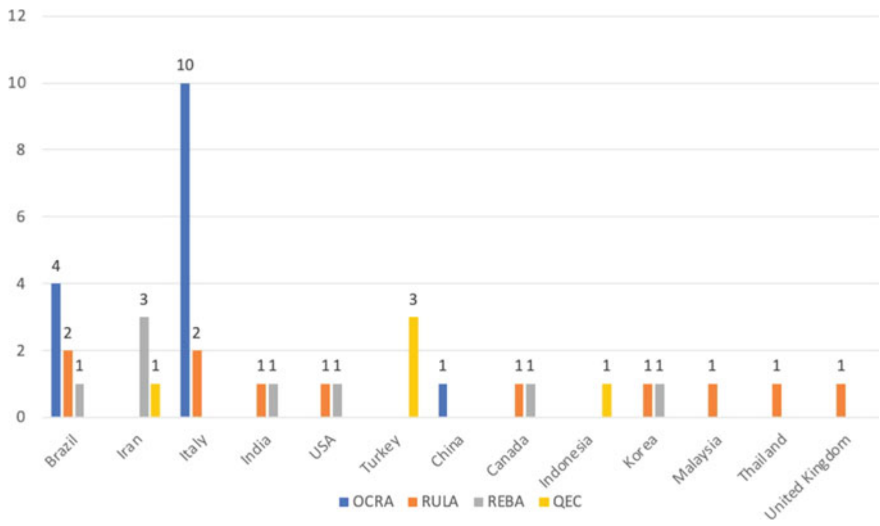

Fig. 4 Methods and respective frequency used by each country

observational method in Brazil and Italy followed by RULA. Turkey was the country that most applied QEC and Iran mostly applied REBA as an observational method.

The limitation of this study relates to how the articles included in the review were selected, as only information in the title and abstract were reviewed initially. Also, the studies did not follow clear criteria for the description of their methods, which mean it was difficult to find information often located in another part of the text. This review only included research published in English peer-reviewed journals, not including potentially relevant studies in other languages. Additionally, the electronic search was limited to three databases. Therefore, future research may include relevant studies in other languages. Additionally, the electronic search can be made across more databases.

4 Conclusions

The findings demonstrated that observational methods are preferred methods to assess musculoskeletal risk in repetitive work tasks. Although methods are varying and there is no specific method chose to measure repetitive working tasks this review revealed that there are some methods preferred by countries. According to this study, between 2014 and 2020 the most commonly used methods across countries were OCRA, RULA, REBA, and QEC. Brazil, Italy, and Iran were the countries that have more articles in literature in which observational methods were applied to assess musculoskeletal risk in repetitive working tasks. The years with more publications issued musculoskeletal risk in repetitive tasks were 2020 and 2018.

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References

Ab, M., Es, L., Mb, P., Nc, F., Fm, O.: Upper limb posture and movement during tracked versus wheeled harvester operation on Pinus thinning. Int. J. Forest Eng. **31**(3), 263–271 (2020). https://doi.org/10.1080/14942119.2020.1822663

Abareshi, F., Yarahmadi, R., Solhi, M., Farshad, A.A.: Educational intervention for reducing work-related musculoskeletal disorders and promoting productivity. Int. J. Occup. Saf. Ergon. **21**(4), 480–485 (2015). https://doi.org/10.1080/10803548.2015.1087729

Antonucci, A.: Comparative analysis of three methods of risk assessment for repetitive movements of the upper limbs: OCRA index, ACGIH(TLV), and strain index. Int. J. Ind. Ergon. **70**, 9–21 (2019). https://doi.org/10.1016/j.ergon.2018.12.005

Bidiawati, J.R.A., Suryani, E.: Improving the work position of worker's based on quick exposure check method to reduce the risk of work related musculoskeletal disorders. Procedia Manuf. **4**, 496–503 (2015). https://doi.org/10.1016/j.promfg.2015.11.068

Bridger, R.: Introduction to ergonomics. J. Chem. Inf. Model. **53**(9), 2nd edn. Taylor & Francis (2003). https://doi.org/10.1017/CBO9781107415324.004

Bulduk, E.Ö., Bulduk, S., Süren, T., Ovalı, F.: Assessing exposure to risk factors for work-related musculoskeletal disorders using Quick Exposure Check (QEC) in taxi drivers. Int. J. Ind. Ergon. **44**(6), 817–820 (2014). https://doi.org/10.1016/j.ergon.2014.10.002

Bulduk, S., Bulduk, E.Ö., Süren, T.: Reduction of work-related musculoskeletal risk factors following ergonomics education of sewing machine operators. Int. J. Occup. Saf. Ergon. **23**(3), 347–352 (2016). https://doi.org/10.1080/10803548.2016.1262321

Calvo, A., Romano, E., Preti, C., Schillaci, G., Deboli, R.: Upper limb disorders and hand-arm vibration risks with hand-held olive beaters. Int. J. Ind. Ergon. **65**, 36–45 (2018). https://doi.org/10.1016/j.ergon.2018.01.018

Colombini, D.: An observational method for classifying exposure to repetitive movements of the upper limbs. Ergonomics **41**(9), 1261–1289 (1998). https://doi.org/10.1080/001401398186306

Da Costa, B.R., Vieira, E.R.: Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am. J. Ind. Med. **53**(3), 285–323 (2010). https://doi.org/10.1002/ajim.20750

Dias, N.F., Tirloni, A.S., dos Reis, D.C., Moro, A.R.P.: Risk of slaughterhouse workers developing work-related musculoskeletal disorders in different organizational working conditions. Int. J. Ind. Ergon. **76**, 102929 (2020). https://doi.org/10.1016/j.ergon.2020.102929

EU-OSHA: Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU (2019). https://doi.org/10.2802/66947

Ghasemi, F., Mahdavi, N.: A new scoring system for the Rapid Entire Body Assessment (REBA) based on fuzzy sets and Bayesian networks. Int. J. Ind. Ergon. **80**(November 2018) (2020). https://doi.org/10.1016/j.ergon.2020.103058

Houshyar, E., Kim, I.-J.: Understanding musculoskeletal disorders among Iranian apple harvesting laborers: ergonomic and stop watch time studies. Int. J. Ind. Ergon. **67**, 32–40 (2018). https://doi.org/10.1016/j.ergon.2018.04.007

Intranuovo, G., De Maria, L., Facchini, F., Giustiniano, A., Caputi, A., Birtolo, F., Vimercati, L.: Risk assessment of upper limbs repetitive movements in a fish industry. BMC Res. Notes **12**(1) (2019). https://doi.org/10.1186/s13104-019-4392-z

Kee, D.: An empirical comparison of OWAS, RULA and REBA based on self-reported discomfort. Int. J. Occup. Saf. Ergon. **26**(2), 285–295 (2020). https://doi.org/10.1080/10803548.2019.1710933

Khan, M.R., Singh, N.K.: Prevalence of musculoskeletal disorders among Indian railway sahayaks. Int. J. Occup. Environ. Health **24**(1–2), 27–37 (2018). https://doi.org/10.1080/10773525.2018.1507187

Li, X., Han, S.H., Gül, M., Al-Hussein, M.: Automated post-3D visualization ergonomic analysis system for rapid workplace design in modular construction. Autom. Constr. **98**(November 2018), 160–174 (2018). https://doi.org/10.1016/j.autcon.2018.11.012

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., ...Tugwell, P.: Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med. **6**(7) (2009). https://doi.org/10.1371/journal.pmed.1000097

Momeni, Z., Choobineh, A., Razeghi, M., Ghaem, H., Azadian, F., Daneshmandi, H.: Work-related musculoskeletal symptoms among agricultural workers: a cross-sectional study in Iran. J. Agromedicine **25**(3), 339–348 (2020). https://doi.org/10.1080/1059924X.2020.1713273

Nino, L., Marchak, F., Claudio, D.: Physical and mental workload interactions in a sterile processing department. Int. J. Ind. Ergon. **76**(October 2018), 102902 (2020). https://doi.org/10.1016/j.ergon.2019.102902

Occhipinti, E., Colombini, D.: A toolkit for the analysis of biomechanical overload and prevention of WMSDs: criteria, procedures and tool selection in a step-by-step approach. Int. J. Ind. Ergon. **52**, 18–28 (2016). https://doi.org/10.1016/j.ergon.2015.08.001

Ozdemir, F., Toy, S.: Evaluation of scapular dyskinesis and ergonomic risk level in office workers. Int. J. Occup. Saf. Ergon. 1–6 (2020). https://doi.org/10.1080/10803548.2020.1757307

Ranavolo, A., Chini, G., Silvetti, A., Mari, S., Serrao, M., Draicchio, F.: Myoelectric manifestation of muscle fatigue in repetitive work detected by means of miniaturized sEMG sensors. Int. J. Occup. Saf. Ergon. **24**(3), 464–474 (2017). https://doi.org/10.1080/10803548.2017.1357867

Rebelo, F.: Ergonomia no dia a dia (M. Robalo (ed.); 1st ed.). Edições Sílabo (2004)

dos Reis, D.C., Ramos, E., Reis, P.F., Hembecker, P.K., Gontijo, L.A., Moro, A.R.P.: Assessment of risk factors of upper-limb musculoskeletal disorders in poultry slaughterhouse. Procedia Manuf. **3**(Ahfe), 4309–4314 (2015). https://doi.org/10.1016/j.promfg.2015.07.423

Salmani Nodooshan, H., Choobineh, A., Razeghi, M., Khales, Shahnazar Nezhad, T.: Designing, prototype making and evaluating a mechanical aid device for patient transfer between bed and stretcher. Int. J. Occup. Saf. Ergon. **23**(4), 491–500 (2017). https://doi.org/10.1080/10803548.2016.1274161

Takala, E.P., Pehkonen, I., Forsman, M., Hansson, G.Å., Mathiassen, S.E., Neumann, W.P., Sjøgaard, G., Veiersted, K.B., Westgaard, R.H., Winkel, J.: Systematic evaluation of observational methods assessing biomechanical exposures at work. Scand. J. Work Environ. Health **36**(1), 3–24 (2010). https://doi.org/10.5271/sjweh.2876

Tirloni, A.S., Dos Reis, D.C., Tirloni, S.F., Moro, A.R.P.: Exertion perception when performing cutting tasks in poultry slaughterhouses: risk assessment of developing musculoskeletal disorders. Int. J. Environ. Res. Public Health **17**(24), 1–15 (2020). https://doi.org/10.3390/ijerph17249534

Tranfield, D., Denyer, D., Smart, P.: Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. **14**(3), 207–222 (2003). https://doi.org/10.1111/1467-8551.00375

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Ergonomics and Safety in the Design of Industrial Collaborative Robotics

A Systematic Literature Review

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Abstract Objective: A systematic literature review was conducted to identify relevant ergonomic and safety factors for designing collaborative workspaces in industrial settings. Background: The growing use of smart and collaborative robots in manufacturing brings some challenges for the human-robot interaction design. Human-centered manufacturing solutions will improve physical and mental well-being, performance, productivity and sustainability. Method: A systematic review of the literature was performed based on the protocol of Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Results: After a search in the databases Scopus and Web of Science, applying inclusion and exclusion criteria, 33 publications in the English language, published between the years 2010 and 2020, remained in the final analysis. Publications were categorized in cognitive ergonomic factors (13), safety factors (10), physical ergonomic factors (6) and organizational ergonomic factors (4).

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The analysis of results reinforced that to optimize the design of collaborative workstations it is imperative to have a holistic perspective of collaboration, integrating multiple key factors from areas such as engineering, ergonomics, safety, sociology and psychological as well as manufacturing efficiency and productivity. Application: Considering the advantages of the use of cobots in manufacturing, the results of this review will be useful to support companies in implementing human-robot collaboration.

Keywords Human-robot interaction · Collaborative robots · Human-centered design · Manufacturing · Performance

1 Introduction

The ongoing implementation of the Industry 4.0 technologies in manufacturing systems is characterized by higher levels of automatization and by the integration of different enabling technologies to improve production flexibility, efficiency, sustainability and inclusion. To achieve this goal, the adoption of collaborative robots (or cobots) in manufacturing is growing since they offer an opportunity for the human and robot to exchange information and share tasks. Cobots, with the support of artificial intelligence, are cognitively and ergonomically aware, adaptable to environmental changes and to multiple control strategies. These technologies can protect workers from hazardous situations and facilitate access to work for many people who are currently excluded, such as disabled people, ageing workers or people who have incapacity due to a work accident or occupational disease (EU-OSHA 2019). Despite all technological progress, the fundamental principles and theories related to physical and cognitive ergonomics are not yet sufficiently explored in collaborative contexts and there is still no strategy for the design of a hybrid workstation that is completely human-centered (Gualtieri et al. 2020). On the other hand, sharing the same workspace and working together with robots may place workers under a high level of performance pressure, increasing the cognitive workload of tasks with a significant impact on mental health. Hence, Human-Robot Collaboration (HRC) should not just be physically safe, but also psychologically comfortable for workers. Cognitive workload has also been studied in human-robot interaction applications, to understand its impact on the functioning of cognitive processes and performance, and consequently on psychological well-being (Rabby et al. 2019). The success of HRC also depends on social acceptance and trust concerning robots. Acceptance of human-robot teaming may ultimately depend on personal preference and implies the analysis of workers' feelings toward the robotic equipment with which they are working (Correia Simões et al. 2020). Regarding trust, workers must have faith in the robot capabilities and factors related to human (e.g., age), robotic (e.g., mode of communication) and contextual properties (e.g., role interdependence) have to be analyzed (Marvel et al. 2020). A systematic literature review was conducted to identify human factors/ergonomics and safety factors that influence human-robot interaction and that should be considered when designing industrial collaborative workspaces.

2 Materials and Methods

Systematic literature reviews allow the identification, evaluation, and interpretation of available data on a specific theme from several scientific studies. For this systematic literature review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement was used (Moher et al. 2009). The search strategy consisted of a comprehensive search that could locate the widest spectrum of articles for consideration and was performed in selected electronic databases, namely: Scopus and Web of Science. Only studies published between January 2010 and 31st December 2020 were included. The combination of keywords used in this literature review was: ((human and robot and interact*) or (human-robot and interact*) or (human-interact* and robot) or (human-interact*) or (hri or collab* and robot) or (collab* and human-robot) or (human-robot and collab* and workstation*) or (co-robotic) or cobot or cobotic or (light and robot*) and (manufactur* or factor* or product* or industr* or lab*) and (activit* or work* or assignment* or job* or task*) and (allocat* or assign* or share) and (criteri* or indicat* or dimension* or determinant* or factor*) and (design or map or representation or model or proposal or method or framework)).

No restrictions were used on the type of document. Only studies written in English were included. After applying the search expressions in both databases, duplicated studies were removed. For the remaining studies, the title and abstract were read. The studies that were not fitting the theme were excluded. The remaining studies were analyzed by reading the full text. After full reading more articles were excluded, based on the following eligibility criteria:

- Studies without focus on human-robot interaction;
- Studies without focus on cognitive, physical, organizational, or safety factors that influence human-robot interaction;
- Studies whose application area was not the industrial sector.

For qualitative analysis of publications, the categorization proposed by the International Ergonomics Association was used, defining three domains of human factors/ergonomics (HF/E), namely: physical, cognitive, and organizational ergonomics (IEA, n.d.). Factors related to Safety were classified as “Safety Factors”. Additionally, to understand the results more clearly, specific topics in each category were created. The publications were integrated into each category and topic according to the main objective of the study. However, each publication studied multiple factors that can be considered in the design of collaborative workspaces.

3 Results and Discussion

The flow diagram of the PRISMA Statement methodology is presented in Fig. 1. A total of 262 records were obtained (after removing 48 duplicates). After the application of eligibility criteria, 33 studies were included.

The studies included in this review were conducted in a manufacturing context. However, most of them (28) did not identify in which specific manufacturing sector the research was carried out. The automobile industry was referred to in four studies and the food industry in only one study. Concerning the manufacturing activities or tasks, assembly tasks were the most studied (14), followed by material handling (11). Packaging (2), code reading (1), food preparation (1), and selection (1) tasks were also studied. Figure 2 present the number of publications included, according to the categorization referred to in the last paragraph of the previous section. Cognitive ergonomics and safety were the domains of HF/E that were approached in more studies. In "Cognitive Ergonomics Factors" the topics presented were: trust (4), motor response (3), teamwork (2), communication (1), acceptance (1), cognitive workload (1) and perception (1). In the "Safety Factors" category, all studies analyzed

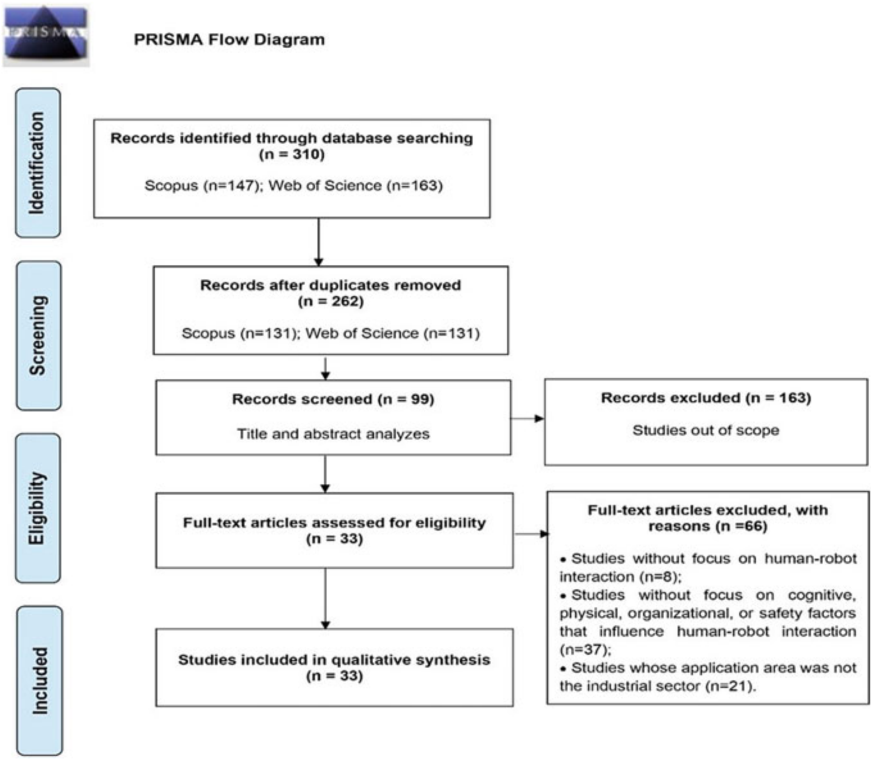

Fig. 1 PRISMA Statement flow diagram

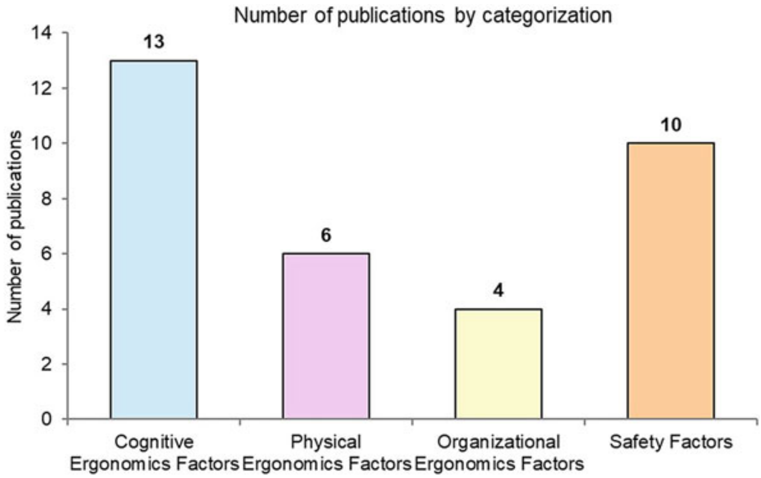

Fig. 2 Summary of the number of publications coded in each category

mechanical hazards related to collisions with human body parts (10). The studies included in the "Organizational Ergonomics Factors" category addressed the human-system performance topic (4). Physical workload/effort (2) and posture (4) were the topics included in the "Physical Ergonomics Factors" category.

Table 1 systematize the qualitative data analysis of the results presented in the articles considered in this review.

3.1 Cognitive Ergonomics Factors

Four studies included in the "Cognitive Ergonomics Factors" were focused on the "Trust" topic (Desai et al. 2013; Reinhardt et al. 2017; Sadrfaridpour and Wang 2018; Sadrfaridpour et al. 2016). These studies applied or developed simulation scenarios, as well as software, algorithms and questionnaires.

According to Kim et al. (2020), trust is one of the key factors for understanding human-robot interaction and that can be influenced by trustworthiness, intelligence, human-likeness, positive affect, and perfect automation schema. "Motor response" was analyzed in three publications (Giuliani and Knoll 2013; Wang et al. 2019; Oyekan et al. 2019). These studies investigated human physical response, considering robot movements or behavior. A relationship between the psychological construction of trust and joint physical coordination was suggested by Wang et al. (2019). Darvish et al. (2018) and Claes and Tuyls (2015), reinforced the importance of flexible human-robot cooperation, developing a solution that simultaneously aimed to ensure human comfort and system efficiency. To Rabby et al. (2019), the cognitive workload is considered the dominant factor in the quantification of human cognitive performance in HRC. Romero et al. (2018) defined cognitive load “as a multidimensional construct representing the mental efforts involved in performing a particular task and their effects on the operator’s cognitive system (pp. 2–3)″. The model proposed by these authors revealed that if task complexity increases or the rob’s error probability increases, human cognitive performance reduces over time. Considering the importance of the development of communication abilities for the success of HRC, Losey and O’Malley (2019) concluded that, due to variability of robot end-users, inferring each individual end-user’s interaction strategy led to improved robot learning and teaching. The studies of Schulz et al. (2018) and Bröhl et al. (2016) applied questionnaires to assess perception and acceptance towards robots, respectively. The use of questionnaires, based on Technology Acceptance Models (Bröhl et al. 2016), were common to investigate factors that influence technology acceptance as HRC.

3.2 Safety Factors

The studies included in this category aimed to optimize productivity or process efficiency, ensuring human safety. For Rojas et al. (2019), the definition of speed limitation, safe robot design, and training—were considered protective measures to have a safe HRC. Predictions of human movement and timely planning have proven crucial for implementing efficient and safe movements, according to Unhelkar et al. (2018). The efficient calculation of the minimum distance between humans and robots (Safeea et al. 2017) and the system’s ability to recognize human activities and to locate the operator’s position in real-time, are also relevant factors to prevent collisions (Meziane et al. 2014). Only two studies of this category used risk assessment methods, Rojas et al. (2019) and Jocelyn et al. (2017).

3.3 Physical Ergonomics Factors

The six studies included in this category concluded that workload and posture analysis were the most critical factors in HRC. Lamon et al. (2019), demonstrated that workload is shared through agents (human and robot), according to their physical capabilities and skill levels. The human contributes with extensive cognitive and sensorimotor skills and the robot accounts for force, accuracy and endurance (Faber et al. 2016). Costa Mateus et al. (2019) considered that the use of an ergonomic risk assessment method such as Rapid Upper Limb Assessment (RULA) can improve the task allocation process. In this category, three studies applied ergonomic risk assessment methods to optimize task allocation, Costa Mateus et al. (2019), Pearce et al. (2018) and Faber et al. (2016). According to Liau and Ryu (2020), task allocation represents the most important step in the implementation of the HRC system.

Table 1 Overview of qualitative data analysis of the results

Reference	Category	Topic	Methods						Factors
			Simulation	Software	Algorithm	Questionnaire	Interview	Risk Assessment	
(Rabby et al. 2019)	Cognitive Ergonomics Factors	Cognitive Performance	X		X				Human performance; Robot performance; Cognitive workload; Usability
(Sadrfaridpour and Wang 2018)		Trust	X	X					Joint movement; Robot speed
(Reinhardt et al. 2017)			X			X			Trust; Predictability
(Desai et al. 2013)			X			X			Trust level
(Sadrfaridpour and Wang 2018)			X	X	X				Human performance; Robot performance; Confidence
(Losey and O'Malley 2019)		Communication	X		X				Learning capacity
(Darvish et al. 2018)			X		X				Reliability; Robustness; Flexibility
(Claes and Tuyls 2015)		Teamwork	X						Marker detection; Mapping and location; Navigation; Object recognition; Communication; Inverse kinematics of the arm
(Schulz et al. 2018)		Perception	X			X			Efficiency; Naturalness; Relaxedness; Intelligence; Comfort
(Bröhl et al. 2016)		Acceptance		X		X			Safety perception; Acceptance
(Wang et al. 2019)		Motor Response	X		X	X			Execution time; Confidence; Number of correct answers; Effectiveness
(Oyekan et al. 2019)			X						Acceleration; Kinetic energy; Reaction direction
(Giuliani and Knoll 2013)			X	X		X			Number of verbal statements; Number of times the robot did not instruct to pick the object; Number of instructions that the robot gave to the participants; Number of times a participant chose the correct object; Duration. User feelings; Robot intelligence; Robot behavior; Task success

(continued)

Table 1 (continued)

Reference	Category	Topic	Methods						Factors
			Simulation	Software	Algorithm	Questionnaire	Interview	Risk Assessment	
(Liu et al. 2016)	Organizational Ergonomics Factors	Human-System Performance	X			X			Task completion time; Fluency; Trust; Capacity; Perception
(McGhan and Atkins 2014)			X	X					Task completion time; Completed task fees; Rate of tasks completed correctly; Rate of tasks completed incorrectly
(Müller et al. 2014)			X		X			X	Process optimization
(Oliff et al. 2018)			X						Type of task; Task duration; Fatigue; Skill level/experience; Environmental conditions; Emotional state; Satiety; Caffeine level
(Kim et al. 2018)	Physical Ergonomics Factors	Posture	X		X				Posture; Displacement vector; Joint overload torque
(Changizi et al. 2019)			X			X			Range; Posture; Speed; Control; Strength; Vision; Hearing; Locomotion; Autonomy; Competence; Relatedness
(Faber et al. 2016)					X				Ergonomic Hazards; Posture
(Costa Mateus et al. 2019)			X					X	Action time; Distance of action; Position of the arm and forearm; Wrist torsion; Angle between arm and forearm
(Pearce et al. 2018)		Physical Workload/Effort	X				X	X	Intensity of effort; Duration of effort; Efforts per minute; Hand/wrist posture; Speed of work
(Lamon et al. (2019))			X		X				Complexity of the task; Dexterity of the agent; Agent effort

(continued)

Table 1 (continued)

Reference	Category	Topic	Methods						Factors
			Simulation	Software	Algorithm	Questionnaire	Interview	Risk Assess-ment	
(Kumar and Sahin 2017)	Safety Factors	Collisions	X	X					Safety; Performance; Productivity
(Rojas et al. 2019)					X			X	Speed; trajectory
(Michalos et al. 2016)			X	X					Joint overload
(Pang et al. 2018)			X	X					Contact force; Resistance
(Jocelyn et al. 2017)							X	X	Hazard; Risk; Risk Acceptance; Reliability
(Unhelkar et al. 2018)			X						Inactivity time; Task completion time; Safety stop time; Safety; Efficiency; Fluency
(Safeea et al. 2017)			X						Human-robot distance
(Beetz et al. 2015)			X	X	X				Position; Speed; Object semantics; Acceleration; Torque
(Meziane et al. 2014)			X		X				Human-robot distance; Collision prevention; Dodge activity; Collision avoidance
(Tian et al. 2016)			X	X	X				Speed reduction; Angular velocity of the joint; Friction torque of the joint

3.4 Organizational Ergonomics Factors

In the “Organizational Ergonomics Factors” category, the studies were focused on the improvement of human-system performance, considering the work organization. According to Liu et al. (2016), the combination of goal inference at the motion level and dynamic task planning significantly improves human-robot team performance. Considering all studies included in this systematic review, only Oliff et al. (2018) referred to environmental conditions as a factor with influence in HRC.

4 Limitations

This review had some limitations that should be noted, namely: only included research published in English peer-reviewed journals and not including potentially relevant studies in other languages. In addition, the search was limited to two databases.

5 Conclusions

Collaborative robots will become a usual presence in manufacturing workplaces. However, the collaboration between humans and robots will only work if it follows an anthropocentric approach that improves human health and well-being, safety, and performance. The human-centered design must comply with physical, cognitive and organizational ergonomics principles and safety requirements. It is critical to developing research in this field by multidisciplinary teams (with expertise in the technological field, ergonomics and human factors and psychology) to create complete and complex scenarios (closer to reality) and to study in-depth the impact on humans resulted by the implementation of technologies in the workplace. The presented systematic literature review can support companies in successfully applying human-robot collaboration.

References

Beetz, M., Bartels, G., Albu-Schaffer, A., Balint-Benczedi, F., Belder, R., Bebler, D., Haddadin, S., Maldonado, A., Mansfeld, N., Wiedemeyer, T., Weitschat, R., Worch, J.H.: Robotic agents capable of natural and safe physical interaction with human co-workers. In: IEEE International Conference on Intelligent Robots and Systems, pp. 6528–6535 (2015). https://doi.org/10.1109/IROS.2015.7354310

Bröhl, C., Nelles, J., Brandl, C., Mertens, A., Schlick, C.M.: TAM reloaded: a technology acceptance model for human-robot cooperation in production systems. In: Stephanidis, C. (eds.) HCI International 2016 - Posters’ Extended Abstracts. HCI 2016. Communications in Computer and

Information Science, vol. 617, pp. 97–103. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-40548-3_16
Changizi, A., Dianatfar, M., Lanz, M.: Comfort design in human robot cooperative tasks. In: Ahram, T., Karwowski, W., Taiar, R. (eds.) International Conference on Human Systems Engineering and Design: Future Trends and Application, vol. 876, pp. 521–526. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-02053-8_79
Claes, D., Tuyls, K.: Human Robot-Team Interaction. In: Headleand, C., Teahan, W., Ap Cenydd, L. (eds.) Artificial Life and Intelligent Agents. ALIA 2014. Communications in Computer and Information Science, vol. 519, pp. 61–72. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-18084-7_5
Correia Simões, A., Lucas Soares, A., Barros, A.C.: Factors influencing the intention of managers to adopt collaborative robots (cobots) in manufacturing organizations. J. Eng. Technol. Manage. - JET-M **57**(May), 101574 (2020). https://doi.org/10.1016/j.jengtecman.2020.101574
Costa Mateus, J.E., Claeys, D., Limère, V., Cottyn, J., Aghezzaf, E.H.: Ergonomic and performance factors for human-robot collaborative workplace design and evaluation. IFAC PapersOnLine **52**(13), 2550–2555 (2019). https://doi.org/10.1016/j.ifacol.2019.11.590
Darvish, K., Wanderlingh, F., Bruno, B., Simetti, E., Mastrogiovanni, F., Casalino, G.: Flexible human-robot cooperation models for assisted shop-floor tasks. Mechatronics **51**(2018), 97–114 (2018). https://doi.org/10.1016/j.mechatronics.2018.03.006
Desai, M., Kaniarasu, P., Medvedev, M., Steinfeld, A., Yanco, H.: Impact of robot failures and feedback on real-time trust. In: 8th ACM/IEEE International Conference on Human-Robot Interaction, 2013, pp. 251–258 (2013). https://doi.org/10.1109/HRI.2013.6483596
EU-OSHA: Digitalisation and occupational safety and health (2019, December). https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-osh-eu-osha-research-programme/view
Faber, M., Kuz, S., Mertens, A., Schlick, C.M.: Model-based evaluation of cooperative assembly processes in human-robot collaboration. In: Schlick, C., Trzcieliński, S. (eds.) Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future. Advances in Intelligent Systems and Computing, vol. 490, pp. 27–31. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-41697-7_10
Giuliani, M., Knoll, A.: Using embodied multimodal fusion to perform supportive and instructive robot roles in human-robot interaction. Int. J. Soc. Robot. **5**(3), 345–356 (2013). https://doi.org/10.1007/s12369-013-0194-y
Gualtieri, L., Palomba, I., Wehrle, E., Vidoni, R.: The opportunities and challenges of SME manufacturing automation: safety and ergonomics in human-robot collaboration. In: Matt, D., Modrák, V., Zsifkovits, H. (eds.) Industry 4.0 for SMEs: Challenges, Opportunities and Requirements, pp. 105–144. Springer Nature Switzerland AG (2020). https://doi.org/10.1007/978-3-030-25425-4_4
IEA: What is ergonomics? (n.d.). https://iea.cc/what-is-ergonomics/. Accessed May 11 of 2021
Jocelyn, S., Burlet-Vienney, D., Giraud, L.: Experience feedback on implementing and using human-robot collaboration in the workplace. Proc. Hum. Factors Ergon. Soc. **61**(1), 1690–1694 (2017). https://doi.org/10.1177/1541931213601911
Kim, W., Lee, J., Peternel, L., Tsagarakis, N., Ajoudani, A.: Anticipatory robot assistance for the prevention of human static joint overloading in human-robot collaboration. IEEE Robot. Autom. Lett. **3**(1), 68–75 (2018). https://doi.org/10.1109/LRA.2017.2729666
Kim, W., Kim, N., Lyons, J.B., Nam, C.S.: Factors affecting trust in high-vulnerability human-robot interaction contexts: a structural equation modelling approach. Appl. Ergon. **85**(2020), 103056 (2020). https://doi.org/10.1016/j.apergo.2020.103056
Kumar, S., Sahin, F.: A framework for an adaptive human-robot collaboration approach through perception-based real-time adjustments of robot behavior in industry. In: 12th System of Systems Engineering Conference, 2017, pp. 1–6 (2017). https://doi.org/10.1109/SYSOSE.2017.7994967

Lamon, E., De Franco, A., Peternel, L., Ajoudani, A.: A capability-aware role allocation approach to industrial assembly tasks. IEEE Robot. Autom. Lett. **4**(4), 3378–3385 (2019). https://doi.org/10.1109/LRA.2019.2926963

Liau, Y.Y., Ryu, K.: Task allocation in human-robot collaboration (HRC) based on task characteristics and agent capability for mold assembly. Procedia Manuf. **51**(2019), 179–186 (2020). https://doi.org/10.1016/j.promfg.2020.10.026

Liu, C., Hamrick, J.B., Fisac, J.F., Dragan, A.D., Hedrick, J.K., Sastry, S.S., Griffiths, T.L.: Goal inference improves objective and perceived performance in human-robot collaboration. In: Proceedings of the 2016 International Conference on Autonomous Agents & Multiagent Systems, pp. 940–948 (2016)

Losey, D.P., O'Malley, M.K.: Enabling robots to infer how end-users teach and learn through human-robot interaction. IEEE Robot. Autom. Lett. **4**(2), 1–8 (2019). https://doi.org/10.1109/LRA.2019.2898715

Marvel, J.A., Bagchi, S., Zimmerman, M., Antonishek, B.: Towards effective interface designs for collaborative HRI in manufacturing. ACM Trans. Hum. Robot Interact. **9**(4), 1–5 (2020). https://doi.org/10.1145/3385009

McGhan, C.L.R., Atkins, E.M.: Human productivity in a workspace shared with a safe robotic manipulator. J. Aerosp. Inf. Syst. **11**(1), 1–18 (2014). https://doi.org/10.2514/1.54993

Meziane, R., Li, P., Otis, M.J.D., Ezzaidi, H., Cardou, P.: Safer hybrid workspace using human-robot interaction while sharing production activities. In: IEEE International Symposium on Robotic and Sensors Environments (ROSE) Proceedings, 2014, pp. 37–42 (2014). https://doi.org/10.1109/ROSE.2014.6952980

Michalos, G., Karagiannis, P., Makris, S., Tokçalar, Ö., Chryssolouris, G.: Augmented reality (AR) applications for supporting human-robot interactive cooperation. In: 48th CIRP Conference on Manufacturing Systems, vol. 41, pp. 370–375 (2016). https://doi.org/10.1016/j.procir.2015.12.005

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Group, T.P.: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLOS Med. **6**(7), e1000097 (2009). https://doi.org/10.1371/journal.pmed.1000097

Müller, R., Vette, M., Scholer, M.: Inspector robot - a new collaborative testing system designed for the automotive final assembly line. In: 5th CATS 2014 - CIRP Conference on Assembly Technologies and Systems, vol. 23, pp. 59–64 (2014). https://doi.org/10.1016/j.procir.2014.10.093

Oliff, H., Liu, Y., Kumar, M., Williams, M.: Integrating intelligence and knowledge of human factors to facilitate collaboration in manufacturing. In: Proceedings of the ASME 2018 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, pp. 1–10 (2018). https://doi.org/10.1115/detc2018-85805

Oyekan, J.O., Hutabarat, W., Tiwari, A., Grech, R., Aung, M.H., Mariani, M.P., López-Dávalos, L., Ricaud, T., Singh, S., Dupuis, C.: The effectiveness of virtual environments in developing collaborative strategies between industrial robots and humans. Robot. Comput. Integr. Manuf. **55**(2019), 41–54 (2019). https://doi.org/10.1016/j.rcim.2018.07.006

Pang, G., Deng, J., Wang, F., Zhang, J., Pang, Z., Yang, G.: Development of flexible robot skin for safe and natural human-robot collaboration. Micromachines **9**(576), 1–15 (2018). https://doi.org/10.3390/mi9110576

Pearce, M., Mutlu, B., Shah, J., Radwin, R.: Optimizing makespan and ergonomics in integrating collaborative robots into manufacturing processes. IEEE Trans. Autom. Sci. Eng. **15**(4), 1772–1784 (2018). https://doi.org/10.1109/TASE.2018.2789820

Rabby, K.M., Khan, M., Karimoddini, A., Jiang, S.X.: An effective model for human cognitive performance within a human-robot collaboration framework. In: Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, 2019, pp. 3872–3877 (2019). https://doi.org/10.1109/SMC.2019.8914536

Reinhardt, J., Pereira, A., Beckert, D., Bengler, K.: Dominance and movement cues of robot motion: a user study on trust and predictability. In: IEEE International Conference on Systems, Man, and Cybernetics, 2017, pp. 1493–1498 (2017). https://doi.org/10.1109/SMC.2017.8122825
Rojas, R.A., Garcia, M.A.R., Wehrle, E., Vidoni, R.: A variational approach to minimum-jerk trajectories for psychological safety in collaborative assembly stations. IEEE Robot. Autom. Lett. **4**(2), 823–829 (2019). https://doi.org/10.1109/LRA.2019.2893018
Romero D., Mattsson S., Fast-Berglund, Å., Wuest T., Gorecky D., Stahre J.: Digitalizing occupational health, safety and productivity for the operator 4.0. In: Moon, I., Lee, G., Park, J., Kiritsis, D., von Cieminski, G. (eds.) Advances in Production Management Systems. Smart Manufacturing for Industry 4.0. APMS 2018. IFIP Advances in Information and Communication Technology, vol. 536. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-99707-0_59
Sadrfaridpour, B., Saeidi, H., Burke, J., Madathil, K., Wang, Y.: Modeling and control of trust in human-robot collaborative manufacturing. In: Mittu, R., Sofge, D., Wagner, A., Lawless, W. (eds.) Robust Intelligence and Trust in Autonomous Systems, pp. 115–142. Springer, Boston (2016). https://doi.org/10.1007/978-1-4899-7668-0_7
Sadrfaridpour, B., Wang, Y.: Collaborative assembly in hybrid manufacturing cells: an integrated framework for human-robot interaction. IEEE Trans. Autom. Sci. Eng. **15**(3), 1178–1192 (2018). https://doi.org/10.1109/TASE.2017.2748386
Safeea, M., Mendes, N., Neto, P.: Minimum distance calculation for safe human robot interaction. Procedia Manuf. **11**(2017), 99–106 (2017). https://doi.org/10.1016/j.promfg.2017.07.157
Schulz, R., Kratzer, P., Toussaint, M.: Preferred interaction styles for human-robot collaboration vary over tasks with different action types. Front. Neurorobotics **12**(36), 1–13 (2018). https://doi.org/10.3389/fnbot.2018.00036
Tian, Y., Chen, Z., Jia, T., Wang, A., Li, L.: Sensorless collision detection and contact force estimation for collaborative robots based on torque observer. In: Proceedings of the 2016 IEEE International Conference on Robotics and Biomimetics, 2016, pp. 946–951 (2016). https://doi.org/10.1109/ROBIO.2016.7866446
Unhelkar, V.V., Lasota, P.A., Tyroller, Q., Buhai, R.D., Marceau, L., Deml, B., Shah, J.A.: Human-aware robotic assistant for collaborative assembly: integrating human motion prediction with planning in time. IEEE Robot. Autom. Lett. **3**(3), 2394–2401 (2018). https://doi.org/10.1109/LRA.2018.2812906
Wang, Y., Lematta, G.J., Hsiung, C.-P., Rahm, K.A., Chiou, E.K., Zhang, W.: Quantitative modeling and analysis of reliance in physical human-machine coordination. J. Mech. Robot. **11**(6), 64–70 (2019). https://doi.org/10.1115/1.4044545

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Aworkstation Assessment Tool Considering Ergonomics Aspects (WATEA)

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Abstract Background: Ergonomic improvements in occupational health in the workplace are a growing need around the world. Workstation assessment is necessary for successful worker performance. Objective: The purpose of this paper is to develop a workstation assessment tool considering ergonomics aspects (WATEA), suggesting the best ergonomic assessment method and enabling the user to apply the suggested method of evaluation in the tool itself. Method: Several ergonomic assessment methods were analyzed and studied to choose the most suitable for evaluating the production workstations of a cork company. Subsequently, WATEA was developed, integrating the chosen methods. Results: Development of an ergonomic assessment tool integrating six methods. WATEA helps the user to choose the best assessment method and also allows for the ergonomic evaluation of workstations using the suggested method. The validation of WATEA took place in a cork company through the practical evaluation of a workstation. Conclusion: To the authors' knowledge, there are few ergonomic assessment tools. This one is innovative because it provides an assessment tool which integrates six ergonomic assessment methods, suggesting the best method and then enabling its assessment through the proposed method. Application: This tool can be used in the analysis and improvement of workstations, considering ergonomic aspects in production industries.

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Keywords Decision support tool · Ergonomic risk · Workstation ergonomic assessment

1 Introduction

Today, industries are under tremendous pressure to be competitive in the markets in which they operate. The existing market conditions and competitiveness challenge manufacturing companies to strengthen and maintain their capabilities to compete in the marketplace. Globalization, rapid technological changes, advances in manufacturing technology and growing demand from well-informed customers are forcing manufacturing organizations to optimize their manufacturing processes, operations, and supply chains to be able to deliver value to customers (Karim and Arif-Uz-Zaman 2013). Bernard and Anderson (1997) stated that an ergonomic evaluation requires continuous monitoring of work activities in order to avoid the possible appearance of Work Musculoskeletal Disorders (WMDSs) caused by the exertion of extended forces, awkward and prolonged working postures, repetitive actions and manual material handling.

According to Yusuff and Abdullah (2016), ergonomic intervention can be a very useful tool in reducing wasteful motion, by identifying ergonomic risk factors during work tasks. Stretching, bending, awkward postures and extreme reaches can all be considered "waste" motions in ergonomics and can not only have a negative impact on the safety and health of workers but also lower productivity and efficiency.

The prevention of occupational risks in the workplace is one of the fields of ergonomics application with the aim of preventing the appearance of musculoskeletal disorders (Naranjo-Flores and Ramírez-Cárdenas 2014). According to Botti et al. (2017), future studies are needed in order to document what the best practices in the integration of WMSD prevention into the organizational framework are, including a look at the management system. An economic evaluation of these practices will still be needed to document the cost-effectiveness of these kinds of approaches.

Injury and absenteeism rates are reduced through the design of ergonomic workplaces and jobs, while productivity, quality and reliability are improved (Botti et al. 2014; Fonseca et al. 2013). Previous studies have shown significant productivity losses due to higher absenteeism and injury rates caused by WMSDs (Cheshmehgaz et al. 2012). Ergonomics comprises three main areas: physical (posture, load handling, repetitive movements, WMSDs, workstation design, safety, and health); cognitive and individual (mental workload, decision-making, human computer interaction, stress, and training); and psychosocial and organizational (communications, design and programming work, cooperative work, organizational culture, and quality management) (IEA [International Ergonomics Association] 2000). Physical risk factors are the subset of work-related risk factors that are comprised of biomechanical and environmental factors, namely posture or extremes positions, the application of excessive force, repetitive movements or vibration, such as described in Table 1 (Feuerstein et al. 2004).

Table 1 Description of the main physical risk factors (Nunes 2005)

Aspect	Description
Posture	The adoption of extreme postures and certain joint movements, maintained for long periods of time, the poor design of jobs and the carrying out of tasks which require the worker to adopt these same postures, cause tension and compression of the tendons and contribute to a risk potential, which can lead to the onset of injury
Strength	The demand for tasks involving manual handling of loads continues to be the biggest cause of problems, due to the efforts being made by various parts of the body, with special emphasis on the lumbar region and the spine
Repeatability	Assessing whether the work is repetitive requires knowing whether there are work cycles or tasks where, for example, identical movements, postures or applications of force by the same anatomical regions are used. Gesture invariability can also be a risk factor for WMSDs
Exposure to mechanical elements	The use of machines, tools or equipment that produce vibrations transmitted to the hands and arms increases the risk of developing chronic diseases. Symptoms are related to numbness and tingling

All individuals are different and, therefore, it is possible to relate the development of WMSDs to individual order factors. These include gender, age, anthropometric characteristics, habits/lifestyles, health status, and reactions to stress (Feuerstein et al. 2004). Table 2 describes the main aspects of the individual factors.

Biomechanical mechanisms are just one of the many factors that contribute to triggering and perpetuating the clinical picture. Other conditions such as those of a psychosocial nature also play a crucial role in the pathophysiology of these conditions (Yeng et al. 2001).

According Serranheira (2007), acceptance of the scientific evidence of contributions originating from the organization of work or its psychosocial influences for the development of WMSDs has been difficult and developed slowly over the years.

High work rates, pressure on working time, monotony of tasks and insufficient social support, as well as the organizational model of production, are among the psychosocial and organizational risk factors. Bongers et al. (2002); Huang et al. (2003).

Researches show that engagement in manual handling or standing for a long time greatly contribute to operators' overall fatigue and work efficiency (Hignett and McAtamney 2000). In order to prevent the occurrence of the WMSDs, many effective ergonomic assessment methods were developed for evaluating the work process. People have great interest in evaluating the risk factors related to WMSDs and subsequent ergonomic interventions in the workplace (Occhipinti and Colombini 2007).

Therefore, a workstation assessment tool based on the six main ergonomic assessment methods is proposed and developed in this paper. Through a brief questionnaire, the best ergonomic assessment method is determined. The great advantage and dif-

Table 2 Description of the main individual risk factors (Uva et al. 2008)

Aspect	Description
Age	The classification of age as an individual risk factor is related to the verification of the decrease in maximum voluntary strength associated with aging, as well as changes in joint mobility. Higher ages undoubtedly present the cumulative results of an exposure that can result in decreased tissue tolerance, strength, muscle and joint mobility; these are true risk factors for WMSDs
Gender	Although gender is considered a risk factor, there are no clear differences in risk between genders when they are subject to identical exposures to various risk factors, even though, on average, women have less muscle strength
Anthropometric characteristics	The (in)compatibility between people's characteristics and work requirements can be a risk factor. The different anthropometric characteristics of workers, particularly with regard to height and weight, can contribute to the genesis of musculoskeletal injuries. Tall or short individuals are often faced with jobs that do not adjust and are scaled to the average values of the population. This becomes a good example, since this type of situation can lead to or aggravate the existence of disease or injury in the population with measurements far from these mean values, especially in the case of individuals with a morphology far from the mean values of the population
Health condition	The pre-existence of diseases such as diabetes, rheumatological diseases, certain kidney diseases or a history of trauma may constitute an increased susceptibility. Pregnancy is also an example of a situation which can lead to changes at the musculoskeletal level

ference of this tool is to allow the user not only to determine the best ergonomic assessment method for each workstation, but also to allow for the assessment using the suggested method.

2 Materials and Methods

The methodology used in this work was first exploratory and descriptive when developing this ergonomic assessment tool; a case study was then used to validate it. According to Yin (2003), a case study is defined as "a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context". Following this key idea, the case study, as a research methodology, helps to understand, explore or describe a given system/problem in which several factors are simultaneously involved, in a real context.

The proposed method embraced three main steps: (1) Step 1—Study of all ergonomic assessment methods. (2) Step 2—Development of the ergonomic assessment tool. (3) Step 3—Tool validation in an industrial context.

If not fully accepted, return to Step 1.

Table 3 Ergonomic assessment methods

Method	Description
RULA	"It is a survey method developed for use in ergonomics investigations of workplaces where work-related upper limb disorders are reported" (McAtamney and Corlett 1993)
REVISED STRAIN INDEX	"It involves the measurement or estimation of six task variables (intensity of exertion, duration of exertion per cycle, efforts per minute, wrist posture, speed of exertion and duration of task per day)." (Steven Moore and Garg 2010)
OWAS	"A practical method for identifying and evaluating poor working postures." (Karhu et al. 1971)
MAC	"It is a check list for guiding safety and professional health inspectors which is used for assessing common risks of lifting, lowering, individual or group lugging." (Health and Safety Executive 2014)
NIOSH EQUATION	"Developing a weight limit for sagittal lifts based on the epidemiology of musculoskeletal injury, biomechanical concepts, physiological considerations, and psychophysical lifting limits." (NIOSH 1981)
KIM	"It provides tools for each of the following sets of tasks: lifting/lowering, holding and carrying, pulling or pushing a load." (BAuA - Federal Institute of Occupational Safety and Health)

It took several cycles of interactive process between theory and practical insights to reach the final tool presented in this paper. One of the concerns found during the development of the tool was its length, since it contains several steps, due to the time constrains of those who will have to use it. The assessment tool consists of six ergonomics questions about the workstation to be analysed, which will guide the user to the best assessment method. RUA (Rapid Upper Limb Assessement), RSI (Revised Strain Index), OWAS (Ovako Working Posture Analysing System, MAC (Manual Handling Assessment Charts), NE (Niosh Equation) and KIM (Key Indicator Method) were the chosen methods because they are the ones that have the greatest applicability in the manufacturing industry workstations. The WATEA user must be familiarized with the methods proposed by the tool, which are described in Table 3.

The better the tools' capacity to identify situations of arduous work, the better the analysis in risk management, which makes the process more robust and effective (Prottesa et al. 2012).

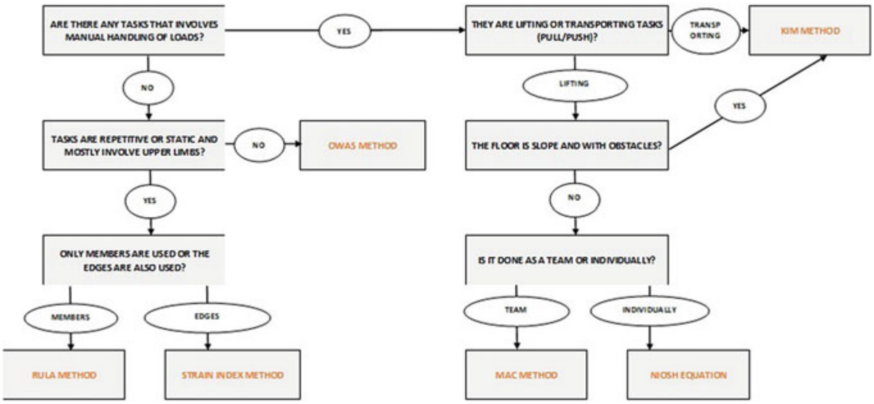

Fig. 1 Flowchart to determine the best ergonomic assessment method

Below is the flowchart with the questions to be answered in the development of the tool, which will help to determine the best assessment method. (Fig. 1).

Once the questionnaire is answered, the best workstation assessment method is suggested and the evaluation can begin. The final result of the evaluation is displayed in different colors depending on the score obtained. Below is the description of how the final result of the RULA method is presented at the end of the evaluation:

Green evaluation—Posture is acceptable. Yellow evaluation—Further investigation is needed and changes may be required. Orange evaluation—Investigation and changes are required soon. Red evaluation—Investigation and changes are required immediately.

The final result of the other methods is presented in a similar way, the only difference being the comment of the proposed evaluation considering the specificity of the type of evaluation of each method.

3 Results

The ergonomic assessment tool proposed in this paper was validated through the application of a case study in a cork stopper company.

The first step was to determine the workstation to be assessed. The manual cork picking process was chosen since it was the one with the highest absenteeism rate due to musculoskeletal problems (Fig. 2).

After choosing the workstation to be assessed, the second step was the questionnaire to determine the best assessment method to use. The sequence of answers obtained led to the RULA method as the best assessment method considering the characteristics of the workstation tasks, which are: arm and forearm extension to 90°, arm abduction, slight wrist rotation, essentially static posture, without relevant load,

Fig. 2 Manual picking process

rotation of the neck, slight trunk inclination and no rotation, and legs supported. The third step was the workstation assessment using the RULA method. This method is divided into two parts to be evaluated. The first part of the method evaluates the position of the arm, forearm and wrist while the second part evaluates the position of the trunk, neck and lower limbs. (Fig. 3).

The RULA method evaluation consists of 15 steps in total and the output will be a final score. Based on this score, the tool will display the evaluation result. Two steps of the RULA method are shown in Fig. 3. The evaluation of this workstation using the RULA method resulted in a score of 5. WATEA presented the final result of the evaluation as shown in Fig. 4.

This result indicates that changes need to be implemented soon since, according to the RULA method evaluation, there is a considerable risk of developing WMSDs in this workstation.

4 Discussion

According to the authors' exhaustive bibliographic analysis, there are several methods for assessing the risk of WMSDs. However, the application of some of these methodologies becomes difficult in real work contexts, given the specific characteristics of the tasks to be analyzed.

The identification of preventive and/or corrective measures, to be implemented to eliminate or minimize the risk of WMSDs, generally requires the use of several methods, in order to obtain results that allow for the argumentation of the measures to be proposed.

Despite the difficulties, interesting results were achieved. WATEA's ease of use allows even users with little knowledge to evaluate workstations in an intuitive, visual

Fig. 3 Parts of the RULA methods assessment

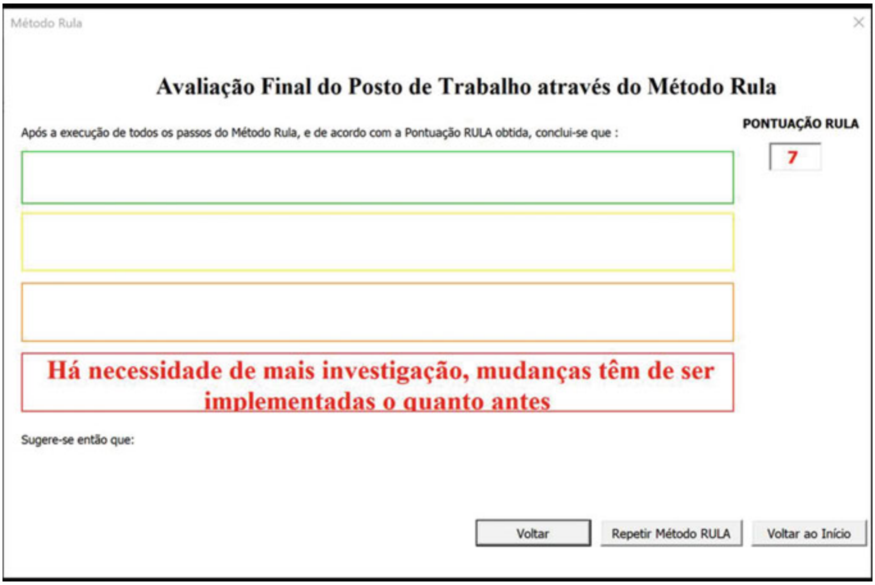

Fig. 4 Final result of the evaluation using the rule method

and simple way. The result of this practical assessment in this case study shows that an intervention must be carried out immediately in the workstation evaluated, and although the time available for the development of this study did not allow it, it would be useful to continue the assessment of other workstations, in a real context.

The initially proposed objectives were achieved and it is expected that this study provides a more careful analysis of the workplace and subsequently contributes to the decision of a possible investment in improving it. In this specific case, one of the solutions could be the automation of the manual task of picking cork stoppers.

This ergonomic assessment tool can be very helpful, since it is simple and intuitive to use. The speed at which the workstation is evaluated is also an asset when carrying out the assessments. This tool was developed in the context of a cork company. It can, however, be applied to other manufacturing companies in other sectors of activity.

As future work, it would be interesting to include the ergonomic assessment for services and administrative areas in the tool by adding other more specific ergonomic assessment methods. An app can be developed from this tool to allow for the assessment to be done through mobile devices such as tablets or mobile phones and thus simplify the assessment.

References

BAuA (Federal Institute of Occupational Safety and Health). Gefährdungsbeurteilung mithilfe der Leitmerkmalmethode [Risk Assessment based on Key Indicator Methods] (2016). http://www.baua.de/leitmerkmalmethoden

Bernard, B.: Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back Cincinnati: NIOSH. In: Bongers, P.M., Kremer, A.M., Ter Laak, J. (eds.) Are psychosocial factors riskfactors for symptoms and signs of the shoulder, elbow, or hand/wrist? a review of the epidemiological literature. Am. J. Ind. Med. **41**(5), 315–342 (2002)

Botti, L., Mora, C., Piana, F., Regattieri, A.: Integrating ergonomics and lean manufacturing principles in hybrid assembly line. Comput. Ind. Eng. **111**, 481–491 (2017)

Botti, L., Gamberi, M., Manzini, R., Mora, C., Regattieri, A.: A bi-objective optimization model for work activity scheduling of workers exposed to ergonomic risk. In: Proceedings of the XIX summer school "Francesco Turco", Ancona (2014)

Cheshmehgaz, H.R., Haron, H., Kazemipour, F., Desa, M.I.: Accumulated risk of body postures in assembly line balancing problem and modeling through a multi-criteria fuzzy- genetic algorithm. Comput. Ind. Eng. **63**(2), 503–512 (2012)

Feuerstein, M., Nicholas, R.A., Huang, G.D., Dimberg, L., Ali, D., Rogers, H.: Job stress management and ergonomic intervention for work-related upper extremity symptoms. Appl. Ergon. **35**(6), 565–574 (2004)

Fonseca, H., Loureiro, I.F., Arezes, P.: Development of a job rotation scheme to reduce musculoskeletal disorders: a case study. In: Perestrelo, G. (ed.), pp. 351–356. Occupational Safety and Hygiene, CRC Press

Health and Safety Executive, Manual handling assessment charts (the MAC tool) (2014). www.hse.gov.uk/pubns/indg383.pdf

Hignett, S., McAtamney, L.: Rapid entire body assessment (REBA). Appl. Ergon. **31**(2), 201–205 (2000)

Huang, G.D., Feuerstein, M., Kop, W.J., Schor, K., Arroya, F.: Individual and combined impacts of biomechanical and work organization factors in work-related musculoskeletal symptoms. Am. J. Ind. Med. **43**, 495–506 (2003)

IEA [International Ergonomics Association] (2000)

Karhu, O., Kansi, P., Kuorinka, I.: Correcting working postures in industry: a practical method for analysis. Appl. Ergon. **8**(4), 199-201 (1971)

Karim, A., Arif-Uz-Zaman, K.: A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations. Bus. Process. Manag. J. **19**(1), 169–196 (2013)

McAtamney, L., Corlett, E.N.: RULA: a survey method for the investigation of work-related upper limb disorders. Appl. Ergon. **24**(2), 91–99 (1993)

Naranjo-Flores, A.A., Ramírez-Cárdenas, E.: "Human factors and ergonomics for lean manufacturing applications, lean Manufacturing in the developing world: methodology, pp. 281–299. Case Studies and Trends from Latin America, Springer, Cham (2014)

NIOSH.: Work practices guide for manual lifting, Report No. 81–122, U.S. Department of health and human services, national institute for occupational safety and health. Cincinnati, Ohio (1981)

Nunes, I.: Lesões Músculo-Esqueléticas Relacionadas com o Trabalho. In: Dashöfer, V. (ed.) Higiene, Segurança, Saúde e Prevenção de Acidentes de Trabalho (Vol. Ergonomia do Trabalho) (2005)

Occhipinti, E., Colombini, D.: Updating reference values and predictive models of the OCRA method in the risk assessment of work-related musculoskeletal disorders of the upper limbs. Ergonomics **50**, 1727–39 (2007)

Serranheira, F., Pereira, M., Santos, C., Cabrita, M.: Auto-referência de sintomas de lesões músculo-esqueléticas ligadas ao trabalho (LMELT) numa grande empresa em Portugal. Rev. Saúde Ocupacional, 37–47 (2003)

Steven Moore, J., Garg, A.: The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am. Ind. Hyg. Assoc. J. **56**(5), 443–458 (2010)
Totorella, G.L., Vergara, L.G.L., Ferreira, E.P.: lean manufacturing implementation: an assessment method with regards to socio-technical and ergonomics practices adoption. Int. J. Adv. Manuf. Technol. **89**, 3407–3418 (2017)
Uva, A.S., Carnide, F., Serranheira, F., Miranda, L.C., Lopes, M.F.: Lesões Músculo-esqueléticas Relacionadas com o Trabalho: Guia de orientação para a Prevenção. Programa Nacional Contra as Doenças Reumáticas, Direção-Geral da Saúde (2008)
Yeng, L.T., Teixeira, M.J., Romano, M.A., Picarelli, H., Settimi, M.M., Greve, J.M.D.A.: Cummulative Trauma Disorders, p. 80. Med, Rev (2001)
Yin, R.K.: Applications of Case Study Research. Sage Publications, Thousand Oaks, CA (2003)
Yusuff, R.M., Abdullah, N.S.: Ergonomics as a lean manufacturing tool for improvements in a manufacturing company. Proc. Int. Conf. Ind. Eng. Oper. Manag. **8–10**, 581–588 (2016)

Occupational Psychosociology and Human Factors

Work Passion and Workaholism: Consequences on Burnout of Health and Non-Health Professionals

Joana Santos, Cátia Sousa, Gabriela Gonçalves, and António Sousa

Abstract Employees who overvalue work over other dimensions of their lives have always been appreciated by organizations. Thus, this study aims to present the analyses of work passions, workaholism and burnout in a Portuguese sample of health and non-health professionals. 437 employees from different professionals' areas (health institutions and others), composed by females ($n = 332$; 75.3%) with a mean age of 38, 58 years old. The results show that the health professionals experience more harmonious passion and have symptoms of burnout. Understanding the work passion of professionals are a very important issue to give tools to reduce occupational diseases.

Keywords Work passion · Workaholism · Burnout · Well-being

1 Introduction

Working is an important part of life and people tend to devote a large part of their lives to it. Some employees see their work only as a source of income, other may want to find satisfaction and entertainment in it (Tóth-Király et al. 2020).

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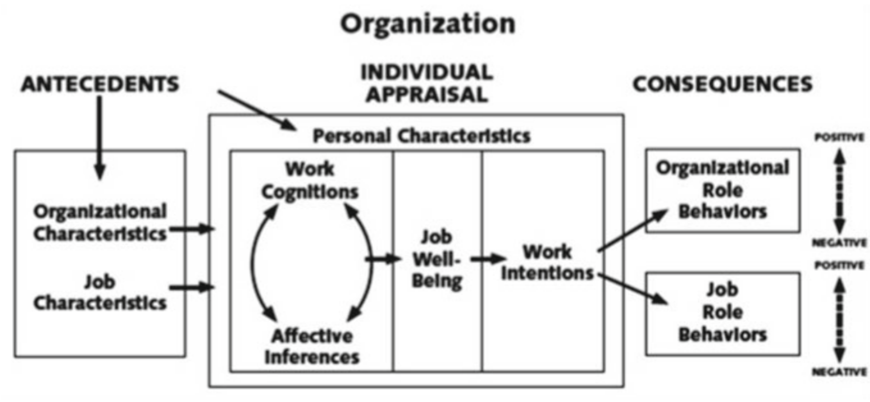

Fig. 1 Employee work passion model (Zigarmi et al. 2018, p. 232)

Passion is defined as a robust inclination towards an activity that people like and consider important, and in which they invest time and energy (Vallerand et al. 2003). In the employee work passion appraisal model (Fig. 1), work passion is defined as "persistent, emotionally positive, based on the feeling of well-being, resulting from cognitive and affective assessments of various professional and organizational situations, which result in intentions and consistent and constructive work behaviors" (Zigarmi et al. 2009, p. 310). The evaluations carried out refer to three groups of characteristics within the work environment: organizational characteristics (e.g., justice, growth, and performance expectations), work characteristics (e.g., work autonomy, variety of tasks, balance of workload) and relationship characteristics (e.g., feedback, collaboration, relationship with colleagues and leader) (Zigarmi et al. 2009; Nimon and Zigarmi 2015).

According to Vallerand et al. (2003) passion reinforces motivation, improving well-being and giving meaning to daily life. However, it can also trigger negative emotions, lead to uncompromising persistence, and interfere with balance achieving. In this sense, a dualistic model of passion for work was proposed, composed of harmonious passion and obsessive passion. These two types of passion depend on how the representations of the activity was internalized in the identity and are associated with different results, as well as with different contextual and dispositional antecedents (Salessi et al. 2017). Some studies supported the role of harmonious passion on employee's performance (Ho et al. 2011) and other highlighted the relations of passion of work and burnout (Dohahue et al. 2012). Despite the theoretical framework proposed by Zigarmi et al. (2009) in Employee Work Passion Appraisal (EWPA) model suggested that the development of employee work passion occurs through appraisals of organization, job, and interpersonal factors that influences employee affect (Egan et al. 2019). So, the emerging of each kind of passion could emerge by a several number of factors, not only the individual, but also because of work intensification has increased significantly (Eurofound 2017) with technological innovations. Egan and colleagues (2019) discussed the importance of develop and refine the model, to extend the model in different organizational context and countries. So, in this study we'll analyze professional of different contexts, distinguish health and non-health employees, because the health employees must face several sources of stress in their jobs, such as time pressures, long hours of work, low sleep hours, low error tolerance and high expectations (Rutledge et al. 2009).

Those employees who prioritize work over other dimensions of their lives have always been appreciated by organizations. Scientifically, higher levels of work investment have been studied in two different perspectives: A positive perspective focuses the work engagement; A negative perspective focuses the workaholism (Tóth-Király et al. 2020).

Workaholism can be understood as an addition, that is, excessive and persistent behavior with negative consequences for the subject (Schaufeli et al. 2008). In 2009, Shimazu and Schaufeli defined this concept as a negative internal impulse to which the subject cannot resist. So is possible to highlight to dimensions of workaholism: (1) Behavioral Dimension (dedicate higher levels of time and energy in work, more than expected; (2) Cognitive Dimension (work compulsively, higher impulse to get involved in work tasks and activities) (Gorgievski et al. 2010; Schaufeli et al. 2008; Schaufeli and Bakker 2004; Shimazu and Schaufeli 2009). Some authors (e.g., Schaufeli et al. 2009), consider that a true workaholism only could be assessed if both dimensions are present.

The extension of workaholism effects could be seen in negative health outcomes (e.g., Balducci et al. 2018), such as burnout (Gonçalves et al. 2017; Schaufeli et al. 2009) or work-family conflict (e.g., Pan 2018). It proves that social relations outside the workaholic's context of workaholics are weaker, compared to the social relations of the other collaborators (Van Beek et al. 2012). So, the workaholism disturbs not only the individual himself, but also all those who deal with him, in work and in personal life (e.g., Pan 2018; Shkoler et al. 2017; Salessi et al. 2017).

Specifically, considering the workaholism and burnout, the workaholism may act has the root cause of burnout, because "excessively and frantically working employees use up their mental resources, leaving them depleted and burned out" (Schaufeli et al. 2008, p. 176). So, they could experience drained of mental resources (exhaustion) or an indifference attitude towards one's job (cynicism) or tendency to evaluate work performance negatively (lack of professional efficacy).

Despite the challenges and demands of nowadays work contexts are generally high for all professional activities, it is our intention to better understand if there are some differences in those constructs in health care and non-health care professionals. Previous studies showed healthcare professionals are frequently very committed to their jobs and that could be seen through high levels of workaholism (Dordoni et al. 2019).

2 Methodology

2.1 Sample

The sample of this study was non-probabilistic composed of 437 employees from different professional area (health institutions and others). The sample was mainly composed by females (n = 332; 75.3%). Their ages ranged from 18 to 63 years (mean = 38, 58). 243 (55.1%) have higher education degree. Major of them (n = 256; 58.0%) are employee with indefinite contract and don't holds management position (n = 371; 84.1%).

2.2 Instruments

The following instruments were applied:

Workaholism Battery (WorkBat): to evaluate the workaholic profile the Portuguese version of Santos et al. (2018) of WorkBat, originally developed by Spence and Robbins (1992) was used. It is a scale composed of 25 items that evaluate three dimensions: psychological involvement with work (8 items, e.g., item 1 "When I have free time I like to relax and do nothing important"); internal compulsion to work (7 items, e.g., item 11 "I feel the duty to work hard even when it is not pleasant") and pleasure derived from work (10 items, e.g., item 22 "I lose track of time when I am involved a) in a project "). Questions are rated on a 7-point Likert scale (1—strongly disagree to 7—strongly agree) and items 1, 2, 3 and 21 are reversible.

Work Passion Scale (Vallerand and Houlfort 2003, adapted to the Portuguese population by Gonçalves et al. 2014). The scale consists of 14 items where the respondents have a 7-point Likert scale, with 1 "Strongly disagree" and 7 "Strongly agree". The scale contains two subscales, harmonious passion, and obsessive passion. Harmonious passion has a high internal consistency ($\alpha = 0.92$). Obsessive passion also has a high Cronbach's alpha ($\alpha = 0.93$). In the present study, the value of Cronbach's alpha was 0.930 us passion and 0.931 for obsessive passion.

Burnout Inventory (SMBM): Originally developed by Shirom and Melamed (2006). This scale consists of fourteen items through three distinct subscales, namely, physical fatigue, emotional exhaustion, and cognitive fatigue. In the physical fatigue dimension, we have, for example, "I feel tired", in emotional exhaustion we have as example "I have difficulty concentrating", and in the dimension of cognitive fatigue we can "I feel unable to be sensitive to the needs of my work colleagues and customers.

General Health Questionnaire (GHQ): The scale of psychological well-being was originally developed by Goldberg and Williams (1988). It is a one-dimensional scale consisting of twelve items, three of which are inverted. As an example of reversed items, we have item 2 "Lost sleep over worry" and item 5 "Felt constantly under strain". On the other hand, we have an example of items with non-reverse direction (9 items), e.g., item 8 “Been able to face problems”; item 1 “Able to concentrate”.

The questionnaire has also some questions to obtain demographic information, including gender, age, school year.

2.3 Procedures

Previously to data collection, the investigators guaranteed an authorization from the Scientific Committee was guaranteed (e.g., entity responsible for supervising the procedures and ethical safeguards of research) and guarantee the ethical criteria (e.g., information about the voluntary and anonymous nature of the study). The study was conducted according to the guidelines of the Declaration of Helsinki regarding research with human beings: information on the objective, risks, and benefits of the study and the possibility of abandoning the study in any of its stages. Participants were answered a self-report questionnaire during, more or less, 15 min. The questionnaire was anonymous and confidential, and no compensation was offered to participants. Data collection was presential accomplished in several places, both collectively and individually (e.g., university classes, public and private companies, public libraries).

2.4 Data Analysis

Data analysis was performed using the SPSS 25 statistical package and AMOS 20 software.

3 Results

3.1 Descriptive Statistics

Table 1 presents the descriptive characteristics of the variable in study, regarding both, health professionals and non-health professionals. All professionals experience more harmonious passion. The workaholism is more experienced by non-health professionals, specifically in workaholism involvement ($t = -11.621$; $p = 0.001$) and drive ($t = -4.952$; $p = 0.001$). In the same direction, the health professional perceives more general health than the other type of professionals ($t = -23.804$; $p = 0.001$)

Table 1 Descriptive Statistics and Mean Differences between professionals (health vs. non-health)

		n	Mean	SD	t	p	Cohen's D
Harmonious Passion	Health prof.	207	4.982	1.354	0.444	0.658	0.044
	Non-health Prof.	200	4.921	1.415			
Obsessive Passion	Health prof.	207	2.752	1.357	−2.540	0.011	−0.252
	Non-health Prof.	200	3.106	1.450			
Workaholism	Health prof.	207	3.776	0.702	−6.770	0.001	−0.671
	Non-health Prof.	200	4.295	0.841			
Work-Involvement	Health prof.	207	3.923	0.800	−11.621	0.001	−1.152
	Non-health Prof.	200	4.914	0.917			
Work-Drive	Health prof.	207	3.645	1.317	−4.952	0.001	−0.491
	Non-health Prof.	200	4.305	1.369			
Workaholism Enjoyment	Health prof.	207	3.734	0.966	−0.582	0.561	−0.058
	Non-health Prof.	200	3.794	1.105			
Burnout	Health prof.	207	3.053	1.513	1.392	0.165	0.138
	Non-health Prof.	200	2.861	1.252			
Burnout-physical fatigue	Health prof.	207	3.542	1.691	1.088	0.277	0.108
	Non-health Prof.	200	3.369	1.499			
Burnout-cognitive fatigue	Health prof.	206	2.865	1.716	1.186	0.236	0.118
	Non-health Prof.	200	2.677	1.461			
Burnout-emotional exhaustion	Health prof.	206	2.417	1.667	1.748	0.081	0.174
	Non-health Prof.	200	2.153	1.346			
General Health Questionnaire	Health prof.	208	5.100	0.944	23.804	0.001	2.357
	Non-health Prof.	200	2.937	0.890			

*d = 0.0 − 0.29 reduced magnitude effect; d = 0.30 − 0.49 effect of moderate magnitude; d > 0.50 effect of high magnitude (Cohen 1988)

3.2 Hierarchical Regression Analyses

Table 2 illustrates explanation of burnout (global and each dimension—physical fatigue, cognitive fatigue and emotional exhaustion) by passion (model 1: Harmonious and Obsessive Passion) and Workaholism (Global and each dimension—involvement, drive and enjoyment).

The physical fatigue of burnout is 8% explained by work passion (model 1), those explanation improves to 16% when consider the workaholism (model 2). The cognitive fatigue of burnout is 9% explained by work passion (model 1), those explanation improves to 11% when consider the workaholism (model 2). Emotional exhaustion of burnout is 9% explained by work passion (model 1), those explanation improves to 11% when consider the workaholism.

The global dimension of burnout is 12% explained by passion (obsessive and harmonious). The explanation improves to 18% when considered the workaholism.

4 Discussion

This study aimed to analyze the health versus non-health professionals, considering work passion, workaholism and burnout. Unlike previous studies, in our results the health professionals experience more harmonious passion and less obsessive passion. The workaholism is higher in other professions than in health professionals. The organizational contexts are determinant to the development and maintenance of workaholism, in concrete some organizations have the reputation to be environments where people need to work hard and play in the same level. (e.g., Fassel 1990; Harpaz and Snir 2003), as some organizations have the repute to be a place where people work hard and play hard. Some other studies covered the personal demographic characteristics (Burke et al. 2014; Harpaz and Snir 2003; Spence and Robbins 1992), the personality (Jackson et al. 2016) and the organizational values (Burke 2000, 2008; Schaef and Fassel 1988) as types of antecedents. So, our results showed that despite the challenge environment that health professionals have to deal, it don't contribute to higher levels of workaholism.

On other hand the higher levels of burnout are experienced by health professionals, such in physical, cognitive, and emotional symptoms. Burnout could appear in all types of jobs, nevertheless the incidence seems to be higher in physicians (De Hert 2020). A study development in Portugal showed "the burnout syndrome in health professionals is frequent, being associated with a poor working conditions perception and reduced professional experience. The incidence of the burnout syndrome shows regional differences which may be associated with different and suboptimal conditions for health care delivery" (Maroco et al. 2016, p. 24).

As far as we can discuss, it is very interesting results, as it seems that health professionals are positive passionate for their jobs but needing more careful attention by managers, because they are in red line regarding burnout. Those are very challenging

Table 2 Hierarchical Regression Burnout

	Burnout Dimension									Burnout		
	Physical fatigue			Cognitive fatigue			Emotional exhaustion					
	b	t	p	b	t	p	b	t	p	b	t	p
Model 1												
Harmonious passion	−0.315	−6.141	0.000	−0.359	−7.103	0.000	−0.337	−6.623	0.000	−0.384	−7.651	0.000
Obsessive passion	−0.142	2.769	0.006	0.212	4.185	0.000	0.230	4.522	0.000	0.211	4.205	0.000
	$r^2 = 0.080; p = 0.000$			$r^2 = 0.102; p = 0.000$			$r^2 = 0.097; p = 0.000$			$r^2 = 0.120; p = 0.000$		
Model 2												
Harmonious passion	−0.205	−3.816	0.000	−0.307	−5.650	0.000	−0.339	−6.120	0.000	−0.308	−5.785	0.000
Obsessive passion	0.125	2.383	0.018	0.172	3.236	0.001	0.184	3.401	0.001	0.176	3.370	0.001
Workaholism	−1.044	−1.462	0.144	−0.064	−0.089	0.929	−0.435	−0.593	0.554	−0.649	−0.919	0.359
Work involvement	0.457	1.613	0.107	0.454	0.125	0.438	0.445	0.189	0.650	0.388	0.324	1.157
Work drive	0.719	2.119	0.035	0.182	0.532	0.595	0.324	0.927	0.354	0.509	1.515	0.130
Work enjoyment	0.281	0.766	0.444	−0.086	−0.233	0.816	0.241	0.640	0.523	0.161	0.445	0.656
	$r^2 = 0.163; p = 0.000$			$r^2 = 0.137; p = 0.000$			$r^2 = 0.114; p = 0.000$			$r^2 = 0.180; p = 0.000$		

times, and the health professionals are in the front line of all challenges that society goes through, taking care of each and every one, but also needing to be taken care of.

The inferential analysis gave us other aspects to discuss, the obsessive passion is a facilitator of burnout experience. In previous studies, obsessive passion seems to have significant impact on the emotional exhaustion dimension of burnout (Lavigne et al. 2012).

5 Conclusion

This research focused on the analysis of consequences of work passion on workaholism and burnout of employees, health, and non-health. The health care professionals compose one of the professional groups most frequently exposed to psychosocial risks at work (Gómez-Salgado et al. 2019). The results showed that the professionals are, mostly harmonious passioned by their works. In the line with Vallerand et al. (2014) we consider the need for further research on the antecedents of passion, so "additional research is needed to increase the understanding of the development of passion" (p. 101). Is important the future research consider personal, social and organizational factors and their interaction.

A deeper analysis should be developed to give some instruments for human resources management to define policies to promote the organizational and individual health of the professionals, such in health or non-health environments.

The results of this study still could be interesting to be considered in the definition of policies to minimize the burnout of employees. The burnout symptoms are explained by work passion and workaholism, so is important to consider that the organizational factors that prioritizes the healthy workplaces and a positive balance between personal, family and work life's conciliation could be a lifeboat to healthy and productive professionals in diverse work environments.

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References

Balducci, C., Avanzi, L., Fraccaroli, F.: The individual "costs" of workaholism: An analysis based on multisource and prospective data. J. Manag. **44**(7), 2961–2986 (2018). https://doi.org/10.1177/0149206316658348

Burke, R.: Workaholism in organizations: psychological and physical wellbeing consequences. Stress Med. **16**(1), 11–16 (2000). https://doi.org/10.1002/(SICI)1099-1700(200001)16:1<11::AID-SMI825>3.0.CO;2-U

Burke, R.: Work motivations, satisfactions, and health: passion versus addiction. In: Burke, R., Cooper, C. (eds.) The Long Working Hours Culture. Causes, Consequences and Choices, pp. 227–251. Emerald, Bingley (2008)
Burke, R.J., Astakhova, M.N., Hang, H.: Work passion through the lens of culture: Harmonious work passion, obsessive work passion, and work outcomes in Russia and China. J. Bus. Psychol. **30**(3), 457–471 (2014). https://doi.org/10.1007/s10869-014-9375-4
Cohen, J.: Statistical Power Analysis for the Behavioral Sciences, 2nd edn. Lawrence Erlbaum Associates, Publishers, Hillsdale (1988)
De Hert, S.: Burnout in healthcare workers: prevalence, impact and preventative strategies. Local Reg. Anesth. **13**, 171–183 (2020). https://doi.org/10.2147/LRA.S240564
Donahue, E.G., Forest, J., Vallerand, R.J., Lemyre, P.N., Crevier-Braud, L., Bergeron, É.: Passion for work and emotional exhaustion: the mediating role of rumination and recovery. Appl. Psychol. Health Well Being **4**(3), 341–368 (2012). https://doi.org/10.1111/j.1758-0854.2012.01078.x
Dordoni, P., Kraus-Hoogeveen, S., Van Der Heijden, B., Peters, P., Setti, I., Fiabane, E.: Live to Work or Work to Live? An Age-Moderated Mediation Model on the Simultaneous Mechanisms Prompted by Workaholism Among Healthcare Professionals. Frontiers in Psychology (2019). https://doi.org/10.3389/fpsyg.2019.00868
Egan, R., Zigarmi, D., Richardson, A.: Leadership behavior: a partial test of an employee work passion model. Hum. Resour. Dev. Q. **30**, 311–341 (2019). https://doi.org/10.1002/hrdq.21346
Eurofound: Innovative changes in European companies: Evidence from the European Company Survey. Publications Office of the European Union, Luxembourg (2017)
Fassel, D.: Working Ourselves to Death: The High Costs of Workaholism, the Rewards of Recovery. Harper Collins, San Francisco (1990)
Goldberg, D., Williams, P.: A user's guide to the General Health Questionnaire. NFER, Windsor (1988)
Gómez-Salgado, J., Navarro-Abal, Y., López-López, M.J., Romero-Martín, M., Climent-Rodríguez, J.A.: Engagement, passion and meaning of work as modulating variables in nursing: a theoretical analysis. Int. J. Environ. Res. Public Health **16**(1), 1–13 (2019). https://doi.org/10.3390/ijerph16010108
Gonçalves, G., Orgambídez-Ramos, A., Ferrão, M.C., Parreira, T. : Adaptation and initial validation of the passion scale in a portuguese sample. Escritos de Psicología-Psychological Writings **7**(2), 19–27 (2014). https://doi.org/10.5231/psy.writ.2014.2503
Gorgievski, M., Bakker, A., Schaufeli, W.: Work engagement and workaholism: comparing the self-employed and salaried employees. J. Posit. Psychol. **5**(1), 83–96 (2010). https://doi.org/10.1080/17439760903509606
Harpaz, I., Snir, R.: Workaholism: its definition and nature. Hum. Rel. **56**(3), 291–319 (2003). https://doi.org/10.1177/0018726703056003613
Ho, V.T., Wong, S.S., Lee, C.H.: A tale of passion: linking job passion and cognitive engagement to employee work performance. J. Manage. Stud. **48**(1), 26–47 (2011). https://doi.org/10.1111/j.1467-6486.2009.00878.x
Jackson, S. S., Fung, M. C., Moore, M. A. C., Jackson, C. J.: Personality and workaholism. Personality and Individual Differences, **95**, 114–120 (2016). https://doi.org/10.1016/j.paid.2016.02.020
Lavigne, G. L., Forest, J., Crevier-Braud, L. . Passion at work and burnout: A two-study test of the mediating role of flow experiences. European Journal of Work and Organizational Psychology, **21**(4), 518–546 (2012). https://doi.org/10.1080/1359432X.2011.578390
Maroco, J., Maroco, A., Leite, E., Bastos, C., Vazão, M., Campos, J.: Burnout in Portuguese healthcare professionals: an analysis at the national level. Acta Médica Portuguesa **29**(1), 24–30 (2016)
Nimon, K., Zigarmi, D.: The work cognition inventory: initial evidence of construct validity for the revised form. J. Career Assess. **23**(1), 117–136 (2015). https://doi.org/10.1177/1069072714523241
Pan, S.-Y.: Do workaholic hotel supervisors provide family supportive supervision? A role identity perspective. Int. J. Hosp. Manag. **68**, 59–67 (2018). https://doi.org/10.1016/j.ijhm.2017.09.013

Rutledge, T., Stucky, E., Dollarhide, A., Shively, M., Jain, S., Wolfson, T., Weinger, M. B., Dresselhaus, T.: A real-time assessment of work stress in physicians and nurses. Health Psychology, **28**(2), 194–200 (2009). https://doi.org/10.1037/a0013145

Salessi, S., Omar, A., Vaamonde, J.D.: Conceptual considerations of work passion. Ciencias Psicológicas **11**(2), 165–178 (2017). https://doi.org/10.22235/cp.v11i2.1488

Santos, J., Sousa, C., Sousa, A., Figueiredo, L., Gonçalves, G. : Psychometric evidences of the workaholism battery in a portuguese sample. J. Spatial Organ. Dyn. - Hum. Factors Safety Health Workplace, V **I**(1), 40–51 (2018)

Schaef, A. W., Fassel, D. (1988). The addictive organization. Harper and Row Publishers.

Schaufeli, W.B., Bakker, A.B.: Job demands, job resources, and their relationship with burnout and engagement: a multi-sample study. J. Organ. Behav.: Int. J. Ind. Occup. Organ. Psychol. Behav. **25**(3), 293–315 (2004). https://doi.org/10.1002/job.248

Schaufeli, W.B., Taris, T.W., Bakker, A.B.: It takes two to tango: workaholism is working excessively and working compulsively. In: Burke, R.J., Cooper, C.L. (eds.) The Long Work Hour's Culture: Causes, Consequences and Choices, pp. 203–226. Emerald, Bingley (2008)

Schaufeli, W., Bakker, A., van der Heijden, M., Prins, J.: Workaholism, burnout and well-being among junior doctors: the mediating role of role conflict. Work Stress **23**(2), 155–172 (2009). https://doi.org/10.1080/02678370902834021

Shimazu, A., Schaufeli, W.: Is workaholism good or bad for employee wellbeing? the distinctiveness of workaholism and work engagement among Japanese employees. Ind. Health **47**(5), 495–502 (2009). https://doi.org/10.2486/indhealth.47.495

Shirom, A., Melamed, S.: A comparison of the construct validity of two burnout measures in two groups of professionals. Int. J. Stress. Manag. **13**, 176–200 (2006)

Shkoler, O., Rabenu, E., Vasiliu, C., Sharoni, G., Tziner, A.: Organizing the confusion surrounding workaholism: new structure, measure, and validation. Front. Psychol. **8**, 1803 (2017). https://doi.org/10.3389/fpsyg.2017.01803

Spence, J., Robbins, A.: Workaholism: definition, measurement, and preliminary results. J. Pers. Assess. **58**(1), 160–178 (1992). https://doi.org/10.1207/s15327752jpa5801_15

Tóth-Király, I., Morin, A., Salmela-Aro, K.: A longitudinal perspective on the associations between work engagement and workaholism. Work Stress (2020). https://doi.org/10.1080/02678373.2020.1801888

Vallerand, R.J., Houlfort, N.: Passion at work: toward a new conceptualization. In: Gilliland, S.W., Steiner, D.D., Skarlicki, D.P. (eds.) Emerging Perspective on Values in Organizations, pp. 175–204. Information Age Publishing, Charlotte (2003)

Vallerand, R.J., Houlfort, N., Forest, J.: Passion for work: Determinants and outcomes. Oxford Handbook of Work Engagement, Motivation, and Self-determination Theory, pp. 85–105 (2014)

Vallerand, R.J., Blanchard, C., Mageau, G.A., Koestner, R., Ratelle, C., Léonard, M., Gagné, M., Marsolais, J.: Les passions de l'ame: on obsessive and harmonious passion. J. Pers. Soc. Psychol. **85**(4), 756–767 (2003). https://doi.org/10.1037/0022-3514.85.4.756

Van Beek, I., Hu, Q., Schaufeli, W., Taris, T., Schreurs, B.: For fun, love, or money: what drives workaholic, engaged, and burned-out employees at work? Appl. Psychol. **61**(1), 30–55 (2012). https://doi.org/10.1111/j.1464-0597.2011.00454.x

Zigarmi, D., Galloway, F. J., Roberts, T. P.: Work locus of control, motivational regulation, employee work passion, and work intentions: An empirical investigation of an appraisal model. J. Happiness Stud. **19**(1), 231–256 (2018)

Zigarmi, D., Nimon, K., Houson, D., Witt, D., Diehl, J.: Beyond engagement: toward a framework and operational definition for employee work passion. Hum. Resour. Dev. Rev. **8**(3), 300–326 (2009). https://doi.org/10.1177/1534484309338171

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Occupational Stress and Cognitive Appraisal Profiles as Predictors of Students' Burnout

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Abstract Objective: Analyze if different patterns of occupational stress experienced by students (lower versus higher) and different cognitive appraisal profiles assumed by students (positive evaluation of academic activity versus negative evaluation of academic activity) affect their experience of burnout over time. Background: The interactive and transactional perspective of adaptation to stress was adopted to analyze how university students evaluate their activity and related academic stress, and how they feel in terms of burnout. Method: Longitudinal study design, with three moments of data collection, with a sample of 175 psychology students, from a Portuguese university. The investigation protocol included the Stress Questionnaire for Students, the Primary and Secondary Cognitive Appraisal Scale, and the Shirom-Melamed Burnout Scale. Results: The results showed that students who experienced higher levels of stress and a negative evaluation of their academic activity also reported higher levels of burnout when compared to students who experienced lower levels of stress and positive evaluation of academic activity. Moreover, a pattern of high stress in M1 increases in 443% the probability to experience moderate to high burnout in M2. A profile of negative evaluation of the academic activity in M1 increases in 594% the probability to experience high burnout in M2. Students exposed to high levels of burnout at M2 are over nine times more likely to experi-

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ence moderate levels of burnout at M3, and over 300 times more likely to experience high levels of burnout at M3. Conclusion: Students who experience higher academic stress and those who evaluate their academic activity more negatively have a higher tendency to experience burnout. Although, the experience of burnout in a specific data point is the main predictor of experiencing burnout in a later moment, highlighting the chronic effects of this syndrome on human wellbeing. Application: This study provides specific indications of how much stress and cognitive appraisal can affect burnout, alerting also for the chronic nature of burnout feelings, which must be considered in safety and occupational health interventions.

Keywords Stress patterns · Cognitive appraisal profiles · University students · Burnout

1 Introduction

Occupational stress represents a major topic in society and academic research has consistently show evidence that levels of stress increased in the last decades, producing several negative effects on individuals, families, organizations, and countries (World Health Organization 2007). The same scenario can be applied to students, particularly the ones included in higher education contexts, where evidence demonstrates that academic stress is related to several negative effects, such as anxiety, depression, and lower self-esteem (Hudd et al. 2000; Larson and Luthans 2006), alcohol and drug abuse (Böke et al. 2019), sleep disturbances (Wallace et al. 2017), and lower academic success and even academic withdrawal (Britt et al. 2017; Frazier et al. 2018). Thus, it becomes important to determine the impact produced by stress on the well-being of students. In this study, the interactive and transactional perspective of adaptation to stress (Blascovich and Mendes 2000; Gomes 2014; Lazarus 1991) was adopted to analyze how university students evaluate their activity and related academic stress, and how they feel in terms of burnout.

Interactive and transactional perspectives of stress not only reinforce the value of stressors on explaining adaptation to work, but also give particular value to cognitive appraisal on the way people respond to work conditions (i.e., how individuals evaluate their activities). Cognitive appraisal includes the dimensions of threat perception (evaluating the work activity as disturbing and negative for personal well-being), challenge perception (evaluating the work activity as stimulating and exciting for personal well-being), coping potential (evaluating the personal resources to cope with the demands of the work activity as sufficient or nor sufficient), and control perception (evaluating the decision making process of work activity as depending of personal control) (Gomes 2014; Lazarus 1991).

Stress and cognitive appraisal may represent important variables to comprehend why some individuals seem more able to deal with stressor conditions at work, than others do. Research demonstrates that high levels of stress at work can diminish individuals' ability to cope with work demands (Niedhammer et al. 2020; Rugulies et al. 2020), but also point out to dimensions of cognitive appraisal as determinants of functional and dysfunctional adaptation to work conditions (Gomes et al. 2013; Kim and Beehr 2020; Paškvan et al. 2016).

Despite the interest of these findings, there is almost no evidence about the possibility of some personal patterns of evaluating the stress and the work activity exacerbate or decrease the risk to negative reactions at work. This is to say, is there a personal tendency of evaluating the sources of stress and the professional activity that can put individuals at more or less risk to dysfunctional reactions at work? In the present research, this question was addressed by analyzing if students that evaluate academic stress differently (i.e., tendency to evaluate their activity as generating lower or higher levels of stress) would respond to their academic activity with different levels of burnout, i.e., with feelings of physical, emotional and cognitive exhaustion) (Shirom and Melamed 2006). In addition, it was also tested whether students that evaluate their academic activity differently (i.e., tendency to considerate student activity more positively or negatively) would respond to their academic activity with different levels of burnout. These questions intend to determine if evaluating the academic activity differently by the students will correspond to distinct reactions to burnout. Put in simple words, is there a more negative or positive pattern of evaluating the academic activity that can influence students' feelings of burnout?

In order to answer to these questions, a longitudinal methodology was adopted to comprehend how stress evaluation and cognitive appraisal corresponded to different levels of burnout across time. The use of longitudinal methodology is more appropriate to capture the psychological fluctuations that occur in human adaptation to stress (Gomes 2014; Lazarus 1991) and that are not captured by the typical use of cross-sectional studies (Podsakoff et al. 2012). Thus, this study started by collecting the indicators of stress and of cognitive appraisal (four to six weeks after the beginning of the academic semester of university students, corresponding to Moment 1 of data collection); then the burnout responses of students (at the middle of the semester, corresponding to Moment 2 of data collection); and finally, the burnout responses of students was collected again (at the end of the semester, corresponding to Moment 3 of data collection).

Figure 1 presents the methodology of data collection. The contribution of stress and cognitive appraisal profiles on burnout was tested these controlling for personal (i.e., gender, age) and academic variables (i.e., course-year and grade-point average) of students because previous research has pointed out their influence on how they evaluate and deal with stress (Hill et al. 2018; Shaw et al. 2017; Mussi et al. 2019).

Considering these aspects, we defined the following goals for the study:

(a) Analyze if different patterns of stress experienced by students (lower versus higher profile) corresponded to different levels of burnout over time.

(b) Analyze if different patterns of cognitive appraisal assumed by students (lower threat and higher challenge, coping potential, and control versus higher threat and lower challenge, coping potential, and control) corresponded to different levels of burnout over time.

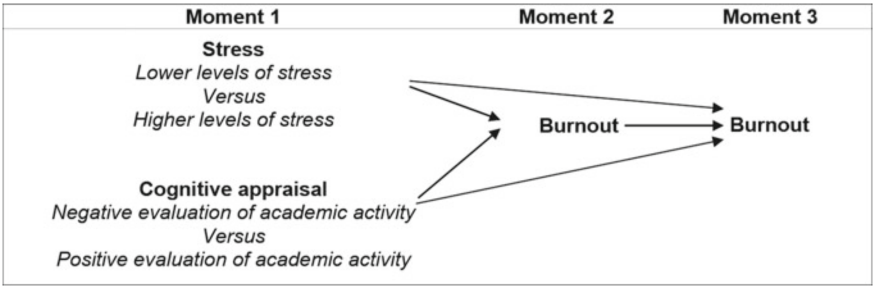

Fig. 1 Methodology of data collection

(c) Analyze if different patterns of stress experienced by students (lower versus higher profile) and different patterns of cognitive appraisal assumed by students (lower threat and higher challenge, coping potential, and control versus higher threat and lower challenge, coping potential, and control) predicted burnout over time.

2 Materials and Methods

2.1 Participants

The population used for this study was the students of a psychology course from a university in the north of Portugal. The final sample consisted of 175 students, with 155 (89%) females, 18 (10%) males, and two (1%) that did not provide information about gender. Students presented a mean age of 21.19 years old (SD = 3.95) ranging from 17 to 42 years. Regarding the year of the course, 40 (23%) students were in the first year, 24 (14%) were in the second year, 36 (21%) were third-year students, 29 (17%) were fourth-year students, and 46 (26%) students were in the last year of the course. The majority of the students (n = 149, 85%) chose psychology as their first option in the university application. Their grade point average was 15.18 (SD = 1.70), ranging from 6.6 to 19.30 (in a scale of 20 values). All participants (N = 175) took part in the three moments of data collection.

2.2 Measures

Stress Questionnaire for Students (SQS; Gomes 2019). It evaluates seven sources of stress in the academic activity of students: (1) academic performance (four items; α for this study = 0.90); (2) academic evaluation (four items; α for this study = 0.76); (3) motivation (four items; α for this study = 0.87); (4) learning (four items; α for this study = 0.89); (5) work overload (four items; α for this study = 0.92); (6)

future expectations (four items; α for this study = 0.82); and (7) financial problems (four items; α for this study = 0.76). Items are answered in a 5-point Likert-type scale (0 = No stress at all; 4 = Very high stress) with higher values indicating higher levels of stress in each dimension. Confirmatory factorial analysis (CFA) revealed good psychometric properties for this instrument [$\chi^2(327) = 696.82$, $p < 0.001$; CMIN/DF = 2.13; RMSEA = 0.074, 90% CI [0.07; 0.08]; CFI = 0.913; TLI = 0.900].

Primary and Secondary Cognitive Appraisal Scale (PSCA, Gomes and Teixeira 2016). Evaluates primary and secondary cognitive appraisal with a total of five scales: (1) importance perception (three items; α for this study = 0.86); (2) threat perception (three items; α for this study = 0.88); (3) challenge perception (three items; α for this study = 0.61); (4) coping perception (three items; α for this study = 0.91); and (5) control perception (three items α for this study = 0.69). Items are answered in a 7-point Likert scale with higher values indicating higher levels of cognitive appraisal in each dimension. Instructions to fulfil the instrument were adapted to academic activity, meaning that participants answered the questions thinking about their student activity. Confirmatory factorial analysis (CFA) revealed good psychometric properties for this instrument [$\chi^2(80) = 146.97$, $p < 0.001$; CMIN/DF = 1.84; RMSEA = 0.063, 90% CI [0.05; 0.08]; CFI = 0.955; TLI = 0.941].

Shirom-Melamed Burnout Scale (SMBS, Shirom and Melamed 2006; Adaptation Simães et al. 2021). Evaluates three dimensions of burnout: (1) physical fatigue (six items; α M1 for this study = 0.93; α M2 for this study = 0.94); (2) cognitive weariness (five items; α M1 for this study = 0.95; α M2 for this study = 0.94); and (3) emotional exhaustion (three items; α M1 for this study = 0.89; α M2 for this study = 0.83). Items are answered in a 7-point Likert scale (1 = Never or almost never; 7 = Always or almost always). Confirmatory factorial analysis (CFA) for M1 revealed good psychometric properties for this instrument [$\chi^2(74) = 133.16$, $p < 0.001$; CMIN/DF = 1.80; RMSEA = 064, 90% CI [0.05; 0.08]; CFI = 0.977; TLI = 0.971] and also for M2 [$\chi^2(70) = 143.04$, $p < 0.001$; CMIN/DF = 2.04; RMSEA = 0.077, 90% CI [0.06; 0.10]; CFI = 0.967; TLI = 0.957].

2.3 Procedure

The study was approved by the Ethics Committee of the first author' university (CEICSH 034/2019), while being in accordance with the National and European regulations on research with humans and personal data protection. After the approval, a meeting was set up with the directors of the course of psychology, clarifying the goals of the study and the proceedings for data collection. Students were invited to participate in the study by accessing an online questionnaire, in an electronic platform (Qualtrics). The link was made available through each student's institutional email. When accessing the electronic platform, students had to sign a voluntary written informed consent, which contained the main goals of the study and the information that guaranteed the confidentiality of the data. Regarding the anonymous character of the data, participants were invited to provide an identification code, not able to reproduce their identities, allowing only the match of the data across the three moments of data collection.

2.4 Data Analysis

The analyses were performed using IBM SPSS Statistics (v. 27) and AMOS (v.27; SPSS Inc. Chicago, IL. USA). First, a data screening was performed by using the PSCA importance perception to select students that attributed a minimum level of importance to the academic activity, as suggested by Gomes and Teixeira (2016). Thus, from the 185 participants that completed the data collection in M1, two were removed from the analysis. Out of the remaining 183, only 175 participants completed the data collection in M2 and M3. Second, regarding the goals of this study, in order to analyze if different patterns of stress experienced by students corresponded to different levels of burnout over time (first goal), and to analyze if different patterns of cognitive appraisal assumed by students corresponded to different levels of burnout over time (second goal) a two-step strategy was used. In the first step, patterns of stress and cognitive appraisal experienced in M1 were explored by using the cluster analysis, with the K-means approach. In the second step, to analyze the main effect of these patterns on burnout, a Mixed ANCOVA (controlling for the effect of students' personal and academic characteristics) was conducted.

To analyze if different patterns of stress and different patterns of cognitive appraisal predicted burnout over time (third goal) a two-step approach was also used. First, the patterns of burnout experienced in M2 and M3 were explored by using cluster analysis, with the K-means approach. Second, a multinomial logistic regression analysis was conducted. An adjusted odds ratio (OR) with a 95% confidence interval (CI) was considered to determine the strength of association between the patterns of burnout and its predictor. As potential confounders, students' personal and academic characteristics, hypothesised to influence the experience of burnout, were considered. Data analyses were accomplished considering a p-value of $<.05$ as statistically detectable.

3 Results

3.1 Constituting the Groups: Patterns of Stress and Cognitive Appraisal

Cluster analysis was conducted to create two groups based on stress. Thus, the K-means approach was found the most suitable considering the sample size. Two

Table 1 Means (Standard Deviations) for the two different stress patterns

Sources of stress	Group: Higher levels of stress	Group: Lower levels of stress
Academic performance	3.22(0.63)	2.38(0.67)
Academic evaluation	3.39(0.57)	2.55(0.78)
Motivation	3.00(0.66)	1.87(0.88)
Learning	3.25(0.66)	2.24(0.82)
Work overload	3.36(0.62)	2.60(0.93)
Future expectations	3.05(0.63)	1.78(0.86)
Financial problems	2.25(1.04)	0.75(0.67)

Table 2 Means (Standard Deviations) for the two different cognitive appraisal patterns

Cognitive appraisal	Positive evaluation of academic activity	Negative evaluation of academic activity
Threat	2.46(0.98)	4.82(0.79)
Challenge	4.45(1.01)	3.69(0.81)
Coping potential	4.26(0.82)	2.98(0.89)
Control	4.57(0.76)	4.11(0.98)

different patterns of stress emerged: higher versus lower levels of stress. Table 1 summarizes each group's characteristics.

The same procedure was executed to create two different clusters. Using the K-means approach, the following patters of cognitive appraisal arose (cf. Table 2). As expected, students who assumed a positive evaluation of their academic activity, perceived lower levels of threat, and higher levels of challenge, coping potential and control than their colleagues who showed a negative profile of cognitive appraisal (negative evaluation of academic activity).

Influence of stress and cognitive appraisal on burnout over time

It was expected that students who showed higher levels of stress and a negative evaluation of academic activity would experience stronger levels of burnout over time. A 2 (Stress: High vs. Low) x 2 (Cognitive appraisal: Positive vs. Negative evaluation) x 2 (Time: Burnout M2 vs. Burnout M3) Mixed ANCOVA was conducted in order to test the three goals of this study. Participants' gender, age, course-year and grade-point average (GPA) were included as covariates. The results showed a main effect of stress, $F(1,167) = 17.17$, $p < 0.001$, $np2 = 0.09$. As expected, students who experienced higher levels of stress also reported higher levels of burnout ($M = 3.82$, $SD = 1.01$) when compared to students who experienced lower levels of stress ($M = 3.17$, $SD = 1.01$). A main effect of cognitive appraisal was also found, $F(1, 167) = 6.17$, $p = 0.014$, $np2 = 0.04$. Students with a positive evaluation of academic activity reported lower levels of burnout ($M = 3.31$, $SD = 1.01$) than students who evaluated their academic activity negatively ($M = 3.76$, $SD = 1.05$). This main effect was qualified by the Cognitive Appraisal x Time interaction, which was found marginally significant, $F(1,167) = 3.05$, $p = 0.083$, np2 = 0.02. Independent-sample t-tests and Paired sample t-tests were conducted to follow-up the interaction. The results showed that students who displayed a positive evaluation of their academic activity presented lower levels of burnout in M2 ($M = 3.27$, $SD = 0.97$) than students who evaluated this experience negatively ($M = 3.92$, $SD = 1.07$), $t(173) = 4.15$, $p < 0.001$. Even though a similar pattern was found for M3, the difference in the levels of burnout reported by students who evaluated their academic experience positively ($M = 3.35$, $SD = 1.05$) or negatively ($M = 3.61$, $SD = 1.02$) was not significant, $t(173) = 1.63$, $p = 0.104$. Interestingly, for students who evaluated their academic activity positively, their levels of burnout did not significantly change between M2 and M3, $t(77) = 0.85$, $p = 0.401$. However, participants who negatively evaluated their academic activity displayed higher levels of burnout on M2 ($M = 3.92$, $SD = 1.07$) than on M3 ($M = 3.61$, $SD = 1.02$), $t(96) = 3.08$, $p = 0.003$. The main effect of time (Burnout M2 vs. Burnout M3) was not significant, meaning that students' levels of burnout did not change over time if Stress and Cognitive Appraisal are taken out of the equation, $F(1,167) = 0.50$, $p = 0.479$. The remaining interactions were also found nonsignificant (all $Fs < 0.66$, $p > 0.418$).

3.2 Patterns of Burnout over Time

Cluster analysis was conducted to create three groups based on the global score of burnout in M2 and M3. Thus, the K-means approach was found the most suitable considering the sample size. Three different patterns of burnout emerged: low versus moderate versus high levels of burnout. Table 3 summarizes each group's characteristics.

Table 3 Means (Standard Deviations) of Physical and Cognitive Fatigue, and Emotional exhaustion on M2 and M3 for Low, Moderate and High levels of burnout groups

	Low levels of burnout	Moderate levels of burnout	High levels of burnout
Burnout M2	n = 52	n = 83	n = 40
Burnout (SMBS) global score	2.41(0.55)	3.69(0.36)	5.08(0.66)
Burnout M3	n = 35	n = 103	n = 37
Burnout (SMBS) global score	2.01(0.49)	3.49(0.42)	4.92(0.49)

3.3 Predictors of Burnout Experience over Time

It was expected that different patterns of stress experienced by students and different patterns of cognitive appraisal assumed by students, predicted different patterns of burnout over time (M2 and M3). A multinomial logistic regression analysis was conducted to estimate the probability of each pattern of burnout on M2 and on M3 (low, moderate and high), regarding the effect of the stress experience (low vs. high) and the cognitive appraisal profile (negative vs. positive), controlling for gender, age, course-year and grade-point average. The coefficients estimates of the two models tested in M2 and M3, for the patterns of moderate and high burnout (regarding the reference class—low burnout) are in Table 4. Regarding Model 1, the odds ratio of experiencing moderate burnout in M2, compared to low burnout, is of 1.74 for each year of the course and of 1.35 for each value of increase in the grade-point average. Nevertheless, the odds ratio of experiencing high burnout in M2, compared to low burnout, is of 1.59 for each year of the course. Regarding goal three, as expected, the odds ratio of an individual with low levels of stress in M1 experience moderate or high burnout in M2, compared to low burnout, is of 0.18 times lower than of an individual with high levels of stress in M1. Additionally, confirming goal three, the odds ratio of an individual with a negative evaluation of the academic activity in M1 experience high burnout in M2, compared to low burnout, is of 6.94 times higher than of an individual with a positive evaluation of the academic activity in M1. Thus, different patterns of stress experience and cognitive appraisal in M1 predicted different patterns of burnout in M2.

Regarding Model 2, individuals exposed to moderate levels of burnout at M2, compared to those exposed at low levels, have an odds ratio of 11.00 times higher of experiencing high levels of burnout at M3 than low burnout. More, individuals exposed to high levels of burnout at M2, compared to those exposed at low levels, have an odds ratio of 9.95 times higher of experiencing moderate burnout at M3 and an odds ratio of 300.24 times higher of experiencing high burnout at M3 than low burnout. Thus, controlling for the effect of burnout in M2, different patterns of stress experience and cognitive appraisal in M1 did not predict different patterns of burnout in M3. However, regarding our third goal, we tested a third and intermediate model, testing only for the effects of stress and cognitive appraisal (in M1)—leaving out the effect of burnout M2. This third model, showed that when the effect of burnout in M2 is not accounted for, the odds ratio of an individual with low stress in M1 experience high burnout in M3, compared to low burnout, is of 0.21 times lower than of an individual with high levels of stress in M1. That is to say, an individual with high stress in M1 has 367% higher probabilities (OR = 4.67) of experiencing high burnout in M3, compared to low burnout, than an individual with low stress in M1.

Table 4 Statistics and coefficients for the multinomial logistic regression

		B	SE	Wald	p	OR	95% CI for Exp(B)
Model 1 (df = 1)							
Moderate versus Low	Gender [0 = male]	−0.21	0.62	0.11	0.742	0.82	[0.24, 2.75]
	Age	−0.02	0.06	0.07	0.786	0.99	[0.88, 1.10]
	Course year	0.55	0.18	9.47	0.002	1.74	[1.22, 2.47]
	Course GPA	0.30	0.15	3.99	0.046	1.35	[1.01, 1.82]
	Stress [0 = low]	−1.69	0.42	16.65	< 0.001	0.18	[0.08, 0.42]
	Evaluation of academic activity [0 = negative]	0.25	0.43	0.35	0.555	1.29	[0.56, 2.98]
High versus Low	Gender [0 = male]	−0.68	0.93	0.53	0.465	0.51	[0.08, 3.15]
	Age	0.04	0.06	0.40	0.527	1.04	[0.93, 1.16]
	Course year	0.47	0.21	4.87	0.027	1.59	[1.05, 2.41]
	Course GPA	0.12	0.17	0.46	0.497	1.12	[0.81, 1.56]
	Stress [0 = low]	−1.72	0.54	10.35	0.001	0.18	[0.06, 0.51]
	Evaluation of academic activity [0 = negative]	1.94	0.59	10.73	0.001	6.94	[2.18, 22.11]
Model 2 (df = 1)							
Moderate versus Low	Gender [0 = male]	1.38	0.82	2.84	0.092	3.99	[0.80, 19.97]
	Age	0.02	0.06	0.08	0.773	0.98	[0.88, 1.10]

(continued)

Table 4 (continued)

		B	SE	Wald	p	OR	95% CI for Exp(B)
	Course year	0.31	0.19	2.51	0.113	1.36	[0.93, 1.99]
	Course GPA	0.23	0.16	2.20	0.138	1.26	[0.93, 1.72]
	Stress [0 = low]	−0.38	0.47	0.65	0.419	0.69	[0.27, 1.71]
	Evaluation of academic activity [0 = negative]	-0.17	0.46	0.14	0.712	0.85	[0.34, 2.07]
	Burnout on M2 [1 = moderate]	0.71	0.47	2.29	0.130	2.04	[0.81, 5.14]
	Burnout on M2 [2 = high]	2.39	1.10	4.33	0.037	9.95	[1.14, 86.68]
High versus Low	Gender [0 = male]	−0.29	1.38	0.04	0.836	0.75	[0.05, 11.13]
	Age	−0.01	0.08	0.01	0.968	1.00	[0.86, 1.16]
	Course year	0.49	0.27	3.36	0.067	1.63	[0.97, 2.73]
	Course GPA	0.12	0.23	0.26	0.608	1.12	[0.72, 1.76]
	Stress [0 = low]	−1.01	0.68	2.25	0.134	0.37	[0.10, 1.37]
	Evaluation of academic activity [0 = negative]	−0.05	0.65	0.01	0.935	0.95	[0.27, 3.38]
	Burnout on M2 [1 = moderate]	2.40	1.13	4.48	0.034	11.00	[1.20, 101.20]
	Burnout on M2 [2 = high]	5.71	1.49	14.73	<.001	300.24	[16.30, 5529.43]

Note: Model 1 $R^2 = 0.27$ (Cox-Snell), 0.30 (Nagelkerke). Model 1 χ^2 (12) = 53.53, $p < 0.001$. Model 2 $R^2 = 0.32$ (Cox-Snell), 0.38 (Nagelkerke). Model 2 χ^2 (16) = 66.89, $p < 0.001$

4 Discussion

Adaptation to occupational stress represents a major topic on social sciences, particularly the ones interested in human factors at work, as is the case of work psychology and sociology, human safety and engineering, and others. This study addresses the question of knowing how stress and cognitive appraisal can put individuals (i.e., university students) at risk of suffering burnout. Research has already demonstrated that these factors are related - mainly the relation between stress and burnout—and that increases of occupational stress can put individuals at more risk for extreme negative reactions of burnout. The present study aligns these suggestions by offering indications of how lower versus higher tendency to feel stress and to positively or negatively evaluating the occupational activity can correspond to the burnout experience. Our goal was not to analyze the relations between stress, cognitive appraisal, and burnout (topic already analyzed in literature) but to analyze the magnitude of trajectories between these variables.

The first goal was to test if different patterns of stress experienced by students (lower versus higher profile) corresponded to different levels of burnout over time. The conclusion is affirmative, being observed that students who experienced higher levels of stress also reported higher levels of burnout, when compared to students who experienced lower levels of stress. Our data confirms research indicating that stress can affect the health and wellbeing of students (Chowdhury et al. 2017; Leppink et al. 2016; Wahed and Hassan 2017), but introduces new insights about how much stress can impact the feelings of burnout which may be pertinent for researchers and practitioners interested in comprehending and intervene on occupational stress.

The second goal was to test if different patterns of cognitive appraisal assumed by students (lower threat and higher challenge, coping potential, and control versus higher threat and lower challenge, coping potential, and control) corresponded to different levels of burnout over time. Indeed, it was observed that students with a positive evaluation of academic activity reported lower levels of burnout than students who evaluated their academic activity negatively. Quite interesting is the fact that these differences seem more evident on M2 of burnout than on M3 of burnout, although in both cases the pattern was the same (i.e., students with a positive evaluation of their academic activity assumed lower levels of burnout than students who evaluated their activity more negatively). Previous research indicates the role of cognitive appraisal on distinct dimensions of human functioning, as is the case of burnout (Gomes et al. 2013); however, this study established a positive and negative pattern of cognitive appraisal and tested the relations with burnout, turning evident that combining primary (threat and challenge perceptions) and secondary (coping perception and control perception) appraisals can, indeed, best capture the relations with adaptation to stress. To the best of our knowledge, this is a novel finding that deserves to be analyzed in future studies.

The third goal was to test if different patterns of stress experienced by students (lower versus higher profile) and different patterns of cognitive appraisal assumed by students (lower threat and higher challenge, coping potential, and control versus higher threat and lower challenge, coping potential, and control) predicted burnout over time. The conclusion is affirmative regarding the predictor value of stress and cognitive appraisal in predicting burnout on M2; however, on the last moment of data collection, the main predictor of burnout on M3 was burnout on M2. Specifically, a pattern of high stress in M1 increases in 443% the probability to experience moderate to high burnout in M2, compared to low burnout. In addition, a pattern of negative evaluation of the academic activity in M1 increases in 594% the probability to experience high burnout in M2, compared to low burnout. Regarding burnout in M3, a pattern of high stress in M1 increases in 367% the probability to experience high burnout in M3. However, when burnout in M2 entered the equation, the effect of stress in M1 was suppressed and the patterns of moderate and high burnout in M2 became the main predictors. In fact, high burnout in M2 increases in 895% the probability of experiencing moderate burnout in M3, and in 29924% the probability of experiencing high burnout in M3. That is, participants exposed to moderate levels of burnout at M2 are over 10 times more likely to experience high levels of burnout at M3, when compared to those who experienced low levels of burnout at M2. Also, participants exposed to high levels of burnout at M2 are over nine times more likely to experience moderate levels of burnout at M3 and over 300 times more likely to experience high levels of burnout at M3, when compared to those who experienced low levels of burnout at M2. Thus, it can be concluded that starting the academic year with moderate and higher levels of burnout can put students at a higher risk of experiencing negative feelings of burnout across time. This finding is more relevant if we consider that research demonstrated that burnout is growing among students (López-Alegría et al. 2020) due to their feelings of pressure to accomplish academic goals and be succeed (Schaufeli et al. 2002). Moreover, there is evidence that stress is a main predictor of burnout (Lin and Huang 2014) and that cognitive appraisal interferes in this relation (Gibbons 2010). The present research extends these findings by providing specific indications of how much stress and cognitive appraisal can impact burnout, alerting also for the chronic nature of burnout feelings.

4.1 Limitations

Although the benefits of collecting data in three different moments to capture the process of human adaptation to burnout, future research may benefit of increasing the number of data collections in order to better detect the evolution of stress, cognitive appraisal, and burnout over time. In addition, it can be interesting to collect these three indicators in all data collections points in order to clarify if burnout in early stages remain the main predictor of burnout in latter stages. In future works, it would also be important to evaluate the accumulation of student activity with another professional activity (i.e., including in the analysis the worker-student variable) and to diverse the sample in order to replicate these findings with different groups of participants (e.g., psychology students from different universities; students from other undergraduate courses; workers sample).

5 Conclusions

Three main conclusions resulted from this study. First, students who have a tendency to experience higher academic stress also have a higher tendency to experience burnout. Second, the same conclusion can be assumed for cognitive appraisal, as students who evaluate their academic activity more negatively have a higher tendency to experience burnout. Third, both stress and cognitive appraisal predict burnout; however, when multiple time points of burnout are analyzed, it can also be concluded that experiencing burnout in a specific data point is the main predictor of experiencing burnout in a later moment, reinforcing the chronic effects of this syndrome on human wellbeing. So, intervention guidelines with students should focus mainly on the reduction of the experience of chronic academic stress reinforcing the need of implementing life skills training program (Gomes et al. 2019) that can help students to cope with academic sources of stress and to be able to evaluate their activity as more challenging. Additionally, it would be important to include the organizational level in the intervention in order to develop positive policies that promote occupational health and safety in the academic context.

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References

Blascovich, J., Mendes, W.B.: Challenge and threat appraisals: the role of affective cues. In: Forgas, J.P. (ed.) Feeling and Thinking: The Role of Affect in Social Cognition, pp. 59–82. Cambridge University Press, Paris (2000)

Böke, B.N., Mills, D.J., Mettler, J., Heath, N.L.: Stress and coping patterns of university students. J. Coll. Student Dev. **60**(1), 85–103 (2019). https://doi.org/10.1353/csd.2019.0005

Britt, S.L., Ammerman, D.A., Barrett, S.F., Jones, S.: Student loans, financial stress, and college student retention. J. Student Financ. Aid **47**(1), 25–37 (2017). http://publications.nasfaa.org/jsfa/vol47/iss1/3

Chowdhury, R., Mukherjee, A., Mitra, K., Naskar, S., Karmakar, P.R., Lahiri, S.K.: Perceived psychological stress among undergraduate medical students: role of academic factors. Indian J. Public Health **61**(1), 55–57 (2017). https://doi.org/10.4103/0019-557X.200253

Frazier, P., Gabriel, A., Merians, A., Lust, K.: Understanding stress as an impediment to academic performance. J. Am. Coll. Health **67**(6), 562–570 (2018). https://doi.org/10.1080/07448481.2018.1499649

Gibbons, C.: Stress, coping and burn-out in nursing students. Int. J. Nurs. Stud. **47**(10), 1299–1309 (2010). https://doi.org/10.1016/j.ijnurstu.2010.02.015

Gomes, A.R.: Positive human functioning in stress situations: an interactive proposal. In: Gomes, A.R., Resende, R., Albuquerque, A. (eds.) Positive Human Functioning from a Multidimensional Perspective: Promoting Stress Adaptation, vol. 1, pp. 165–194. Nova Science, New York, NY (2014)

Gomes, A.R.: Stress Questionnaire for Students (SQS). Unpublished technical report. Escola de Psicologia, Universidade do Minho, Braga (2019)

Gomes, A.R., Faria, S., Gonçalves, A.M.: Cognitive appraisal as a mediator in the relationship between stress and burnout. Work & Stress **27**(4), 351–367 (2013). https://doi.org/10.1080/02678373.2013.840341

Gomes, A.R., Fontes, L., Maciel, T., Simães, C., Resende, R.: Treino de competências de vida: Uma proposta teórica e desafios futuros [Life skills training: a theoretical proposal and challenges for the future]. In: Aroni, A., Fernandes, A., Ferreira, F., Bortolai, L. (eds.) Pensando a Educação na atualidade: Olhares múltiplos, pp. 137–152. Itapetininga, Edições Hipótese (2019)

Gomes, A.R., Teixeira, P.: Stress, cognitive appraisal, and psychological health: Testing instruments for health professionals. Stress and Health **32**, 167–172 (2016). https://doi.org/10.1002/smi.2583

Hill, M.R., Goicoche, S., Merlo, L.J.: In their own words: stressors facing medical students in the millennial generation. Med. Educ. Online **23**(1), 1–10 (2018). https://doi.org/10.1080/10872981.2018.1530558

Hudd, S., Dumlao, J., Erdmann-Sager, D., Murray, D., Phan, E., Soukas, N., Yokozuka, N.: Stress at college: effects on health habits, health status and self-esteem. Coll. Student J. **34**(2), 217–227 (2000)

Kim, M., Beehr, T.A.: Thriving on demand: challenging work results in employee flourishing through appraisals and resources. Int. J. Stress Manage. **27**(2), 111–125 (2020). https://doi.org/10.1037/str0000135

Larson, M., Luthans, F.: Potential added value of psychological capital in predicting work attitudes. J. Leadersh. Organ. Stud. **13**(2), 75–92 (2006). https://doi.org/10.1177/10717919070130020601

Lazarus, R.S.: Emotion and Adaptation. Oxford University Press, New York (1991)

Leppink, E.W., Odlaug, B.L., Lust, K., Christenson, G., Grant, J.E.: The young and the stressed. J. Nerv. Mental Dis. **204**(12), 931–938 (2016). https://doi.org/10.1097/NMD.0000000000000586

Lin, S.-H., Huang, Y.-C.: Life stress and academic burnout. Active Learn. Higher Educ. **15**(1), 77–90 (2014). https://doi.org/10.1177/1469787413514651

López-Alegría, F., Oyanedel, J.C., Rivera-López, G.: Burnout syndrome in Chilean midwifery students. SAGE Open **10**(1) (2020). https://doi.org/10.1177/2158244020902090

Mussi, F.C., da Pires, C.G.S., Carneiro, L.S., Costa, A.L.S., Ribeiro, F.M.S.E.S., Santos, A.F.: Comparison of stress in freshman and senior nursing students. Revista da Escola de Enfermagem **53**(e03431), 1–7 (2019). https://doi.org/10.1590/S1980-220X2017023503431

Niedhammer, I., Milner, A., Geoffroy-Perez, B., Coutrot, T., LaMontagne, A.D., Chastang, J.F.: Psychosocial work exposures of the job strain model and cardiovascular mortality in France: results from the STRESSJEM prospective study. Scand. J. Work Environ. Health **46**(5), 542–551 (2020). https://doi.org/10.5271/sjweh.3902

Paškvan, M., Kubicek, B., Prem, R., & Korunka, C.: Cognitive appraisal of work intensification. Int. J. Stress Manage. **23**, 124–146 (2016). https://doi.org/10.1037/a0039689

Podsakoff, P.M., MacKenzie, S.B., Podsakoff, N.P.: Sources of method bias in social science research and recommendations on how to control it. Annu. Rev. Psychol. **63**, 539–569 (2012). https://doi.org/10.1146/annurev-psych-120710-100452

Rugulies, R., Framke, E., Sørensen, J.K., Svane-Petersen, A.C., Alexanderson, K., Bonde, J.P., Farrants, K., Flachs, E.M., Magnusson Hanson, L.L., Nyberg, S.T., Kivimäki, M., Madsen, I.E.: Persistent and changing job strain and risk of coronary heart disease: a population-based cohort study of 1.6 million employees in Denmark. Scand. J. Work Environ. Health **46**(5), 498–507 (2020). https://doi.org/10.5271/sjweh.3891

Schaufeli, W.B., Martínez, I.M., Pinto, A.M., Salanova, M., Barker, A.B.: Burnout and engagement in university students a cross-national study. J. Cross-Cultural Psychol. **33**(5), 464–481 (2002). https://doi.org/10.1177/0022022102033005003

Shaw, M.P., Peart, D.J., Fairhead, O.J.W.: Perceived stress in university students studying in a further education college. Res. Post-Compuls. Educ. **22**(3), 442–452 (2017). https://doi:10.1080/13596748.2017.1362534

Shirom, A., Melamed, S.: A comparison of the construct validity of two burnout measures in two groups of professionals. Int. J. Stress Manage. **13**(2), 176–200 (2006). https://doi.org/10.1037/1072-5245.13.2.176

Simães, C., Rodrigues, J., Gonçalves, A.M., Faria, S., Gomes, A.R.: Work-family conflicts, cognitive appraisal, and burnout: testing the mediation effect with structural equation modelling. Br. J. Educ. Psychol. (2021). https://doi.org/10.1111/BJEP.12420

Wallace, D.D., Boynton, M.H., Lytle, L.A.: Multilevel analysis exploring the links between stress, depression, and sleep problems among two-year college students. J. Am. Coll. Health **65**(3), 187–196 (2017). https://doi.org/10.1016/j.physbeh.2017.03.040

Wahed, W.Y.A., Hassan, S.K.: Prevalence and associated factors of stress, anxiety and depression among medical Fayoum University students. Alex. J. Med. **53**(1), 77–84 (2017). https://doi.org/10.1016/j.ajme.2016.01.005

WHO, World Health Organization: Raising awareness of stress at work in developing countries. A modern hazard in a traditional working environment. [Consultado em Janeiro de 2011]. Disponível em www.who.int/occupational_health/publications/stress/en/ (2007)

A. Rui Gomes Psychology Research Centre, School of Psychology, University of Minho, Braga, Portugal, PhD (2005).

Clara Simães Health Sciences Research Unit: Nursing (UICISA: E/ESEnfC), School of Nursing, University of Minho, Braga, Portugal, PhD (2012).

Catarina Morais Research Centre for Human Development, Faculty of Education and Psychology, Universidade Católica Portuguesa, Porto, Portugal, PhD (2018).

Adriana Couto Adaptation, Performance, and Human Development Research Group, School of Psychology, University of Minho, Braga, Portugal, Bachelor (2019).

Psychosocial Working Climate in a Portuguese Metallurgical Industry

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Abstract Objective: This study was carried out in a small metallurgical industry to characterize the psychosocial work climate, aiming to verify the extent to which workers are exposed to psychosocial risk factors and establish a theoretical relationship with their safety and health. Background: Psychosocial occupational risks have been gaining prominence and attention within the organizations occupational safety and health activities. One of the important steps in assessing these risks is the determination of the psychosocial climate, based on capturing the employees' shared perceptions regarding their psychosocial working conditions. Method: The data collection instrument used was the COPSOQ II Questionnaire, Middle Version. Results: It was found that there are statistically significant differences between two sectors, the administrative-technical sector has higher levels in quantitative requirements, in labor conflicts, in the work/family conflict, sleep problems and stress levels. While the productive sector has lower levels of influence at work, development possibilities, transparency of the work role played, self-efficacy, the meaning of work, commitment to the workplace, and job satisfaction. Conclusion: It was concluded that the psychosocial work conditions present some factors with a high incidence of exposure in workers, highlighting threats to their health and safety in the work

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context. Application: An action plan was structured with several recommendations, scaled according to a logic of action priorities.

Keywords Psychosocial risks · Metallurgical industry · COPSOQ II

1 Introduction

Metallurgical industries are organizations of great importance in the Portuguese industrial economy and business, which emphasizes the relevance of this study. In addition, previous research has shown that occupational health and safety activities are not very consistent in this sector in general. The risk assessments carried out are mostly focused on the functional analysis of workstations and work equipment, being psychosocial risk factors neglected by most companies, not being identified or assessed by 83% of these entities (AIMMAP 2015).

This article stems from a study conducted in a small metalworking industry with the purpose of characterizing the psychosocial work environment. The aim was to verify the expose to psychosocial risk factors and establish a theoretical relationship with their safety and health. This objective is based on the assumption that workers' perceptions of how management values their health and well-being at work is the basis of the psychosocial safety climate, and is also related to the potential for achieving good results in preventing illnesses, such as depression and burnout, and organizational factors that lead to loss of productivity and lack of motivation among workers (Dollard and Bakker 2010).

Organizations should keep in mind that the cost of occupational health problems is considerably high, and attention needs to be paid to developing a productive, but at the same time psychosocially healthy workplace. Strengthening the psychosocial work climate is seen by workers as a sign of safety and confidence and can assist in managing the detrimental effects of psychosocial risk factors that exist today, which are unavoidable but can be reduced and minimized (Law et al. 2011; Castro and Ramos 2017).

Psychosocial occupational risks have been gaining prominence and attention within the organization's activities of occupational safety and health. These risks are related to the probability of negative effects on the mental, physical, and social health of workers, caused by employment and living conditions, organizational, interpersonal, and social factors related to work that may interact with their mental functioning and well-being (Neto 2015). They refer to the set of conditions related to the work environment, organization and content of tasks, work procedures and methods, articulation between work and personal/family spheres, and relationships between workers and supervisors (Marchant and Garrido, 2012, cited by Neto et al. 2014; Castro and Ramos 2017). When the exposure to bad psychosocial conditions is prolonged in time increases the possibility of workers experiencing psychophysiological tension, which can be a precursor to diseases, anguish, and loss of performance (Marchant and Garrido, 2012, cited by Neto et al. 2014; Castro and Ramos 2017).

One of the important steps in assessing these risks is the psychosocial climate determination, based on capturing the perceptions shared by employees regarding their psychosocial working conditions. This article will focus only on this dimension of the climate study, but it can then be used by the company to develop the rest of the psychosocial risk assessment process.

Safety climate studies usually capture workers' perceptions through questionnaires. We followed the same methodological procedure using the COPSOQ—Copenhagen Psychosocial Questionnaire, which was developed by Kristensen and Borg, with the cooperation of the Danish National Institute for Occupational Health, to analysis psychosocial risks in all types of activity sectors and professions (Kristensen 2001; Silva et al. 2011). Its creation has proven to be very relevant, with massive use at international level. Its dimensions are used in multiple studies, facilitating the comparison between different investigations. This instrument gathers international consensus regarding its validity and easy understanding in the analysis of psychosocial work factors. The questionnaire provides valid ratings of a wide range of psychosocial factors of the work environment (Pejtersen et al. 2010), helping in the determination of the psychosocial climate present in that work context.

The middle version of the COPSOQ was used because it is the most appropriate tool for this application, not being excessively long, but containing a comprehensive identification of psychosocial dimensions. In addition, since this version is the most widely used, it allows for a comparison with the standard Portuguese labor reality (Silva et al. 2011).

Thus, with this approach, we were able to characterize the workers perceived psychosocial working conditions in the metallurgical industry studied. With this research of the psychosocial work climate, we intended to determine the existence of psychosocial dimensions that could be putting workers at risk to their safety and health, to propose an action plan with measures that contribute to reducing or eliminating risk exposures and their consequences.

2 Material and Methods

2.1 Study Population

The company under study is a national industry on metal forming. It was founded at the end of 2015 and had a rapid rise in the market. Its area of operation covers the entire national territory, and it has also started its internationalization process.

This company employs 40 people, divided between the production area and administrative-technical services. The working hours of the factory are from 06:00 to 22:00, from Monday to Friday. The production schedule is divided into two work shifts, from 06:00 to 14:00 and 14:00 to 22:00. The working hours for employees in the administrative support, commercial, quality, planning and logistics areas are from 08:00 to 18:00. The psychosocial indicators were calculated in global terms and segmented manner, to verify the possible influence of the work sector. This division was made due to the fact that these two sectors are associated with different types of work: the production area is more associated with physical work, and the administrative-technical sector is more associated with mental and cognitive effort.

2.2 Data Collection Instrument

Data were collected using the instrument most appropriate to the study objective, taking into account the research questions and objectives formulated. The COPSOQ II Questionnaire—Middle Version (Kristensen 2001) was used to the data collection adapted and validated for the Portuguese population (Silva et al. 2011). This choice assents in the fact that it is an internationally validated instrument and to the history of the organization under study, in which the psychosocial dimension of work had not yet been characterized, so it was urgent to analyze this type of risk factors in a general and comprehensive way. Finally, the size of the organization was also considered when choosing the medium version, since the company has more than 30 employees.

In addition to the COPSOQ questions, some sociodemographic and professional questions were introduced to characterize the employees. The instrument was delivered to all employees of the company, totalizing 40 questionnaires collected (response rate of 100%). The data collection occurred between February and March 2020.

The surveys were delivered personally, and their content was explained, also the reason for their application. The questionnaire was filled in a paper form because the production employees do not have an institutional e-mail address and it could be more complicated to fill it out on a digital platform. The participants were informed to read the questionnaire carefully, so that all existing doubts could be clarified. The answers obtained were anonymous and the confidentiality of the results obtained was ensured throughout the process, in strict compliance with the ethical principles of data protection and personal information.

2.3 Data Analysis

The research data collected through the questionnaires were subjected to a data treatment and analysis process, using the software IBM Statistical Package for the Social Sciences (SPSS), version 25 for Windows, and the data were graphically treated in Microsoft Office Excel.

3 Results

The psychosocial characterization working conditions in this metallurgical industry is based on the workers' perception. The group of forty workers is composed mostly of men (70%), which is a characteristic of the metallurgical activity. The mean age is 32.1 years, with a minimum of 19 years and a maximum of 51 years. Most of the workers have secondary schooling (42.5%) or 3rd cycle basic education (25%). About 53% of the workers are married or in cohabiting situation, and 47% are single or divorced. Most of them don't have children (52.5%).

Most workers have a fixed-term contract (65%), with only 35% having a permanent contract. This scenario is also justified by the fact that the company is recent and most of the workers have been working there for less than three years (70%). About 20% have worked at the company for no more than six months, with 50% having a seniority between 7 and 36 months. The remaining percentage corresponds to those who have been in service for more than three years.

Considering psychosocial working conditions, Fig. 1 presents the classification of exposures to the different psychosocial dimensions under analysis and their health risk. It considers a percentage distribution by tercis, in which the "tripartite division assumes a "traffic light" type interpretation, according to the health impact that exposure to a given dimension represents, namely: green (favorable situation for health), yellow (intermediate situation) and red (risk for health)" (Cunha and Neto 2019:121).

Results show that several dimensions have a favorable perspective and others have an unfavorable perspective. On the positive side, there is a low incidence of

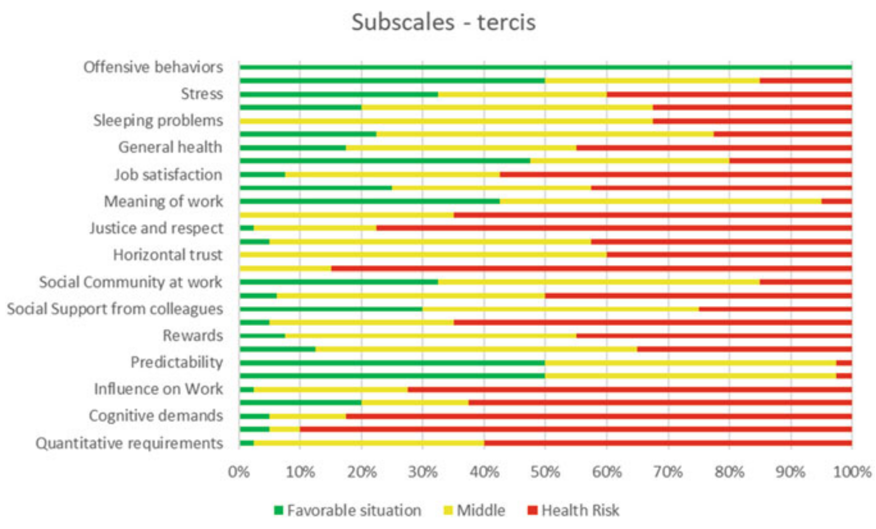

Fig. 1 Classification of exposures to different psychosocial dimensions

phenomena such as offensive behaviors, sleeping problems, depressive symptoms, job insecurity, and general health. On the contrary, there is a high incidence of factors such as work demands, little influence at work, predictability of work, inadequate quality of leadership and support from superiors, work conflicts, and insufficient justice, respect, and satisfaction in the workplace.

Once defined the workers' general psychosocial indicators, we also aim to understand if there were differences between the two work areas in the organization (production and administrative-technical sectors). So non-parametric Mann-Whitney statistical test was used to assess the existence of any statistically significant differences between mean indicators. The data obtained are shown in Table 1.

The analysis of the table shows statistically significant differences between the two sectors for quantitative requirements ($p = 0.007$), influence at work ($p = 0.008$), development possibilities ($p = 0.044$), transparency of the work role played ($p = 0, 005$), work conflicts ($p = 0.011$), self-efficacy ($p = 0.013$), meaning of work ($p < 0.001$), commitment to the workplace ($p < 0.001$), job satisfaction ($p = 0.010$), work-family conflict ($p = 0.011$), sleeping problems ($p = 0.008$), and stress ($p = 0.007$).

Results showed that the administrative-technical sector was found to have higher levels of quantitative demands, role conflicts, work-family conflict, sleeping problems, and stress levels. While the productive sector shows lower levels of influence on work, development possibilities, role clarity, self-efficacy, meaning of work, commitment to the workplace, and job satisfaction. Table 2 shows the mean values of the psychosocial indicators found in this metallurgical industry, as well the reference values for the Portuguese population in general and for the industry sector. The correct interpretation of the mean values of the subscales presupposes that each of them is analyzed individually. There are subscales in which the interpretation can be straightforward, i.e., the higher the score, the more favorable is the health situation, and these dimensions are considered as protective moderating factors. On the contrary, there are other subscales in which the interpretation is indirect, that is, a high score corresponds to an unfavorable health situation, and these dimensions are considered risk factors.

Comparing the results of this study and the results obtained in the 2011 validation study for the Portuguese population in general and the industry in specific (Silva et al. 2011), can be concluded that, in most subscales, the averages obtained in the company under study are more unfavorable for workers' health and well-being. The only dimensions in which this metallurgical industry presents more favorable results are job insecurity and sleeping problems, so it can be concluded that workers feel more secure in keeping their job in the company, which is curious given the high contractual precariousness existing in this company, with a low proportion of workers with stable contracts. In general health, depressive symptoms, and offensive behaviors, the averages obtained are very close.

Table 1 Psychosocial indicators by company sector

Subscales	Production		Sector administrative-technical		
	Mean	SD(1)	Mean	SD(1)	p(2)
1. Quantitative requirements	3.44	0.56	4.11	1.02	0.007
2. Work pace	4.73	0.55	4.25	0.97	0.168
3. Cognitive demands	3.83	0.87	4.36	0.66	0.080
4. Emotional demands	3.41	1.37	4.25	0.75	0.110
5. Influence on Work	1.83	0.55	2.56	0.74	0.008
6. Development possibilities	3.44	1.00	3.94	0.79	0.044
7. Predictability	1.80	0.53	2.08	0.87	0.582
8. Role clarity	2.38	0.69	3.22	0.61	0.005
9. Rewards	2.12	0.55	2.61	0.86	0.136
10. Role conflicts	3.44	0.77	4.17	0.58	0.011
11. Social support from colleagues	2.94	0.80	3.00	0.86	0.790
12. Social support from supervisor	1.70	0.46	1.69	0.61	0.845
13. Social community at work	3.11	0.69	3.33	0.62	0.383
14. Quality of leadership	1.55	0.46	1.83	0.66	0.231
15. Horizontal trust	3.29	0.59	3.11	0.50	0.488
16. Vertical trust	2.14	0.39	2.44	0.70	0.261
17. Justice and respect	1.79	0.45	2.03	0.76	0.606
18. Self-efficacy	3.16	0.42	3.75	0.66	0.013
19. Meaning of work	3.09	0.68	4.06	0.62	<0.001
20. Commitment to the workplace	2.23	0.86	3.83	1.01	<0.001
21. Job satisfaction	2.03	0.57	2.79	0.82	0.010
22. Job insecurity	2.82	1.22	2.08	1.24	0.136
23. General health	3.36	0.85	3.08	0.90	0.327
24. Work-family conflict	2.50	0.76	3.44	0.94	0.011
25. Sleeping problems	1.68	0.78	2.54	0.75	0.008
26. Burnout	3.23	1.11	3.54	0.86	0.657
27. Stress	2.82	1.04	3.96	1.10	0.007
28. Depressive symptoms	2.27	0.95	2.83	0.75	0.080
29. Offensive behaviors	1.33	0.35	1.19	0.19	0.345

(1) SD = Standard deviation (2) Mann-Whitney Test

Table 2 Psychosocial indicators found in the company and in the Portuguese population

Subscales	Current study		Portuguese population-overall (1)		Portuguese population-industry (1)	
	Mean	SD	Mean	SD	Mean	SD
1. Quantitative requirements	3.71	0.80	2.48	0.86	2.51	0.91
2. Work pace	4.53	0.82	3.18	1.00	3.34	0.95
3. Cognitive demands	4.04	0.81	3.79	0.71	3.67	0.74
4. Emotional demands	3.70	1.22	3.42	1.15	3.12	1.18
5. Influence on work	2.06	0.69	2.83	0.89	2.86	1.00
6. Development possibilities	3.58	0.90	3.85	0.81	3.77	0.83
7. Predictability	1.91	0.65	3.23	0.92	3.41	0.96
8. Role clarity	2.71	0.78	4.19	0.72	4.30	0.71
9. Rewards	2.34	0.75	3.71	0.87	3.79	0.87
10. Role conflicts	3.69	0.82	2.94	0.69	2.82	0.70
11. Social support from colleagues	2.96	0.83	3.44	0.77	3.41	0.79
12. Social support from supervisor	1.77	0.57	3.13	0.97	3.26	0.96
13. Social community at work	3.16	0.73	3.97	0.81	4.02	0.82
14. Quality of leadership	1.73	0.62	3.49	0.93	3.57	0.88
15. Horizontal trust	3.28	0.55	2.79	0.64	2.84	0.67
16. Vertical trust	2.23	0.55	3.60	0.60	3.61	0.64
17. Justice and respect	1.84	0.56	3.37	0.81	3.41	0.84
18. Self-efficacy	3.39	0.60	3.90	0.67	3.88	0.71
19. Meaning of work	3.41	0.81	4.03	0.72	4.07	0.77
20. Commitment to the workplace	2.86	1.17	3.40	0.90	3.57	0.92
21. Job satisfaction	2.34	0.76	3.37	0.75	3.58	0.75
22. Job insecurity	2.45	1.24	3.13	1.47	3.57	1.35
23. General health	3.35	0.86	3.44	0.91	3.44	0.97
24. Work-family conflict	2.79	0.95	2.67	1.05	2.44	1.02
25. Sleeping problems	1.85	0.86	2.46	1.05	2.47	1.09
26. Burnout	3.16	1.13	2.70	0.97	2.68	0.99
27. Stress	3.16	1.24	2.70	0.90	2.67	0.91
28. Depressive symptoms	2.41	0.97	2.35	0.91	2.27	0.93
29. Offensive behaviors	1.24	0.29	1.23	0.48	1.19	0.45

(1) *Source* Silva et al. (2011)

4 Discussion and Conclusions

The results allowed us to conclude that the psychosocial working conditions in this metallurgical industry have some adverse aspects, with factors having high incidence of exposure in the workers studied, highlighting threats to their health and safety at work. The data also reveal psychosocial working conditions less favorable than the national standard obtained by applying the same methodology. These data deserve a depth reflection by the company and the planning of an intervention capable of responding to the problems identified.

The diagnosis made created an important knowledge base, as well an opportunity to continue the path that was started with the integration of these elements in the daily management of work teams and health and safety at work activities. An action plan was structured with several recommendations, staggered according to a logic of priorities for action. In this article, the main aspects are highlighted.

The high work demands, particularly in terms of a fast pace of work and physical, mental and emotional stress, can lead to symptoms such as stress and burnout, being the basis of several work-related diseases (Moncada et al. 2002; Gil-Monte 2012; Cunha and Neto 2019). Therefore, the time available to perform the tasks should be adapted to the level of better planning, seeking to ensure that the work teams have the amount of people and time necessary to ensure the completion of all the required service. On the other hand, increasing the influence at work also deserves attention, in order to allow workers a higher level of decision-making and planning autonomy. The level of influence at work was another problem diagnosed, and it is important to seek the involvement of workers in their work decisions (Havermans et al. 2017; Neto et al. 2017). A combination of three negative factors, high demands, low influence, and low social support became clear. Therefore, it is crucial that the intervention seeks to enhance the worker's autonomy regarding work content and organization, amount and pace of work, type and order of tasks, methods to be used, and participation in decision-making. It is important that be given flexibility to workers, so that there is a work plan that can be organized with their collaboration and then managed by them (Neto et al. 2017).

The combination of high demands, little control and low social support at work has a significant risk potential for workers' health (Leka and Jain 2010; Gil-Monte 2012). The promotion of a good work environment, which is highly related to social support and leadership quality, is complemented by vertical trust between workers and their superiors, and fairness and respect. It is very important that there is cooperation between all parties, and it is the basis for trust and psychosocial well-being (Schuller 2019).

Most workers consider that there is no supportive and trusting relationship with their supervisors. Intervention in this area should involve a direct demonstration of trust and dialogue between supervisors and subordinates, focusing on the clarity of the information transmitted and interactions transparency. These are crucial aspects for there to be trust, fairness, and respect in relationships, in conflict resolution, in dealing with suggestions, and in work distribution. All these dimensions' condition job satisfaction and commitment (Cunha and Neto 2019; Vivian and Neto 2020).

In view of these findings, it becomes essential that the organization seeks to continue this project. The data obtained should be used and complemented with others so that a process of analysis and assessment of psychosocial risks at work can be advanced. The study carried out is a relevant basis for this process, which is why this is one of the priority proposals established. It was also proposed that a worker's consultation be carried out in order to collect suggestions to improve the organization and activities planning, as well the introduction of a monthly meeting to facilitate communication between services and teams. In the same line, it was considered a priority to promote information and training actions about psychosocial risks in the company, involving all hierarchical levels, to develop knowledge and a culture of prevention.

Although it has not been possible to explain here all the particularities and richness of the study carried out, it is believed that its importance and usefulness for this metallurgical industry has been highlighted. The characterization conducted allowed us to introduce the subject in the company and to make clear the need to evaluate and control psychosocial risks at work. It is hoped that the basis created is solid enough to implement the proposals made, in particular the psychosocial risk assessment process, because they would allow the company to comply with a legal requirement, but also to favor a longitudinal monitoring of the workers and the psychosocial indicators assessed, in order to register the potential improvements arising from the implementation of the proposed measures.

References

AIMMAP: Associação dos Industriais Metalúrgicos, Metalomecânicos e afins. Metalurgia e Metalomecânica: Manual de Prevenção. Available at https://www.act.gov.pt/(pt-PT)/Publicacoes/ProjetosApoiados/2013/Documents/Manual%20metalurgia%20e%20metalomec%C3%A2nica.pdf (2015)

Castro, I., Ramos, D.: Understanding the management of occupational health and safety risks through the consultation of workers. In: Arezes et al. (eds.) Occupational Safety and Hygiene V, pp. 17–21. Taylor & Francis Group, London (2017). ISBN 978-1-138-05761-6. https://doi.org/10.1201/9781315164809-5

Cunha, S., Neto, H.V.: Condições psicossociais de trabalho em profissionais de saúde de uma Unidade de Cuidados Continuados. CESQUA - Cadernos de Engenharia de Segurança. Qualidade e Ambiente. No. 2, 110–131 (2019)

Dollard, M.F., Bakker, A.B.: Psychosocial safety climate as a precursor to conducive work environments, psychological health problems, and employee engagement. J. Occup. Organ. Psychol. **83**(3), 579–599 (2010). https://doi.org/10.1348/096317909X470690

Gil-Monte, P.R.: Riesgos psicosociales en el trabajo y salud ocupacional. Rev. Peru. Med. Exp. Y Salud Publica **29**(2), 237–241 (2012)

Havermans, B.M., Boot, C., Houtman, I., Brouwers, E., Anema, J., van der Beek, A.: The role of autonomy and social support in the relation between psychosocial safety climate and stress in health care workers. BMC Public Health **17**(1), 558 (2017). https://doi.org/10.1186/s12889-017-4484-4

Kristensen, T.: A new tool for assessing psychosocial factors at work: the copenhagen psychosocial questionnaire. National Institute of Occupational Health, 19. Disponível em. https://www.researchgate.net/publication/304022303%0AA (2001)
Law, R., Dollard, M.F., Tuckey, M.R., Dormann, C.: Psychosocial safety climate as a lead indicator of workplace bullying and harassment, job resources, psychological health and employee engagement. Accid. Anal. Prev. **43**(5), 1782–1793 (2011). https://doi.org/10.1016/j.aap.2011.04.010
Leka, S., Jain, A.: Health impact of psychosocial hazards at work: an overview. World Health Organization. Available in https://apps.who.int/iris/bitstream/handle/10665/44428/9789241500272_eng.pdf;jses (2010)
Moncada, S., Llorens, C., Kristensen, T.S.: Manual para la evaluación de riesgos psicosociales en el trabajo. Disponível em. https://wilfredosanguineti.files.wordpress.com/2010/01/metodo-istas21-para-la-evaluacion-de-riesgos-psicosociales.pdf (2002)
Neto, H.V.: Estratégias Organizacionais de gestão e intervenção sobre riscos psicossociais do trabalho. Int. J. Work. Cond. **9**, 1–21 (2015). https://doi.org/10.25762/zxhk-x250
Neto, H.V., Areosa, J., Arezes, P. (eds.): Manual sobre riscos psicossociais no trabalho. Civeri Publishing, Porto (2014)
Neto, H.V., Areosa, J., Arezes, P. (eds.): Liderança e Participação em Segurança e Saúde no Trabalho. Civeri Publishing, Porto (2017)
Pejtersen, J.H., Kristensen, T.S., Borg, V., Bjorner, J.B.: The second version of the copenhagen psychosocial questionnaire. Scand. J. Public Health **38**(SUPPL. 3), 8–24 (2010). https://doi.org/10.1177/1403494809349858
Schuller, K.: Interventions as the centrepiece of psychosocial risk assessment - why so difficult? Int. J. Work. Health Manag. **13**(1), 61–80 (2019). https://doi.org/10.1108/IJWHM-07-2018-0098
Silva, C., Amaral, V., Pereira, A., Bem-haja, P., Pereira, A., Rodrigues, V., Nossa, P.: Copenhagen psychosocial questionnaire II: Portugal e Países Africanos de Língua Oficial Portuguesa (2011). https://doi.org/10.1177/1403494809353652
Vivian, J.C., Neto, H.V.: A relação entre condições psicossociais de trabalho e rotatividade voluntária de trabalhadores nas organizações. Int. J. Work. Cond. (20), 51–70 (2020). https://doi.org/10.25762/0aa7-cq43

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Safety Climate Perception Among Students: A Literature Review

Vinicius Cozadi de Souza and Rui B. Melo

Abstract The understanding of the risk to which a professional is subject to begins at graduation, from the moment that there is contact with risk environments. The main goal of this paper was analyzing studies carried out on safety climate among students, with particular emphasis on the factors that contribute to the development of a positive safety culture, since there is a lack of studies in the area, especially those involving university students. The research and analysis of the scientific literature was carried out from January to April 2021, referring to the main world databases and using inclusion and exclusion criteria for the selection of the main articles. Some factors are critical for the risk assessment of students in the educational context. As observed, there are factors that positively influence safety among university students, as well as factors that make the environment more prone to the occurrence of damages and accidents. It was also observed that the environment with the greatest risk potential for students were the academic laboratories. Gender, age and course length have a relative influence on the perception of risks, but it seems that safety education has a much relevant role developing safety culture.

Keywords Safety culture · Organizational climate · Safety perception · Education

1 Introduction

Over the past 30 years, accidents and safety have been studied from many points of view, from engineering to social psychology, to contribute to the reduction of occupational accidents. A milestone within the safety climate is Zohar's research, who

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contextualized the theme after a literature review and presented the first safety climate assessment tool. Zohar (1980) aimed at describing a particular type of organizational climate and at examining its implications. The climate was seen as a summary of the perceptions of actions that employees shared about their work environments. These coherent sets of organizational perceptions, when shared and summarized for industrial employees, are defined as an organizational climate.

The understanding of the risk to which a professional is subject to starts at graduation, from the moment that contact with risk environments occurs (Neto et al. 2018).

The theme has been gaining relevance among researchers from all over the world, to reduce occupational accidents and develop preventive measures, including in Brazil. Most of the risks to which students are exposed to are due to exposure to biological, chemical, physical, psychosocial, and mechanical agents (Rigo and Fontana 2018). These agents exist mainly in laboratories, in clinical practices, internships and practical classes.

It is natural, then, that the environment where graduation occurs, and the perception of the safety climate influence behavior and are an important source of research.

Literature is quite limited for this type of analysis in the educational sector. This may be due to the low rate of occupational accidents in the sector, although those that occur may have important implications that go beyond direct economic costs (Suárez-Cebador et al. 2015).

Safety culture and safety climate are closely related, and in some studies, they were used as a single concept, but there is no consensus among researchers on a single definition (Kalteh et al. 2019).

Safety climate is defined as shared perceptions about organizational values, norms, beliefs, practices, and procedures in the field of safety from the worker's point of view, which can be observed at general or specific levels, and provides a temporal measure of the team's perceptions of the observable aspects of the safety culture (Silva et al. 2004). From this concept, we can understand that the safety climate is generally considered as a superficial level of safety culture (Steward et al. 2016). For these authors, the safety climate is a temporary state, as it portrays a moment of the safety culture that is relatively unstable and easily subject to interference when there are objective changes in the environment.

It can be inferred that preventive education has the potential to promote safety culture, for workers, customers and users, and the development of strategies that promote it and add value to life (Rigo and Fontana 2018).

Safety climate and safety culture arouse questions still not accurately answered. Therefore, the main objective of this paper was to analyze studies carried out on safety climate among students, with particular emphasis on the factors that contribute to the development of a positive safety culture, since there is a lack of studies in the area, especially those involving university students.

2 Materials and Methods

The research and review of the scientific literature was carried out from January to April 2021, and relied on the following databases: SciELO, VHL, PubMed, ScienceDirect, MedLine and Capes. We sought articles from scientific journals primarily in English and Portuguese, especially since 2000, although some previously published were also included.

Two research questions supported this review:

Q1. Is safety among high school and university students a major concern for researchers?

Q2. Which factors influence safety climate among those students?

The keywords used were accidents at work, safety climate, safety culture, students, exposure to biological agents, educational institution, laboratory instruction, hazards, safe practices, accident risk, occupational risks, laboratory safety, safety training, university, and safety values. They were grouped with the Boolean additive operator.

The inclusion criteria for scientific articles were:

a. research whose object of study was the educational sector,
b. studies that included measurements or prevalence of safety climate, safety culture and safety risks in educational institutions,
c. investigations involving evaluation of preventive measures or identification of good safety practices.

On the other hand, the exclusion criteria were:

a. studies that do not involve university or high school students,
b. papers that do not include any of the following keywords in the abstract: safety culture, safety climate, risky behavior, or organizational climate
c. lack of full-text availability.

The analysis of the articles was made by themes and later by confronting them.

3 Results and Discussion

From the search, 113 articles were found, from which 26 were selected after applying the inclusion and exclusion criteria and eliminating the repeated ones.

According to the analyzed references, some factors are critical for students' risk assessment in the educational context. We have noticed that there are factors that positively influence safety, as well as factors that make the environment more prone to the occurrence of damages and accidents. We have grouped them into two categories: individual and organizational.

It was observed that the context with the greatest risk potential for students were the academic laboratories, with special emphasis for the chemical ones, where hazardous products are used. The research on the perception of risks in chemical laboratories identified three most common risk factors: handling hot materials and sharp objects, splashes of chemical substances and inhaling chemical substances. The latter was classified as the highest perceived risk factor (Chumbley et al. 2019).

Despite the risks pointed out in the previous research, Ayi and Hon (2018), when analyzing the responses obtained in their studies, concluded that students believed that the risk associated with laboratory activities was low or very low. Many participants, from both studies, did not formally assess the risk before starting the activity in the lab. These findings suggest that safety may not be a high priority within Canadian university labs.

Although more studies are necessary to better explore laboratory environments and the risks students face, this article only analyzed research dealing with students' perception of safety climate. The relationship between safety climate and safety attitudes should be explored to assess its potential contribution to preventing accidents in academic laboratories.

3.1 Individual Factors that Affect Student's Safety

According to Faller et al. (2010), few accidents occur in the classroom and at the university level. From 2855 students analyzed in their research, 252 experienced accidents in the educational context.

3.1.1 Gender Impact on Safety

When considering the number of accidents with bone fractures, it was observed that 2/3 happen to women (Suárez-Cebador et al. 2015). It is worth considering that this rate may be due to biological factors such as osteoporosis. These data agree with the findings of Bentley and Haslam (2005).

Walters et al. (2017), in a study on students' awareness, attitudes and safety practices in chemical laboratories of higher education, observed that females were more likely to use safe practices compared to males. Corroborating these results, Crowe (1995) statistically found that female participants are more concerned with safety than men. Young women are more likely to adopt safer behavior than young males (Blair et al. 2004).

In a multicenter study with students of natural sciences and social sciences from different universities, carried out in Germany, the gender influence in the number of accidents proved to be insignificant. The risk of suffering an accident was similar for female and male students, which can be justified by the fact that the requirements for the course are the same for both genders (Faller et al. 2010).

Based on the previous studies (Bentley and Haslam 2005; Crowe 1995, Faller et al. 2010; Suárez-Cebador et al. 2015; Walters et al. 2017), women are more prone to falls and fractures, probably due to intrinsic biological factors, however, they are more cautious and then can prevent further accidents. However, male students appear to be more prone to less safe behavior.

Women showed greater confidence in their abilities than men. They are used to working in groups, while men usually work alone. Working in groups can help identify an individual's strengths and weaknesses, exhibiting great productivity (Tumala et al. 2019).

In equal circumstances, as in sports-related colleges, where the requirements are the same for all students, the gender factor is not representative in relation to safety issues (Sumilo and Stewart-Brown 2006).

3.1.2 Influence of Age on Safety Decision-Making

In a study involving sports students in the United Kingdom, by Sumilo and Stewart-Brown (2006), it was found that younger students had significantly higher risk of serious injuries.

In university chemistry laboratories, age was negatively associated with the general risk perceived by students. However, a significantly positive effect of age on safe behavior was found (Álvarez-Chávez et al. 2019).

In the study by Gong (2019), it was concluded that students in their final year of graduation tend to be more aware of the safety values than students in the first years, which may be due to age and to the safety knowledge acquisition throughout the course.

It was surprising to find that younger students were more sensitive to perceiving the commitment of educational institutions to safety than older students. For example, people under the age of 21 perceived the regular commitment to safety and the compliance of the higher educational institutions with safety more than older students (Salazar-Escoboza et al. 2020).

It seems that the age of the student is not significant for the perception of risk, but there are divergences in the studies. Factors such as practices, job training, risk knowledge, among others, can be more relevant than age.

3.1.3 Personal Motivation and Self-efficacy for Safe Behavior

When analyzing data from the study by Chumbley et al. (2019), a strong association was observed between personal motivation and safe behavior in agricultural students at university level. It is believed that fear is the main motivator of risk perception. As reported, the students realized that they were less well informed than the laboratory staff, responsible for implementing preventive and corrective actions to minimize the risk factors present in their laboratory. Overall, these results showed that students could feel more confident to successfully deal with the assessed risk factors, despite their vulnerability and the possibility of suffering serious harm. The perceived ability to control and avoid risks may reflect students' self-efficacy.

Self-efficacy refers to a person's belief that he is capable of successfully accomplishing a certain task (Álvarez-Chávez et al. 2019).

In their study, Keiser and Payne (2018) found that women showed greater agreement regarding the personal motivation construct for safe behavior.

3.2 Hazard Recognition and Risk Perception

The study of safety climate, which helps people to understand risks and make decisions, is one of the key issues of perception: people do not tend to over rate spectacular and rare risks and minimize common risks. Unknown risks, in a safety climate, are overlapped by known risks: people underestimate risks in controlled situations and overestimate them in situations they cannot control (Luo 2020).

There is a relationship between the professional's perception of risk (individual, environmental and organizational) and their attitudes at work. However, the subject is complex and there is no clear proof, probably due to the few studies developed to date (Antunes et al. 2010; Luo 2020; Moreno-Arroyo et al. 2016).

Risk perception was suggested as a key component of behavior change theories because it can contribute to identifying barriers to the adoption of desired behaviors (Álvarez-Chávez et al. 2019).

3.2.1 Safe Individual Behavior

Safe individual behavior is perceived through safety awareness, safety perception and safety participation. Cognition has a significant influence on safety climate. To be safe, people become aware of a strong safety climate and act against unsafe behavior. A good safety climate can promote individual safety behavior, thereby reducing accidents and injuries (Luo 2020). At the personal level, the safety climate includes safety attitudes, safety awareness, risk cognition and psychological perception (Luo 2020).

3.3 Organizational Factors

3.3.1 Teaching Safety at Undergraduate Level

Continuous teaching of safety throughout the graduation course can build attitudes and promote a safety culture among students. According to Perrin et al. (2018), education is a mission and a difficult challenge, which implies important commitments, therefore, decision makers at the university must find an adequate way to integrate safety contents in the curricular system of the courses. For Benintendi (2016), the concepts of safety process should be provided and integrated, as much as possible, within the basic disciplines in chemical engineering courses.

3.4 Influence of Course Length on Safety Culture

Several studies have shown that the length of the graduation course has no significant influence on safety beliefs among university students as they progress throughout the course (Blair et al. 2004; Hasan and Younos 2020). In fact, the study by Gong (2019) shows that students from different school years did not reveal different safety culture levels. The statistical analysis revealed that differences among school years are not significant.

University graduates confirmed the trend towards the development of a safety culture among bachelors in the field of environmental protection, environmentalists and safety engineers of technological processes and productions, whose bases were formed during the period of studies at the university (Kuznetsova et al. 2018).

As stated above, the development of safe behavior among university students depends, among other factors, on the institution's commitment, on safety practice in the curricular organization, either as mandatory modules or as a content of different modules throughout the course.

3.4.1 Safety Training and Supervision

In a study done in Saudi Arabia, Moreno-Arroyo et al. (2016) evaluated the perceptions of nursing students about the infection prevention climate at the training hospital, concluding that they must be well informed and competent and apply their knowledge and skills in practice. Universities and training hospitals need to educate for prevention and focus on infection control education.

Safety training can improve safety behavior and there is an interaction between safety behavior and safety climate. The perception of employees who received safety training was stronger than the perception of those who did not. This may be related to behavioral changes. Workplace-based training should be followed with reinforcement of safe behavior among all employees (Wu et al. 2007).

The recommendation of some authors is that training on patient safety should have a dual approach, with a formal side in the faculties, applied and reinforced during the practice in the care unit (Kuznetsova et al. 2018).

According to Gong (2019), undergraduate students generally behave safely in the presence of safety supervision, which along with intensive training can influence maintaining a good safety culture.

When laboratory users perceive that there has been an increase in compliance with safety standards, as well as adequate training provided by the institution's professors and researchers in relation to safety, the feeling of risk decreases, that is, safety learning happens by example and the requirements (Salazar-Escoboza et al. 2020).

In this study, students reported a sense of safety in the laboratories because they were aware that there were responsible people around them, and they received training. Accordingly, Gong (2019) also found that undergraduate students generally behave safely in the presence of safety supervision.

Promoting safety education in university life can create positive behaviors towards the development of a safety culture (Hasan and Younos 2020).

It can be concluded that training and attitudes of the team in relation to safety, within institutions, are important steps towards safety education.

3.4.2 Involvement in Safety Management

A manager must comply with law-related safety practices and formulate safety rules for operational behavior, so that students know that management has implemented relevant safety rules. When students perceive a higher level of safety, they are more willing to get involved in the safety management activity. Strong safety management practices can promote a safety climate and vice versa and are related to low accident rates (Luo 2020).

Investigations of the main incidents that occurred in the university's chemistry labs emphasize the need to improve management's commitment to safety through the implementation of internal safety policies and procedures, providing education in chemical safety (Álvarez-Chávez et al. 2019).

Managers can analyze the safety climate, observing employee attitudes, safety supervision, safety production environment, safety training and education and safe individual behavior, through safety awareness, the safety perception of the environment and, mainly, the participation of students (Luo 2020).

A survey of Chinese university students (Gong 2019) found that when managers, teachers, researchers, and workers in educational institutions are committed to safety and act accordingly, students perceive these attitudes and follow their exam-

Table 1 Factors that positively influence student safety

Factor	Effect
Gender	Women are more cautious
Motivation	Fear is the main motivator
Training and supervision	Students feel safer
Good risk perception	Key component of desirable behavior-change theories
Safe individual behavior	People aware of a strong safety climate act against unsafe behavior
Involvement in safety management	Involvement in management improves the safety climate

Table 2 Non-significant factors

Factor	Effect
Course length	Depends on other variables
Age	Depends on other variables

ple. Accordingly, Perrin et al. (2018) state that the involvement of all people in the work environment is a requirement for meaningful management in the safety climate.

Tables 1 and 2 summarize the factors that were found to have a positive influence and those which were not significant for the safety climate among students, respectively.

4 Conclusions

It is concluded, at the end of this review, that the factors that negatively affect safety culture among university students do not seem to be as important as the integration of safety education. Gender, age, and duration of the course have a relative influence on the perception of risks, but everything indicates that safety education has a much more relevant role developing safety culture.

The cross-sectional and non-longitudinal studies analyzed in this review have several limitations as to the factors that interfere in safety climate and safety culture, among them, the intense controversy and even divergence among the authors, the use of very different evaluation measures, the use of interviews not always validated and social and historical aspects of different cultures that influence responses, according to the context of the society in which they are carried out. However, it represents an important step in the study of safety education in university students and demonstrates the need for more research.

Therefore, future studies should address more schools, more universities and particularly courses where the lack of safety culture among students can limit the perception of risks and put lives at risk: not only students' lives but also those of employees, teachers and, in the future, even patients' lives.

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References

Álvarez-Chávez, C.R., Marín, L.S., Perez-Gamez, K., Portell, M., Velazquez, L., Munoz-Osuna, F.: Assessing college students risk perceptions of hazards in chemistry laboratories. J. Chem. Educ. **96**, 2120–2131 (2019). https://doi.org/10.1021/acs.jchemed.8b00891

Antunes, H. M., Cardoso, L.O., Antunes, R. P. G., Gonçalves, S. P., Oliveira, H.: Biossegurança e ensino de medicina na Universidade Federal de Juiz de Fora, (MG). Revista Brasileira de Educaç tildeao Médica, **34**(3), 335–345 (2010). https://doi.org/10.1590/s0100-55022010000300002
Ayi, H. R., Hon, C. Y.: Safety culture and safety compliance in academic laboratories: A Canadian perspective. Journal of Chemical Health and Safety, **25**(6), 6–12 (2018). https://doi.org/10.1016/j.jchas.2018.05.002
Benintendi, R.: The bridge link between university and industry: a key factor for achieving high performance in process safety. Educ. Chem. Eng. 1–10 (2016). https://doi.org/10.1016/j.ece.2016.02.002
Bentley, T., Haslam, R.: Epidemiological approaches to investigating causes of occupational falls (2005). https://dspace.lboro.ac.uk/. https://core.ac.uk/download/pdf/288381483.pdfd
Blair, E.H., Seo, D.C., Torabi, M.R., Kaldahl, M.A.: Safety beliefs and safe behavior among midwestern college students. J. Safety Res. **35**(2), 131–140 (2004). https://doi.org/10.1016/j.jsr.2003.11.003
Chumbley, S., Hainline, M., Wells, T.: Examining university-level agricultural students safety climate attitudes in the agricultural mechanics laboratory. J. Agric. Educ. **60**(2), 54–68 (2019). https://doi.org/10.5032/jae.2019.02054
Crowe, J.W.: Safety values and safe practices among college students. J. Safety Res. **26**(3), 187–195 (1995). https://doi.org/10.1016/0022-4375(95)00010-N
Faller, G., Mikolajczyk, R.T., Akmatov, M.K., Meier, S., Krämer, A.: Accidents in the context of study among university students-A multicentre cross-sectional study in North Rhine-Westphalia, Germany. Accid. Anal. Prev. **42**(2), 487–491 (2010). https://doi.org/10.1016/j.aap.2009.09.012
Gong, Y.: Safety culture among Chinese undergraduates: a survey at a university. Saf. Sci. **111**, 17–21 (2019). https://doi.org/10.1016/j.ssci.2018.09.010
Hasan, M.K., Younos, T.B.: Safety culture among Bangladeshi university students: a cross-sectional survey. Saf. Sci. **131**, 1–10 (2020). https://doi.org/10.1016/j.ssci.2020.104922
Kalteh, H.O., Mortazavi, S.B., Mohammadi, E., Salesi, M.: The relationship between safety culture and safety climate and safety performance: a systematic review. Int. J. Occup. Safety Ergon. 1–12 (2019)
Keiser, N.L., Payne, S.C.: Safety climate measurement: an empirical test of context-specific vs. general assessments. J. Bus. Psychol. **33**, 479–494 (2018). https://doi.org/10.1007/s10869-017-9504-y
Kuznetsova, N.V., Soloviev, A.A., Botasheva, L.K., Lebedev, I.A., Sarkisyan, K.S., Kurdyumov, V.I., Chistyakov, K.A., Prokopyev, A.I.: Bachelors safety culture formation in the field of environmental protection. EurAsian J. BioSci. **12**(2), 157–166 (2018)
Luo, T.: Safety climate: current status of the research and future prospects. J. Safety Sci. Resil. **1**(2), 106–119 (2020). https://doi.org/10.1016/j.jnlssr.2020.09.001
Moreno-Arroyo, M.C., Puig-Llobet, M., Falco-Pegueroles, A., Lluch-Canut, M.T., García, I.C., Roldán-Merino, J.: Qual a percepção do risco biológico tem os estudantes da licenciatura em enfermagem? Rev. Lat. Amer. Enfermagem **24**, 1–9 (2016). https://doi.org/10.1590/1518-8345.0722.2715
Neto, J.A.C., Lima, M.G., Santos, J.L.C.T. Dos, Costa, L.A., Estevanin, G.M., Freire, M.R., Ferreira., R.E.: Conhecimento e Adesão às Práticas de Biossegurança entre Estudantes da Área da Saúde. Brazilian J. Surg. Clin. Res. **21**(2), 82–87 (2018)
Perrin, L., Gabas, N., Corriou, J.P., Laurent, A.: Promoting safety teaching: an essential requirement for the chemical engineering education in the French universities. J. Loss Prev. Process Ind. **54**, 190–195 (2018). https://doi.org/10.1016/j.jlp.2018.03.017
Rigo, A.H.B., Fontana, R.T.: Education for biosafety in clinical analysis laboratories. Trabalho & Educação **27**(1), 179–193 (2018)
Salazar-Escoboza, M.A., Laborin-Alvarez, J.F., Alvarez-Chavez, C.R., Noriega-Orozco, L., Borbon-Morales, C.: Safety climate perceived by users of academic laboratories in higher education institutes. Saf. Sci. **121**, 93–99 (2020). https://doi.org/10.1016/j.ssci.2019.09.003

Silva, S., Lima, M.L., Baptista, C.: OSCI: An organisational and safety climate inventory. Saf. Sci. **42**(3), 205–220 (2004). https://doi.org/10.1016/S0925-7535(03)00043-2

Steward, J.E., Wilson, V.L., Wang, W.H.: Evaluation of safety climate at a major public university. J. Chem. Health Saf. **23**(4), 4–12 (2016). https://doi.org/10.1016/j.jchas.2015.10.016

Suárez-Cebador, M., Rubio-Romero, J.C., Carrillo-Castrillo, J.A., López-Arquillos, A.: A decade of occupational accidents in Andalusian (Spain) public universities. Saf. Sci. **80**, 23–32 (2015). https://doi.org/10.1016/j.ssci.2015.07.008

Sumilo, D., Stewart-Brown, S.: The causes and consequences of injury in students at UK Institutes of Higher Education. Public Health **120**, 125–131 (2006). https://doi.org/10.1016/j.puhe.2005.01.018

Tumala, R.B., Almazan, J., Alabdulaziz, H., Felemban, E.M., Alsolami, F., Alquwez, N., Alshammari, F., Tork, H.M.M., Cruz, J.P.: Assessment of nursing students perceptions of their training hospital's infection prevention climate: a multi-university study in Saudi Arabia. Nurse Educ. Today **81**, 72–77 (2019). https://doi.org/10.1016/j.nedt.2019.07.003

Walters, A.U.C., Lawrence, W., Jalsa, N.K.: Chemical laboratory safety awareness, attitudes and practices of tertiary students. Saf. Sci. **96**, 161–171 (2017). https://doi.org/10.1016/j.ssci.2017.03.017

Wu, T.C., Liu, C.W., Lu, M.C.: Safety climate in university and college laboratories: impact of organizational and individual factors. J. Safety Res. **38**(1), 91–102 (2007). https://doi.org/10.1016/j.jsr.2007.01.003

Zohar, D.: Safety climate in industrial organizations: theoretical and applied implications. J. Appl. Psychol. **65**(1), 96–102 (1980). https://doi.org/10.1037/0021-9010.65.1.96

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Anxiety, Depression and Stress Among University Students: The Mediator Role of Work in Time of COVID-19

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Abstract Objective: This study explored the differences between working and non-working students in terms of mental health. Our aim is to investigate the effects of combining work and study in terms of prevalence of anxiety, depression and stress during this pandemic. Background: The overall impact of COVID-19 lockdown on education led to emotional disorders and the emergence of negative psychological effects. Method: A cross-sectional study was conducted in a sample of 478 working and non-working students in Portugal. The Depression Anxiety Stress Scale was employed to assess symptoms of depression, anxiety and stress. Data were collected using an online survey. Results: 32, 28 and 24% of university students show severe or extremely severe levels of anxiety, depression and stress, respectively. Significantly higher scores of depression and stress were reported by non-working students compared with working-students but no significant differences between both groups were found on anxiety. Conclusion: University working students presented a better psychological health compared to non-working students, who seem to have suffered a higher psychological impact during the COVID-19 time. Application: Academic psychological services may have to take preventive measures in future situations. More studies should be developed to better understand the mediator role of work in crisis situations.

Keywords Working students · Non-working students · Mental health · Emotional disorders · Work activity

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1 Introduction

The disease caused by Coronavirus Disease 2019 (COVID-19) was first detected in December 2019 in China, and in January 2020 the World Health Organization (WHO 2020) stated it as an international public health emergency. On March 11, the COVID-19 epidemic was declared a pandemic. This situation forced all countries to take unusual measures with the closure of schools, universities and many public institutions. The effects of home confinement and social isolation on individuals' health and well-being indicate a fearful impact on mental health (Hossain et al. 2020; Wang 2020).

The overall impact of COVID-19 lockdown on education and the transition to distance learning process led to a high incidence of emotional disorders and the emergence of negative psychological effects among university students (Brooks et al. 2020; Khan et al. 2020; Sahu 2020; Demetriou et al. 2021; Henssler et al. 2021): some may have problems with loneliness and isolation, frustration and boredom, because of the reduce social connectivity, lack of contact with friends, colleagues and partners; others no longer receive the advice and skills development on the university campus, which can aggravate psychological symptoms. The changes and the variations on studies schedule's, the delays of the research projects and the interruptions of the internships compromise their individual plans, and induce high levels of anxiety among university students. Some studies have explored the impacts of COVID-19 on the mental health of university students, mainly with moderate or severe symptoms of anxiety, depression, and stress (Asif et al. 2020; Maia and Dias 2020; Wang et al. 2020; Abas et al. 2021).

There is a growing trend of working during university studies, the number of working students has increased over the years, and now many students choose to work while attending a university learning course. In some situations, students have a positive experience but in other situations this dual role can lead to increased emotional disorders, such as anxiety, depression or stress. However, few studies have explored the mediator role of working and studying simultaneously on the mental health of working university students. Mounsey et al. (2013) found no significant difference in depression between working and non-working students; nevertheless, working students showed more anxiety than non-working students. The pressure to balance academic demands from the university, working tasks and social life could be overwhelming for working students and conduce to have higher depression rate and more stress than non-working students (Tetteh and Attiogbe 2019). However, working while studying can have benefits and help working students in preparing their future career, have a more focused and structured life and, also, a way to enhance self-confidence in social interactions (Nurwulan and Selamaj 2020).

Therefore, some studies showed some contradictions regarding the impact of working while studying that may occur due to the differences in students' characteristics, university environment, and the nature of the work (Nurwulan and Selamaj 2020). Research recognized several adverse psychological effects in individuals during pandemic time with high risk of mental health problems, in particular depression, anxiety, stress-related disorders and anger (Henssler et al. 2021; Maia and Dias 2020; Shafiq et al. 2021). The purpose of this study is to investigate the effects of combining work and study in terms of prevalence of anxiety, depression and stress on characteristics of working students and non-working students during this pandemic time.

2 Materials and Methods

A cross sectional study was conducted in Portuguese university students. The study protocol was approved by the Ethics Committee of Fernando Pessoa University. Data were collected in several universities across Portugal. An online survey was launched on March 25th, 2021, and continued open through 10 days. The time to complete the survey was around 10 min. The psychological impact associated with lockdown due to the COVID-19 was evaluated using the Depression Anxiety Stress Scale (DASS-21) (Lovibond and Lovibond 1995; Antony et al. 1998). The DASS-21 is a 4-point Likert-type scale (0 = did not apply to me at all; 3 = applied to me very much or most of the time) that measures the negative emotional states experienced during the last week through. The Depression, Anxiety and Stress Scale—21 Items (DASS-21) is a set of three self-report scales designed to measure the emotional states of depression, anxiety and stress. We used the Portuguese version of the Depression Anxiety Stress Scale, EADS-21 items (Pais Ribeiro 2004). It has shown a hierarchical factor structure with three factors (Depression, Anxiety, and Stress) with a good internal consistency and convergent and discriminant validity. Data analysis was performed using IBM SPSS Statistics Version 26. We conducted t-tests for mean comparisons, Pearson correlation to determine the relation between mental health dimensions and age and ANOVAs to determine interactions effects of work, gender and parenthood.

3 Results

478 university students participated in this study, 27.8% of them are working students (n = 133). 69% are female. The sample covers the entire mainland and insular Portuguese territory, with the largest percentage (15.8%) residing in the city of Porto. 57, 8% of the sample study in universities sited in Porto. Psychology is the most represented course with 18% of the sample attending courses in this field. 81.8% attend graduation courses and 54.4% study in public universities. 55.2% of the sample referred that most academic activities were done online from the beginning of the pandemic in 2020. 38.4% of working students developed their professional activities face to face at their professional settings or institutions. Table 1 shows a summary of sample characteristics.

Table 1 Sample description

		Non-working Students n = 345	Working students n = 133	Total n = 478
Age		19.95 (dp = 2.692) Min = 18; Max = 45	24.62 (dp = 7.897) Min: 18; Max. 51	21.25 (dp = 5.184)
		%		
Gender	Female	71	63.9	69
	Male	29	36.1	31
	Single	97.4	85.7	94.1
Marital status	Married or Living in a registered civil partnership	2.6	11.3	5
	Divorced or separated	0	2.3	0.6
	Widowed	0	0.8	0.2
Parenthood	No	97.4	85.71	94.1
	Yes	2.6	14.29	5.9
Academic activities during pandemic (from 2020)	Completely face-to-face	1.2	0.8	1
	Mostly face-to-face	10.4	6.0	9.2
	50% face-to-face, 50% online	32.2	21.1	29.1
	Mostly online	52.2	63.2	55.2
	Completely online	4.1	9.0	5.4
Professional activities during pandemic (from 2020)	Completely face-to-face	–	38.34	–
	Mostly face-to-face	–	15.79	–
	50% face-to-face, 50% online	–	14.28	–
	Mostly online	–	8.28	–
	Completely online	–	23.31	–

Table 2 University students (%) on each level of anxiety, depression and stress (Reference scores for each level in Lovibond and Lovibond 1995)

Labels	Anxiety (%)	Depression (%)	Stress (%)
Normal	43.5	41.0	44.8
Mild	5.6	12.3	12.3
Moderate	19.2	18.6	19.0
Severe	8.6	11.3	15.3
Extremely severe	23.0	16.7	8.6

Table 3 Gender and parenthood differences on anxiety, depression and stress

	Gender Mean (Sd)				Parenthood Mean (Sd)			
	Male (n = 148)	Female (n = 330)	t (df)	P	No (n = 450)	Yes (n = 28)	t (df)	P
Anxiety	6.521 (5.319)	4.108 (4.114)	3.196 (476)	<0.001	5.898 (5.112)	3.786 (4.467)	2.135 (476)	<0.05
Depression	7.80 (5.847)	6.020 (5.110)	4.900 (476)	<0.01	7.462 (5.658)	3.821 (5.041)	3.323 (476)	<0.01
Stress	9.773 (5.245)	6.264 (4.681)	6.986 (476)	<0.001	8.833 (5.315)	6.321 (5.019)	2.434 (476)	<0.05

Prevalence of anxiety, depression and stress among university students. Prevalence of anxiety, depression and stress among university students is presented in Table 2. Analysing main sample DASS-21 scores, results show a high percentage of students with levels of anxiety, depression and stress higher than normal (56.5%, 59% e 55.2%, respectively). Moreover, 31.6, 28 e 23.9% of the sample shows severe or extremely severe levels on the three dimensions of mental health (anxiety, depression and stress, respectively).

T-test for independent samples (Table 3) shows significant differences between male and female and between students with and without children in all three mental health dimensions. As represented in Fig. 1, female students and students without children show higher levels of anxiety, depression and stress.

The three dimensions of mental health are significantly related with age. Pearson's r shows that higher levels of anxiety ($r = -0.135$; $p < 0.01$), depression ($r = -0.170$; $p < 0.001$) and stress ($r = -0.144$; $p < .01$) are associated with the youngest students.

As expected, we found strong and direct relations among three dimensions with p-values lesser than 0.001 (Anxiety-Depression: $r = 0.697$; Anxiety-Stress: $r = 0.820$; Depression-Stress: $r = 0.730$).

Surprisingly, no significant differences were found among students from different academic attendance groups (from completely face to face to completely online) on anxiety, depression and stress ($p > 0.05$).

The mediating role of work on psychological health

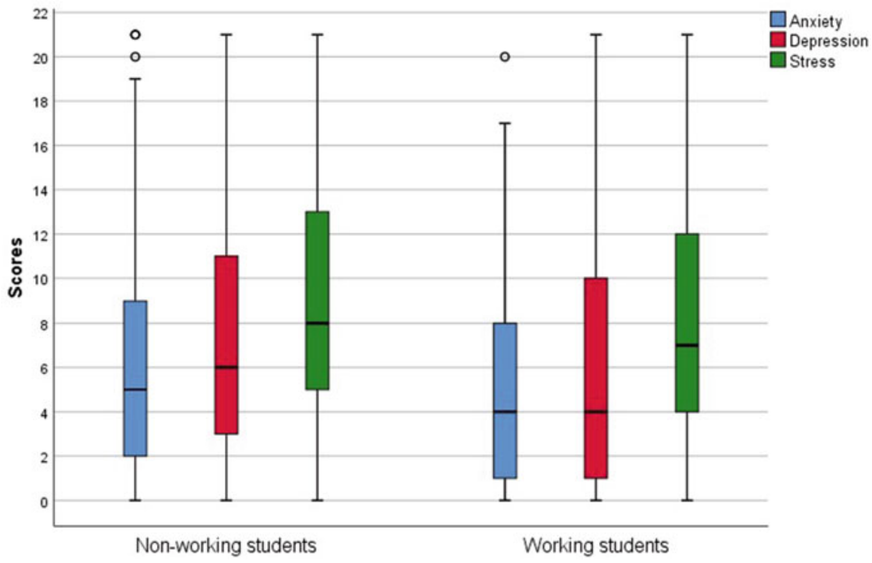

Fig. 1 Box-and-whisker plot for working and non-working students

Table 4 Group differences between working and non-working students on dimensions of mental health

	Non-working students (n = 345) Mean (sd)	Working students (n = 133) Mean (sd)	t (df)	p
Anxiety	6.015 (5.143)	5.150 (4.939)	1.664 (476)	>0.05
Depression	7.641 (5.595)	6.233 (5.806)	2.439 (476)	<0.05
Stress	9.015 (5.393)	7.835 (5,058)	2.179 (476)	<0.05

Mean comparison between working and non-working students (see Table 4) reveals significant differences on depression ($p < 0.05$) and stress ($p < 0.05$) but no differences on anxiety ($p > 0.05$). As represented in Fig. 1, non-working students show higher mean scores of depression and stress than working students.

4 Discussion

The main aim of the present research was to explore the differences between working and non-working students on the prevalence of anxiety, depression, and stress during this pandemic time. Globally, in our sample were found a large percentage of students with high levels of anxiety, depression, and stress. This result is in accordance with the studies were the students presented significantly higher levels of anxiety, depression, and stress, during the period of the pandemic in 2020 compared with normal times (Abas et al. 2021; Asif et al. 2020; Maia and Dias 2020).

Analyzing student's psychological health in 2021, we found high levels of anxiety, depression, and stress, especially among women and younger students. Previous studies consistently suggest higher indicators of depression, anxiety and stress among women (Maia and Dias 2020; Wang et al. 2020; Wenjuan et al. 2020). In terms of age, our results are in accordance with recent literature which shows that although aging increases the risk of COVID-19 infection and mortality, the levels of anxiety, depression and stress are significantly higher at younger ages. In fact, it seems that the youngest are more concerned over the future consequences and economic challenges caused by the pandemic—greater anxiety among young people may be due to their greater access to information through social media, which can also cause stress (Salari et al. 2020).

The results comparing working and non-working students indicates that the working students have less levels of depression and stress, but no differences were found between both groups on anxiety. During lockdown, with the closure of universities and colleges, such physical and social interaction has been restricted resulting in stress and they experienced a lack of emotional engagement and physically connection in a social setting.

Nevertheless, working students reveal a better psychological health. In fact, our data reveals that a large percentage of the working students (54.13%) performed their professional activities mostly or completely face-to-face. Thus, these working students can engage in more social relations and interactions with the co-workers and so, work can provide a more structured and balanced life during conflicts situations like pandemic isolation. Although, the difficulties to manage work, family and self, being a working student allowed to strengthened their personal resilience and engagement and enhance emotional self-confidence during this pandemic situation (Nurwulan and Selamaj 2020; Tetteh and Attiogbe 2019). In fact, working activity can have a positive psychological effect, as other studies have pointed out, highlighting the importance of social support at work for the well-being (Barros et al. 2017; Hossain et al. 2020; Tetteh and Attiogbe 2019) by providing advice, attachment, care, and friendship, and reducing the negative impact of stressors on well-being (Thoits 2010; Usher et al. 2020).

These findings are also in line with previous research that demonstrated that work can be beneficial to an employee's mental health. This evidence establishes that having a work activity is related with better self-reported well-being, bigger access to resources to cope with demands; a greater sense of autonomy and social interactions; which can reduce depression and anxiety symptoms and endorse opportunities for personal development and mental health promotion (Modini et al. 2016; Petrie et al. 2018; Waddell and Burton 2006).

4.1 Limitations

Although this research has made significant contributions and can be used by the universities and government to attendance the adverse psychological effects during Covid-19 and lockdown, it has some limitations. A larger sample, especially of working students, could give more confident results. Moreover, establishing causality in any relationship between work and mental health is complex, as psychological health may be both a cause and a consequence of a change in work environment and performance. Then, more studies should be conducted to better understand this relation.

5 Conclusions

On March 27, 2020, the World Health Organization warned that stress, anxiety, and fear would increase because of the COVID-19 pandemic situation. Our study indicates that in times of an epidemic, people, concretely university students, tend to experience anxiety, stress, and depression. Mental health is the key component of a sustainable society. A productive educational performance depends on students' health, which is greatly influenced by their psychological conditions. Our results highlight that work can be a protective factor for stressful times in psychological health. Nerveless, further research is required to gain better understanding about which factors of work environment can contribute to positive mental health outcomes. Furthermore, at present it is unclear whether it is the process of working per se or factors associated with the workplace (interactions with others, daily structure and financial reward) or the unique combination of both that serve as protective factors for a better psychological health.

The effects of quarantine and isolation must be recognized for strengthening mental health services. When individuals experience complex psychosocial stressors due to restricted mobility and social interaction, mental health factors should be evaluated to plan future interventions, aiming the guarantee of well-being among individuals and populations. In summary, we defend that work activity can have a positive effect on mental health if a social environment and support are provided for working students.

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References

Abas, I.M.Y., Alejail, I.I.E.M., Ali, S.M.: Anxiety among the Sudanese university students during the initial stage of COVID-19 pandemic. Heliyon **7**(3), e06300 (2021). https://doi.org/10.1016/j.heliyon.2021.e06300

Antony, M.M., Bieling, P.J., Cox, B.J., Enns, M.W., Swinson, R.P.: Psychometric properties of the 42-item and 21-item versions of the Depression Anxiety Stress Scales (DASS) in clinical groups and a community sample. Psychol. Assess. **10**, 176–181 (1998). https://doi.org/10.1037/1040-3590.10.2.176

Asif, S., Mudassar, A., Shahzad, T.Z., Raouf, M., Pervaiz, T.: Frequency of depression, anxiety and stress among university students. Pak. J. Med. Sci. **36**(5), 971–976. https://doi.org/10.12669/pjms.36.5.1873

Brooks, S.K., Webster, R.K., Smith, L.E., Woodland, L., Wessely, S., Greenberg, N., Rubin, G.J.: The psychological impact of quarantine and how to reduce it: rapid review of the evidence. Lancet **395**(10227), 912–920 (2020). https://doi.org/10.1016/S0140-6736(20)30460-8

Barros, C., Fonte, C., Alves, S., Gomes, I.: Mental health and well-being among psychologists: protective role of social support at work (467–471). In: Arezes, P.M., Baptista, J.S., Barroso, M.P., Carneiro, P., Cordeiro, P., Costa, N., Melo, R.B., Miguel, S., Perestelo, G.: (eds.) Occupational Safety and Hygiene V. London: CRC Press—Taylor & Francis (2017). ISBN: 978-1-138-05761-6

Demetriou, L., Hadjicharalambous, D., keramioti, L.: Examining the relationship between distance learning processes and university students' anxiety in times of COVID-19. Eur. J. Soc. Sci. Stud. **6**(2), 123–141. https://doi.org/10.46827/ejsss.v6i2

Henssler, J., Stock, F., van Bohemen, J., Walter, H., Heinz, A., Brandt, L.: Mental health effects of infection containment strategies: quarantine and isolation-a systematic review and meta-analysis. Eur. Arch. Psychiatry Clin. Neurosci. **271**(2), 223–234 (2021). https://doi.org/10.1007/s00406-020-01196-x

Hossain, M., Sultana, A., Purohit, N.: Mental health outcomes of quarantine and isolation for infection prevention: a systematic umbrella review of the global evidence. Epidemiol Health. **42**, 1–11 (2020). https://doi.org/10.2139/ssrn.3561265

Khan, A.H., Sultana, M.S., Hossain, S., Hasan, M.T., Ahmed, H.U., Sikder, M.T.: The impact of COVID-19 pandemic on mental health & wellbeing among home-quarantined Bangladeshi students: a cross-sectional pilot study. J. Affect. Disord. **277**, 121–128 (2020). https://doi.org/10.1016/j.jad.2020.07.135

Lovibond, S.H., Lovibond, P.F.: Manual for the Depression Anxiety Stress Scales, 2nd edn. Psychology Foundation, Sydney (1995)

Maia, B.R., Dias, P.C.: Anxiety, depression and stress in university students: the impact of COVID-19. Estudos de Psicologia (Campinas) **37**, e200067 (2020). https://doi.org/10.1590/1982-0275202037e200067

Modini, M., Joyce, S., Mykletun, A., et al.: The mental health benefits of employment: results of a systematic metareview. Australas. Psychiatry **24**(4), 331–336 (2016). https://doi.org/10.1177/1039856215618523

Mounsey, R., Vandehey, M.A., Diekhoff, G.M.: Working and non-working university students: anxiety, depression, and grade point average. Coll. Stud. J. **47**(2), 379–389 (2013)

Nurwulan, N.R., Selamaj, G.: Working university students in riau archipelago: dual role and depression. J. Educ.: J. Educ. Stud. **5**(2), 123–135 (2020). http://dx.doi.org/10.30983/educative.v5i2.3330

Odriozola-González, P., Planchuelo-Gómez, Á., Irurtia, M.J., de Luis-García, R.: Psychological effects of the COVID-19 outbreak and lockdown among students and workers of a Spanish university. Psychiatry Res. **290**, 113108 (2020). https://doi.org/10.1016/j.psychres.2020.113108

OPP: Comentário técnico e contributo OPP - estratégia de resposta covid-19 - saúde mental. Ordem dos Psicólogos Portugueses, Lisboa (2020)

Pais Ribeiro, J., Honrado, A., Leal, I.: Contribuição para o estudo da adaptação portuguesa das escalas de ansiedade, depressão e stress (EADS) de 21 itens de Lovibond e Lovibond. Psicologia, Saúde e Doenças **5**(2), 229–239 (2004)

Petrie, K., Joyce, S., Tan, L., Henderson, M., Johnson, A., Nguyen, H., Modini, M., Groth, M., Glozier, N., Harvey, S.B.: A framework to create more mentally healthy workplaces: a viewpoint. Aust. N. Z. J. Psychiatry **52**(1), 15–23 (2018). https://doi.org/10.1177/0004867417726174

Sahu, P.: Closure of universities due to coronavirus disease 2019 (COVID-19): impact on education and mental health of students and academic staff. Cureus **12**(4), e7541 (2020). https://doi.org/10.7759/cureus.7541

Salari, N., Hosseinian-Far, A., Jalali, R., et al.: Prevalence of stress, anxiety, depression among the general population during the COVID-19 pandemic: a systematic review and meta-analysis. Glob. Health **16**(57), 1–9 (2020). https://doi.org/10.1186/s12992-020-00589-w

Shafiq, S., Nipa, S.N., Sultana, S., Rahman, M.R.-U.-, Rahman, M.M.: Exploring the triggering factors for mental stress of university students amid COVID-19 in Bangladesh: a perception-based study. Child. Youth Serv. Rev. **120**, 105789 (2021). https://doi.org/10.1016/j.childyouth.2020.105789

Tetteh, E.N., Attiogbe, E.J.K.: Work-life balance among working university students in Ghana. High. Educ., Ski. Work.-Based Learn. **9**(4), 525–537 (2019). https://doi.org/10.1108/HESWBL-08-2018-0079

Thoits, P.A.: Stress and health: major findings and policy implications. J. Health Soc. Behav. **51**, S41–S53 (2010). https://doi.org/10.1177/0022146510383499

Thomas, P., Hui, L., Umberson, D.: Family relationships and well-being. Innov. Aging **1**(3) (2017). https://doi.org/10.1093/geroni/igx025

Waddell, G., Burton, K.: Is Work Good for Your Health and Well-Being? The Stationary Office, London (2006)

Wang, C., Pan, R., Wan, X., Tan, Y., Xu, L., Ho, C.: Immediate psychological responses and associated factors during the initial stage of the 2019 coronavirus disease (COVID-19) epidemic among the general population in China. Int. J. Environ. Res. Public Health **17**(5), 1729 (2020). https://doi.org/10.3390/ljerph17051729

Wenjuan, G., Siqing, P., Xinqiao, L.: Gender differences in depression, anxiety, and stress among college students: a longitudinal study from China. J. Affect. Disord. **263**(15), 292–300 (2020). https://doi.org/10.1016/jad.2019.11.121

WHO.: Mental health and psychosocial considerations during the COVID-19 outbreak. Geneva, Author (2020). https://www.who.int/docs/default-source/coronaviruse/mental-health-considerations.pdf

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Functional Capacity Profiles Adjusted to the Age and Work Conditions in Automotive Industry

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Abstract Objective: to define functional capacity profiles adjusted to the chronological age and the work conditions in the automotive industry. Background: Ageing population trends have significant implications for the public finances of European countries. To answer this challenge, many governments have introduced policy reforms to encourage older people to continue to work until a later age stage. Method: 122 workers in the assembly area of an automotive industry were involved in this study. Functional capacity was assessed by 4 tests of the Isermhagen Work System protocol: Lifting Low (LL), Lifting High (LH), Overhead Working (OW) and Handgrip (HG). The exposure was evaluated by the European Assembly worksheet. Linear regression models were built to identify the predictive factors of the functional decline. Results: Regarding the reference values by age group, the lifting low test, in the 45–57-year-old group had an average of 500 g more than the 20–24 year-old. In the lifting high test, the highest average is in the 35 to 39 age group and the lowest in the 40–44 age group, with a difference of 2.90 kg. The variable height appears as predictive factor for Handgrip position 2 (HG2) and Handgrip position 5 (HG5) improvement. The variable weight, on the other hand, appears in LH, HG2, and HG5. Interestingly, the Low Risk Score (LRS) and Moderate Risk Score (MRS) by European Assembly Worksheet (EAWS), appear only in the HG2 test. The OW measure has no predictive influence on analysed factors. Conclusion: Additionally, these features help the occupational professionals to adjust the load limit that the worker may perform. No statistically significant decline was found in the group of workers older than 45 years in the functional capacity tests, but more detailed studies with workers aged 20–29 years are suggested.

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1 Introduction

Ageing population trends have significant implications for the public finances of European countries, with an impact on public expenditures on health care, long-term care, and pensions, coupled with a decline in tax revenue. It is expected that in 2060, 40% of workers in the European Union will be 55 years old (WHO 2015). To answer this challenge, many governments have introduced policy reforms to encourage older people to continue to work until a later age stage (Avendano and Cylus 2005; Iavicoli et al. 2018; Ilmarinen and Juhani 2012). This option is mainly supported due to the increase in life expectancy. However, these measures should be accompanied by new policies on education, public health, and social living conditions. In fact, the extension of active life could represent a challenge for work conditions changes, in order to tailor the work exposure to the functional decline of older workers, especially those with jobs physically demanding (Norheim et al. 2017; Grobler 2013; Lakke et al. 2013; Landau et al. 2008). Additionally, older workers have some chronic conditions and comorbidities and could interact, thereby exacerbating the negative impact of disease on their quality of life and work ability (Norheim et al. 2017; Cruz-Jentoft et al. 2019). The high physical demands associated with awkward postures, high repetitive movements, and others, can result in decreased functional capacity, especially in older workers, and in the prevalence of work-related musculoskeletal disorders (WMSDs). Consequently, there may be an increase in absenteeism and incapacity for work (Eaves et al. 2016; Tuomi et al. 2001). It is essential to compare the work capacity profiles of workers exposed to high physical demand activities, such as the automotive industry workers, to check for possible imbalances between job demands and functional capacity (Müglich et al. 2015). Data related to the variation of physical capacity amongst workers who perform physically demanding work will be useful in order to support occupational and health policies to promote healthy workplaces at all ages. This study aims to define functional capacity profiles adjusted to chronological age and work conditions in the automotive industry (1), to determine the predictive factors associated to the functional decline in the automotive industry (2).

2 Materials and Methods

About 1000 workers from an assembly are from an automotive industry were invited to participate in this study. From those, only 500 workers were considered eligible. For the sample selection purposes, the Physical Activity Questionnaire (Par-Q) (Thomas et al. 1992) was used to guarantee that all workers were healthy. Then, workers were divided into six age groups. In the final sample, a randomization method to define the sequence of the tests was applied. The final sample was composed of 147 workers and the total duration of the study was 16 weeks.

The main inclusion criterion was based on age parameter, i.e., to have between 20 and 60 years old The exclusion criteria were defined as: (1) had at least one positive question test (Warburton et al. 2011). Par-Q validated by the European Portuguese Language (Monteiro et al. 2000); (2) Blood Pressure higher than 159 × 99 mmHg, measured before the beginning of the functional capacity assessment; (3) Heart rate above 100 bpm before the assessment; (4) had a medical restriction diagnosed by the occupational health department; (5) had pain intensity in any region of the body above 3 points on the Numeric Rating Scale in the Nordic questionnaire on the previous 7 days. All workers were informed about the purposes and procedures of the study and given their informed written consent. The study protocol was approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon.

Sociodemographic data (including seniority) health (Hypertension, Diabetes, Exhaustion, and others), and life habits were collected using a questionnaire designed for the purpose of this study.

The Par-Q were applied to screen individuals for the practice of physical activity (mild to moderate activity level) (Thomas et al. 1992).

Functional capacity evaluation (FCE) was applied to evaluate the capacity of the worker to answer to work demands (Reneman et al. 2005; Soer et al. 2006). For the present study, only four functional capacity tests based on the Isernhagen Work Systems (IWS) protocol (Isernhagen 1992; Soer et al. 2009) were selected:

– lifting low (LL): One (1) plastic box, made of rigid material, with standard, sizes 40 × 30 × 26 cm, with side handles. One (1) structure for conducting the tests. Weights of 1, 2, and 5 kg. The test was performed with the worker in the standing position, being asked to carry out five lifts of the box, from the table (74 cm high) to the floor and vice versa, with a time limit of 90 s. It is started with a weight of 5 kg, and then it is added up to 5 increments of weight, reaching the maximum possible weight that the participant supports. However, in this case, we have limited to 25 kg due to the activity standards applied in the automotive industry.
– Lifting high (LH): One (1) plastic box, made by rigid material, with standard, sizes 40 × 30 × 26 cm, with side handles. One (1) structure for conducting tests. Weights of 1, 2, and 5 kg. The worker was in a standing position and was asked to carry out five lifts from the table (74 cm) up to head height and vice versa, with a time limit of 90 s. It is started with a weight of 5 kg, and then it is added up to 5 increments of weight, reaching the maximum possible weight that the participant supports. We have also limited to 25 kg due to the activity developed in the automotive industry.
– Overhead working (OW): One (1) wooden board with 20 holes (10 on each side of the board) and adjustable in height. One (1) structure for conducting test. Weight of 1 kg, 20 screws, and 20 nuts were used. The worker was in a standing position, with hands at the head height, and with a load of 1 kg placed on each wrist; then it was asked to insert screws and nuts into the 20 holes in the wood board.
– Handgrip position 2 (HG2) and Handgrip position 5 (HG5): Jamar Smart Digital Hand Dynamometer in position 2 and 5. The worker was in a sitting position

with arms abducted, forearms pronated, wrist neutral, elbow flexed at 90°. The dynamometer is then delivered and is required to perform three times the maximum force, with the dominant hand; the test was performed in the positions 2 and 5 of the dynamometer. The workers had one minute of rest for each measurement, totalizing six measurements between positions 2 and 5.

European Assembly Worksheet (EAWS) was used to evaluate the exposure to biomechanical risk factors (Schaub 2013). This tool of ergonomic analysis was originally used in the evaluation of the work of assembly in the automotive industries. The Nordic Questionnaire allowed to collect data related to musculoskeletal pain symptoms (in the previous 12 months and 7 days) in nine regions: Neck, Shoulders, Elbows, Fists/Hands, Thoracic, Low Back Regions, Hips/Thighs, Knees, Ankle/Feet (Mesquita et al. 2010).

For the monitoring of the heart rate, the Polar H10 HR M-XXL was used. According to the Office of Disease Prevention and Health Promotion (OPHP) the heart rate target, in moderate and intense efforts is defined by 70 at 85% of the maximum heart rate. Thus, the formula 220-age × 0.70 was used as reference (Piercy et al. 2018).

The height was used, following the ISAK standards, with the participant positioned in relation to the stadiometer, with the feet in vertical position (together or slightly apart) and the arms extended along the body. The head was oriented according to the Frankfurt plan, parallel to the floor. The participant is asked to perform the "grow or unwind" inspiration while the board is positioned over the participant's head, exerting constant pressure on the scale was used (Marfell-Jones et al. 2006). The most recent weight reported by workers was collected.

2.1 Data Analysis

To select the final sample of employees, the eligibility criterion was applied. Statistical analyses were initially separated between men and women and divided into six age groups (20–24; 25–29; 30–34; 35–39; 40–44; 45–57 years- old).

However, after applying the statistics, it was found that there were no statistically significant differences between the groups of men and women, and therefore the final population was divided only by age groups. The following was observed:

1 Descriptive statistics were applied for all variables: absolute and relative frequencies for nominal variables and means and central tendency for quantitative variables were determined;
2 Normal distribution of continuous variables was verified by Kolmogorov-Smirnov;
3 To confirm if there was a statistically significant difference between the means of the six age groups, regarding functional capacity, the Student's tests for the parametric variables, or the Manny-Whitney tests for the nonparametric variables were applied.

4 The normative values were performed for each age group, according to the functional capacity, from the mean, median, standard deviation and the risk threshold (mean minus the standard deviation).
5 Percentiles of functional capacity tests were made, based on the EAWS. Additionally, the EAWS values were coded into three task risk demanding categories, low risk score (LRS), moderate risk (MRS), and high risk score (HRS) according the final score of the work shift/day. However, no workers were exposed to high risk score workstations in the study.
6 Predictive analysis of work and personal factors of the workers' functional decline was determined by multiple linear regressions (stepwise method). All statistical analyses were performed with SPSS (version 22.0; IBM, Chicago, IL) and a critical level of $p < 0.05$ was defined as significantly.

3 Results

Of the 147 workers in the sample who participated in the study, after applying the eligibility criterion based on the Nordic questionnaire, the final sample of the present study consisted of 122 workers of both sexes (82% men and 18% women). Regarding the LL and HG2 functional capacity tests, in the age groups, the averages were, respectively: 20–24 (24.4 ± 1.41; 43.4 ± 9.69); 25–29 (24.6 ± 1.08; 51.3 ± 9.93); 30-34 (24.5 ± 1.01; 51.1 ± 13.7); 35–39 (25.0 ± 0.01; 52.6 ± 5.85); 40–44 (24.2 ± 1.75; 48.3 ± 10.5); 45–57 (25.0 ± 0.01; 48.7 ± 6.24). The other variables included in the descriptive analysis were: Seniority in the company (seniority); weight; height; body mass index; the functional capacity tests LH, OW and HG5 and the EAWS variables that is Extra Point (EP), Posture, Force, Manual Material Handling (MMH) and the Overall Score. All variables were divided by age groups and are presented in Table 1.

The reference values for the Portuguese workers of the functional capacity are presented in Table 2. Regarding the reference values by age group, in the LL test, the 45–57-year-old group had an average of 0.6% more than the 20–24 year-olds. In the LH test, the highest average is in the 35–39 age group and the lowest in the 40–44 age group, with a difference of 2.9%.

In Table 2, for the OW test, the highest average was found in the 25–29 age group, and the lowest was found in the 40–44 age group—about 0.3%. The lowest average HG2 was in the 20–24 age group and HG5 in the 40–44 age group. The highest mean handgrip strength was found in the 35–39 age group.

Table 3 shows the percentiles of functional capacity stratified by the EAWS Low-Risk Score (LRS) and Moderate Risk Score (MRS). Table 3 shows the LL and LH tests, related to the EAWS final score. The 5th and 25th percentiles of the LH test stand out, with a variation of 3 and 2%, respectively, between the LRS and MRS categories. In the other percentiles, the results are quite similar. The 95th percentile of the HG2 test in the LRS category stands out at 65.5 kg, while the MRS category is 2% below the LRS value.

Table 1 Descriptive analyses

	20-24 n 25			25-29 n 33			30-34 n 14			35-39 n 15			40-44 n 24			45-57 n 11		
	Min	Max	x±*SD*	Min	Max	x±*SD*	Min	Max	x±*SD*	Min	Max	x±*SD*	Min	Max	x±*SD*	Min	Max	x±*SD*
Seniority (years)	0.20	1.20	0,66±0.32	0.20	7.85	1.47±2.15	0.34	11.35	3.25±3.75	0.31	10.8	2.52±3.42	0.40	22.5	10.6±9.79	0.20	23.1	18.7±7.56
Weight (kg)	50.0	90	66.3±11.1	55.0	119	77.9±14.5	52.0	110	80.3±18.4	66.0	98.0	77.2±9.14	45.0	105	73.5±13.2	70.0	94.0	76.8±8.18
Height (cm)	158	193	1.74±0.08	150	194	175±0.08	153	198	172±0.11	164	182	173±0.04	155	191	171±0.08	165	180	172±0.04
BMI (kg/m^2)*	16.9	29.4	21.8±2.98	19.0	38.1	25.3±4.40	20.3	36.8	26.6±4.53	22.1	30.0	25.5±2.27	18.7	35.3	25.1±4.35	22.9	32.1	25.8±2.66
Functional Capacity test																		
LL (kg)*	20.0	25.0	24.4±1.41	20.0	25.0	24.6±1.08	22.0	25.0	24.5±1.01	25.0	25.0	25.0±0.01	20.0	25.0	24.2±1.75	25.0	25.0	25.0±0.01
LH (kg)*	12.0	25.0	22.0±3.95	15.0	25.0	23.4±2.59	15.0	25.0	22.4±3.22	20.0	25.0	24.4±1.04	12.0	25.0	21.5±3.99	20.0	25.0	23.5±1.80
OW(min)*	2.22	3.58	2.80±0.44	2.10	4.09	2.81±0.48	2.10	4.29	2.58±0.55	2.16	3.22	2.59±0.35	1.54	3.40	2.49±0.36	2.05	4.25	2.58±0.62
HG2(kg)*	26.0	60.0	43.4±9.69	30.0	69.0	51.3±9.93	22.0	66.0	51.1±13.7	40.0	60.0	52.6±5.85	24.0	64.0	48.3±10.5	35.0	57.0	48.7±6.24
HG5(kg)*	13.0	59.0	32.0±10.5	15.0	50.0	33.5±8.34	13.0	53.0	35.7±12.6	21.0	49.0	35.9±6.27	13.0	48.0	31.8±9.44	21.0	43.0	32.3±5.97
EAWS																		
E.P*	1.12	7.10	3.43±1.48	0.82	7.75	3.38±1.71	0.05	19.2	4.65±4.48	0.83	5.70	3.57±1.33	0.18	8.35	3.63±1.93	1.84	8.86	3.67±2.01
Posture	8.72	29.6	16.8±5.49	5.72	38.6	15.0±4.96	2.60	22.8	12.7±5.85	8.03	28.1	16.1±6.01	2.47	22.1	11.9±5.78	5.51	30.2	13.6±8.70
Force	1.03	16.8	5.96±3.38	0.02	16.1	4.96±3.78	1.52	14.3	6.06±3.33	0.70	9.29	4.49±2.97	0.06	8.33	3.83±2.52	0.47	11.6	5.43±3.83
MMH*	0.01	16.1	2.34±3.20	0.01	11.1	2.50±2.83	0.01	12.1	2.22±3.62	0.01	5.61	1.93±2.23	0.01	4.86	1.09±1.49	0.00	7.43	1.18±2.27
Overall Score	19.1	34.8	26.8±4.67	10.9	41.8	25.8±7.48	16.4	37.8	26.9±5.79	18.2	35.2	26.0±5.58	5.28	34.8	19.9±7.65	13.6	41.8	23.8±8.58

Table 2 Normative values for the functional capacity tests in the working population of the automotive industry

Age	Test	Mean	Median	SD	Risk threshold
20–24	LL (kg)	24.4	25.0	1.41	22.9
(n25)	LH (kg)	22.0	24.5	3.87	18.1
	OW (min)	2.79	2.51	0.46	2.33
	HG2 (kg)	43.8	46.0	9.67	34.1
	HG5 (kg)	31.8	33.0	10.3	21.5
25–29	LL (kg)	24.8	25.0	0.87	23.9
(n33)	LH (kg)	23.7	25.0	2.53	21.1
	OW (min)	2.81	3.00	0.48	2.33
	HG2 (kg)	51.3	52.0	9.93	41.3
	HG5 (kg)	33.5	35.0	8.34	25.1
30–34	LL (kg)	25.0	25.0	0.01	24.9
(n14)	LH (kg)	23.2	25.0	3.24	19.9
	OW (min)	2.58	2.44	0.55	2.03
	HG2 (kg)	51.1	56.5	13.7	37.4
	HG5 (kg)	35.7	40.5	12.6	23.1
35–39	LL (kg)	25.0	25.0	0.01	24.9
(n16)	LH (kg)	24.4	25.0	1.36	23
	OW (min)	2.63	2.46	0.38	2.25
	HG2 (kg)	52.4	52.5	5.62	46.7
	HG5 (kg)	35.8	35.0	6.08	29.7
40–44	LL (kg)	24.3	25.0	1.75	22.5
(n22)	LH (kg)	21.5	22.5	4.1	17.4
	OW (min)	2.51	2.48	0.36	2.15
	HG2 (kg)	47.7	49.0	10.7	37
	HG5 (kg)	31.4	30.0	9.72	21.6
45–57	LL (kg)	25.0	25.0	0.01	24.9
(n11)	LH (kg)	23.5	25.0	1.89	21.6
	OW (min)	2.58	2.39	0.62	1.95
	HG2 (kg)	48.7	49.0	6.24	42.4
	HG5 (kg)	32.3	33.0	5.91	26.3

Table 4 shows the predictive models of variables that can influence functional capacity, such as gender, age, height, body weight, and the final EAWS score categorized as low (LRS) and moderate (MRS) risk.

Sex has a predictive influence in all functional capacity tests, except in tghe Overhead Working test. The variable height appears as predictive factor for Handgrip position 2, 2 and 5 improvement. The variable weight, on the other hand, appears in Lifting High, HG2, and HG5. Interestingly, the Low Risk Score and Moderate Risk Score by EAWS, appear only in the HG2 test. The OW measure has no predictive influence on analysed factors.

Table 3 Percentiles of functional capacity stratified by EAWS risk

	LL		LH		OW		HG2		HG5	
	LRS	MRS	LRS	MRS	LRS	MRS	LRS	MRS	LRS	MRS
Mean	24.6± 1	24.6± 1	22.7± 3	22.6± 3	2.65 ± 0	2.82 ± 0	48.9 ± 1	46.8 ± 9	33.1 ± 8	33.9 ± 1
	0.37	0.25	0.40	0.84	0.47	0.51	0.0.4	0.93	0.64	0.1
Range	17–25	20–25	20–25	20–25	1.54–4.25	2.16–4.19	22–69	25–65	13–53	14–59
Percenti										
5	20.0	20.0	15.0	12.0	2.11	2.21	30.0	26.0	18.0	15.0
25	25.0	25.0	20.0	22.0	2.34	2.42	41.2	39.0	27.2	24.0
50	25.0	25.0	25.0	25.0	2.48	2.55	50.0	46.0	34.0	33.0
75	25.0	25.0	25.0	25.0	3.06	3.26	57.0	55.0	39.0	38.0
95	25.0	25.0	25.0	25.0	3.41	4.09	65.5	63.0	46.0	49.0

* $p < 0.05$; LL-Lifting Low; LH: Lifting High; OW: Overhead Working; HG2: Handgrip position 2; HG5: Handgrip position 5; LRS: Low Risk Score; MRS: Moderate Risk Score

Table 4 Prediction models of functional decline by sex, age, height, body weight and work exposure

Test	Constant	Sex	Age (y)	Body height (cm)	Body weight (Kg)	LRS	MRS	r^2
LL	19.2*	1.62*	−0.01	2.04	0.01	−0.24	0.34	0.33
LH	5.92	4.91*	0.01	5.42	0.05*	−0.66	0.86	0.50
OW	1.06	−0.01	−0.07	1.17	−0.01	0.13	−0.13	−0.03
HG2	−13.6	10.8*	0.04	24.5*	0.15*	−2.92*	2.89*	0.44
HG5	−27.3	8.77*	−0.03	26.3*	0.14*	−2.3	2.30	0.45

4 Discussion

This study aims to define functional capacity profiles adjusted to chronological age and work conditions in the automotive industry to determine the predictive factors associated to the functional decline in the automotive industry. It is important to note that the present study was conducted with healthy workers. All workers involved in the present study had the functional capacity to meet the workload. These profiles provide information of sufficient functional capacity for successful work in the low and moderate EAWS final score category. The four functional capacity tests based on the IWS protocol were performed according to the types of activities developed in the automotive industry, avoiding deviation from actual and specific job requirements (Innes and Straker 2003).

In this study, it is interesting to note that the group of workers over 45 years old did not show a decline in functional capacity, when compared to the other groups. Such above-mentioned situation can be supported, with another study, which found a decline in the productivity of workers, occurred more significantly after 60 years old (Börsch-Supan and Weiss 2016). But it is important to note that in the present study, it was not evaluated workers over 60 years old.

Another important finding occurred in the group of 20–29 years old, in the Overhead Working and Handgrip measure tests, with the lowest averages found, among all age groups. When comparing the age group of the present study, with other study conducted in 1985 in the American population, where the handgrip strength measure was verified, the population of the present study is 10 kg less than the American population (Mathiowetz et al. 1985).

This can prove that the 20–29 age group should be taken into consideration regarding the developmental aspect of possible work-related musculoskeletal disorders. This is because workers are weaker in terms of physical strength, and this is closely related to the type of activity they were previously doing (Fain and Weatherford 2016; Okunribido et al. 2011).

The ability of some tests is predictive to a large extent, dependent on workers' characteristics such as gender, height, and weight. A similar situation occurred in a study that aimed to create normative values of functional capacity in various types of occupational activities (Gross and Battié 2003; Soer et al. 2009; Kunelius et al. 2007). It is important to note that age was not a predictor factor in any of the functional capacity tests. This situation occurred in two other studies for handgrip strength tests (Budziareck et al. 2008; Soer et al. 2009). This may be associated with the age group of the studies, as the decline in workers over 60 years is more characteristic (Gilles and Wing 2003; Bohannon and Schaubert 2005; Bohannon et al. 2011; Börsch-Supan and Weiss 2016; Soer et al. 2009). It is essential to highlight that in the Handgrip position 2 measurement, the Low Risk Score and Moderate Risk Score measurement were considered as predictors besides gender, height, and weight.

4.1 Limitations

We can state that the phenomenon of the healthy worker may have occurred, as a bias because workers considered healthy tend to stay longer in their occupational activities, and this may be closely associated with the individual's basal health condition. This may be associated with early interventions in the face of some musculoskeletal disorder, proper health maintenance with regular screening, and practice of physical exercise (Kenny et al. 2016; Chowdhury et al. 2017; Martin-Ruiz and Von Zglinicki 2014; Matheson et al. 2014; Palmer et al. 2017). In the automotive industry where the study took place, the ergonomics team periodically screened the workplace conditions as well as the occupational health department's screening of health conditions, and this practice may have influenced the healthy maintenance of employees (Merkus et al. 2019). Another factor that influences the response of the functional capacity in older workers may be related to the practice of rotation plans incorporated in the automotive industry to avoid fatigue and musculoskeletal disorders. The rotation plans are adopted during the work shift. For example, the worker is not exposed to more than 2 h and 30 in the same activity, and the employee must know multiple tasks. Furthermore, work variation reduces fatigue and the risk of musculoskeletal disorders (Grant et al. 1997; Rissén et al. 2002) as long as job changes involve an effective change in the work muscle groups being used (Diego-Mas et al. 2009; Grant et al. 1997; Rissén et al. 2002).

5 Conclusions

The age-adjusted functional capacity profiles and working conditions are essential to assist the recommendations and interventions from ergonomics team and the occupational health department, since when comparing the functional capacity profiles adjusted for age and working conditions. It allows to evaluate possible imbalances between the workload and the functional capacity, and, when it is necessary to plan workers return work. Additionally, these features help the occupational professionals to adjust the load limit that the worker may perform. No statistically significant decline was found in the group of workers older than 45 years in the functional capacity tests, but more detailed studies with workers aged 20–29 years is suggested.

References

Avendano, M., Cylus, J.: The economics of healthy and active ageing series WORKING AT OLDER AGES Why it's important, how it affects health, and the policy options to support health capacity for work (2019). Retrieved from http://www.euro.who.int/pubrequest

Bohannon, R.W., Schaubert, K.L.: Test-retest reliability of grip-strength measures obtained over a 12-week interval from community-dwelling elders. J. Hand Therapy (2005). https://doi.org/10.1197/j.jht.2005.07.003

Bos, J., Kuijer, P.P.F.M., Frings-Dresen, M.H.W.: Definition and assessment of specific occupational demands concerning lifting, pushing, and pulling based on a systematic literature search. Occup. Environ. Med. (2002). https://doi.org/10.1136/oem.59.12.800

CDC: Older employees in the workplace. Nat. Healthy Worksite **1**, 1–6 (2012)

Cruz-Jentoft, Alfonso J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., Schols, J.: Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing (2019). https://doi.org/10.1093/ageing/afy169

Diego-Mas, J.A., Asensio-Cuesta, S., Sanchez-Romero, M.A., ArtachoRamirez, M.A.: A multi-criteria genetic algorithm for the generation of job rotation schedules. Int. J. Ind. Ergon. (2009). https://doi.org/10.1016/j.ergon.2008.07.009

Eaves, S., Gyi, D.E., Gibb, A.G.F.: Building healthy construction workers: Their views on health, wellbeing and better workplace design. Appl. Ergon. **54**, 10–18 (2016). https://doi.org/10.1016/j.apergo.2015.11.004

Fain, E., Weatherford, C.: Comparative study of millennials' (age 20-34 years) grip and lateral pinch with the norms. J. Hand Therapy (2016). https://doi.org/10.1016/j.jht.2015.12.006

Gilles, M.A., Wing, A.M.: Age-Related changes in grip force and dynamics of hand movement. J. Motor Behav. (2003). https://doi.org/10.1080/00222890309602123

Grant, K.A., Habes, D.J., Bertcche, P.K.: Lifting hazards at a cabinet manufacturing company: Evaluation and recommended controls. Applied Occupational and Environmental Hygiene. https://doi.org/10.1080/1047322X.1997.10389500

Grobler, C.J.: Self-reported work-related musculoskeletal injuries and isometric handgrip strength. Occup. Med. **63**(3) (2013). https://doi.org/10.1093/occmed/kqt007

Gross, D.P., Battié, M.C.: Construct validity of a Kinesiophysical functional capacity evaluation administered within a worker's compensation environment. J. Occup. Rehab. (2003). https://doi.org/10.1023/A:1026276822721

Iavicoli, I., Leso, V., Cesari, M.: The contribution of occupational factors on frailty. Arch. Gerontol. Geriat. **75**, 51–58 (2018). https://doi.org/10.1016/j.archger.2017.11.010

Ilmarinen, J.: Promoting active ageing in the workplace. ... /Articles/Promotingactive-Ageing-in-the-Workplace, pp. 1–7 (2012). http://www.ipbscordoba.es/uploads/Documentos/promoting-active-ageing-in-the-workplace.pdf

Isernhagen, S. J.: Functional capacity testing and industrial injury treatment. In: Orthopaedic Physical Therapy Secrets, 3rd (edn.) (2016). https://doi.org/10.1016/B978-0-323-28683-1.00030-8

Isernhagen, S.J.: Functional capacity evaluation: Rationale, procedure, utility of the kinesiophysical approach. J. Occup. Rehabil. **2**(3), 157–168 (1992). https://doi.org/10.1007/BF01077187

Kenny, G.P., Groeller, H., Mcginn, R., Flouris, A.D.: Age, human performance, and physical employment standards 1. Appl. Physiol. Nutr. Metab. **41**(June), 92–108 (2016). https://doi.org/10.1139/apnm-2015-0483

Kunelius, A., Darzins, S., Cromie, J., Oakman, J.: Development of normative data for hand strength and anthropometric dimensions in a population of automotive workers. Work (2007)

Lakke, S.E., Soer, R., Geertzen, J.H.B., Wittink, H., Douma, R.K.W., Schans, C.P. Van Der Reneman, M.F.: Construct validity of functional capacity tests in healthy workers (2013)

Landau, K., Rademacher, H., Meschke, H., Winter, G., Schaub, K., Grasmueck, M., Schulze, J.: Musculoskeletal disorders in assembly jobs in the automotive industry with special reference to age management aspects. Int. J. Ind. Ergon. (2008). https://doi.org/10.1016/j.ergon.2008.01.006

Marfell-Jones, M., Olds, T., Stewart, A., Carter, L.: EstándaresInternacionales para Mediciones Antropométricas. Sociedad Internacional Para El Avance de La Kineantropometria (ISAK) (2006). https://doi.org/10.1002/ange.19881000805

Martin-Ruiz, C., Von Zglinicki, T.: Biomarkers of healthy ageing: expectations and validation. Proc. Nutr. Soc. (2014). https://doi.org/10.1017/S0029665114000147

Massy-Westropp, N.M., Gill, T.K., Taylor, A.W., Bohannon, R.W., Hill, C.L.: Hand Grip Strength: Age and gender stratified normative data in a population-based study. BMC Res. Notes **4** (2011). https://doi.org/10.1186/1756-0500-4-127

Matheson, L.N., Verna, J., Dreisinger, T.E., Leggett, S., Mayer, J., Louis, S.: Age and gender normative data for lift capacity **49**, 257–269 (2014). https://doi.org/10.3233/WOR-131671

Mathiowetz, Virgil. (19852002). Comparison of Rolyan and Jamar dynamometers for measuring grip strength. Occup. Therapy Int. **9**(3), 201–209. https://doi.org/10.1002/oti.165

Merkus, S.L., Lunde, L.K., Koch, M., Warsted, M., Knardahl, S., Veiersted, K.B.: Physical capacity, occupational physical demands, and relative physical strain of older employees in construction and healthcare. Int. Arch. Occup. Environ. Health (2019). https://doi.org/10.1007/s00420-018-1377-5

Mesquita, C.C., Ribeiro, C., Moreira, P., Mesquita, C.C., Ribeiro, C., Moreira, P.: Portuguese version of the standardized Nordic musculoskeletal questionnaire: cross cultural and reliability (2010)

Monteiro, W.D., Soter, P., Cavalcante, S., Farinatti, P.: Validation of the Par-Q questionnaire: sensitivity and specificity of the method in military personnel of the Brazilian Air Force. In: 8th Congress of Physical Education and Sport Sciences of Portuguese-speaking countries, vol. 2000, pp. 7–13 (2000)

Müglich, D., Sinn-behrendt, A., Bruder, R.: Requirements to assess physical work-ability of production workers in the manufacturing industry. In: Proceedings 19th Triennial Congress of the IEA, (August), pp. 1–8 (2015b)

Norheim, K.L., Hjort Bønløkke, J., Samani, A., Omland, Ø., Madeleine, P.: The effect of aging on physical performance among elderly manual workers: protocol of a cross-sectional study. JMIR Research Protocols (2017). https://doi.org/10.2196/resprot.8196

Okunribido, O.O., Wynn, T., Lewis, D.: Are older workers at greater risk of musculoskeletal disorders in the workplace than young workers?—A literature review. Occup. Ergon. (2011). https://doi.org/10.3233/OER-2011-0192
Palmer, K.T., D'Angelo, S., Harris, E.C., Linaker, C., Gale, C.R., Evandrou, M., Walker-Bone, K.: Frailty, prefrailty and employment outcomes in Health and Employment after Fifty (HEAF) study. Occup. Environ. Med. **74**(7), 476–482 (2017). https://doi.org/10.1136/oemed-2016-104103
Piercy, K.L., Troiano, R.P., Ballard, R.M., Carlson, S.A., Fulton, J.E., Galuska, D.A., … Olson, R.D.: The physical activity guidelines for Americans. JAMA - Journal of the American Medical Association (2018). https://doi.org/10.1001/jama.2018.1485
Reneman, M.F., Soer, R., Gerrits, E.H.J.: Basis for an FCE methodology for patients with work-related upper limb disorders. J. Occup. Rehabil. (2005). https://doi.org/10.1007/s10926-005-5942-x
Rissén, D., Melin, B., Sandsj´o, L., Dohns, I., Lundberg, U.: Psychophysiological stress reactions, trapezius muscle activity, and neck and shoulder pain among female cashiers before and after introduction of job rotation. Work and Stress (2002). https://doi.org/10.1080/02678370210141530
Schaub, K., Caragnano, G., Britzke, B., Bruder, R.: The European assembly worksheet. Theor. Issues Ergon. Sci. **14**(6), 616–639 (2013). https://doi.org/10.1080/1463922X.2012.678283
Silva, C., Amaral, V., Pereira, A., Bem-Haja, P., Pereira, A., Rodrigues, V., Nossa, P.: Copenhagen psychosocial questionnaire-Portugal e Paises Africanos de Lingua oficial Portuguesa. Mental Health **5**(5), 5 (2006). https://doi.org/10.1177/1403494809353652
Silva, C., Pereira, A., Bem-haja, P.: Índice de Capacidade para o Trabalho: Portugal e Paises Africanos de Lingua Oficial Portuguesa Universidade de Aveiro Instituto Finlandês de Saúde Ocupacional Universidade de Coimbra—Centro de Estudos e Investigação de Saúde UC Sindicato de Enfermeiros (2011). (January)
Soer, R., Gerrits, E.H.J., Reneman, M.F.: Test-retest reliability of a WRULD functional capacity evaluation in healthy adults. Work (2006)
Soer, R., van der Schans, C.P., Geertzen, J.H., Groothoff, J.W., Brouwer, S., Dijkstra, P.U., Reneman, M.F.: Normative Values for a Functional Capacity Evaluation. Arch. Phys. Med. Rehabil. **90**(10), 1785–1794 (2009). https://doi.org/10.1016/j.apmr.2009.05.008
Soer, R., Brouwer, S., Geertzen, J.H., Van Der Schans, C.P., Groothoff, J.W., Reneman, M.F.: Decline of functional capacity in healthy aging workers. YAPMR **93**(12), 2326–2332 (2012). https://doi.org/10.1016/j.apmr.2012.07.009
Soer, R., Hollak, N., Deijs, M., Van Der Woude, L.H., Reneman, M.F.: Matching physical work demands with functional capacity in healthy workers: can it be more efficient? Appl. Ergon. **45**(4), 1116–1122 (2014). https://doi.org/10.1016/j.apergo.2014.01.011
Sousa-Santos, A.R., Afonso, C., Moreira, P., Padrão, P., Santos, A., Borges, N., Amaral, T.F.: Weakness: the most frequent criterion among pre-frail and frail older Portuguese. Arch. Gerontol. Geriatr. **74**, 162–168 (2018). https://doi.org/10.1016/j.archger.2017.10.018
Steiber, N.: Strong or weak handgrip? normative reference values for the German population across the life course stratified by sex, age, and body height. PLoS ONE **11**(10), 1–14 (2016a). https://doi.org/10.1371/journal.pone.0163917
Suzman, R., Beard, J.: Global Health and Aging. NIH Publication No. 117737, vol. 1(4), pp. 273–277 (2011). https://doi.org/11-7737
Thomas, S., Reading, J., Shephard, R.J.: Revision of the physical activity readiness questionnaire (PAR-Q). Can J. Sport. Sci. (1992)
Tuomi, K., Huuhtanen, P., Nykyri, E., Ilmarinen, J.: Promotion of work ability, the quality of work and retirement. Occup. Med. **51**(5), 318–324 (2001). https://doi.org/10.1093/occmed/51.5.318
Warburton, D.E.R., Jamnik, V.K., Bredin, S.S.D., Gledhill, N.: On the power-law of the internet and the prediction of BGP convergence. Health Fit. J. Canada **4**(2), 4(2), 3–17 (2011). ISSN 1920-6216. https://doi.org/10.1109/ICISP.2006.24
Ware, J.E., Kosinski, M., Keller, S.D.: A 12-Item short-form health survey: construction of scales and preliminary tests of reliability and validity. Med. Care (1996). https://doi.org/10.1097/00005650-199603000-00003
World Health Organization (WHO): World report on ageing and health (2015)

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Other Occupational and Environmental Issues

Environmental Determinants of Home Accident Risk Among the Elderly. A Systematic Review

Tuíra Maia and Laura Martins

Abstract Objective: The purpose of this study is to identify the main risk factors for home accidents among the elderly through a systematic review. Background: It is known that 40% of domestic accidents occur due to environmental risk factors, however, few studies systematically describe these factors. Method: The aim of this study is to identify the main risk factors for domestic accidents among the elderly through a systematic review. For this, studies published in the period between 2011 and 2021 were considered, which addressed domestic accidents in the elderly population. The bibliographic search was carried out in the Scielo, CAPES, LILACS and Scopus electronic databases. Only articles in English, Portuguese and Spanish were included. Results: Six articles were considered for this review. The risk factors found were: inadequate lighting, slippery surfaces, absence of handrails on the stairs, absence of support bars, uneven floors, environments with an excess of furniture and objects, high mattress or beds, loose rugs, presence of unstable furniture, electrical wires scattered on the floor, poorly positioned furniture, inadequate height of the toilet, obstacles inside the house, presence of stairs to access the housing, and uneven sidewalk outside. Conclusion: This study allowed us to identify the risk factors related to the environment that are most prevalent in domestic accidents among the elderly. Application: This study can help design and health professionals to direct accident prevention strategies in the home environment.

Keywords Aging · Risk factors · Environment · Prevention

1 Introduction

Aging is a global phenomenon that represents a response to the transformations caused by the fall in fertility and mortality rates, as well as the increase in life expectancy (Medeiros et al. 2014). This increase in longevity associated with socio-

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cultural changes has promoted an increase in the participation and autonomy of older people, however, often without the necessary environmental conditions and adaptations to perform activities and actions safely (Degani et al. 2014).

Accidents and unintentional injuries rank fifth among the causes of death of the elderly in the United States (Rubenstein 2006). In Brazil, approximately 30–40% of the elderly population suffer some type of accident, among them, the most recurrent is the fall (Oliveira et al. 2014). Although aging is considered a natural phenomenon, the decline in functional capacity is inevitable with advancing age. This functional decline associated with extrinsic and intrinsic factors makes the elderly more vulnerable to accidents (Brasil 2011). Intrinsic factors are related to health conditions linked to the individual himself, such as muscle weakness, reduced hearing and visual acuity, changes due to the use of medications, acute diseases, among others (Neto et al. 2017).

Extrinsic factors, in turn, are those found in the interaction of the elderly with the environment in which they live, being home the place with the highest exposure to these risks. These factors can be determinant in the occurrence of accidents, including slippery floors, inadequate lighting and presence of carpets without fixation and unstable furniture (Neto et al. 2017).

Despite rapid scientific advances, the occurrence of domestic accidents still causes serious repercussions on the quality of life and autonomy of this population. Therefore, it becomes necessary to identify the risks involved in these accidents in order to identify and understand in a deep and thorough way the aspects involved in each environment for the development of actions that can contribute to the organization of safer environments for the elderly.

When considering domestic accidents as one of the main causes of morbidity and mortality, especially in the elderly, and the physical, emotional, financial and social damage to the individual, family and society, it shows the relevance of conducting this research to expand the knowledge about the risk of domestic accidents in the elderly in order to identify the risk factors, especially the environmental ones, which can be more easily modified, favoring the discovery of forms of prevention that can be incorporated into the practices of design and health professionals, aiming at a safe aging. Thus, the aim of this study is to identify, through a systematic review, the main risk factors for domestic accidents among the elderly.

2 Materials and Methods

This is a systematic literature review conducted according to the simplified model proposed by Conforto et al. (2011). Through this review, it was possible to map the environmental risk factors for the occurrence of domestic accidents among the elderly for the development of the theoretical framework of this thesis, as well as data processing for the development of the protocol. The research question was formulated through the PICo strategy comprising: What are the determining environmental factors for the occurrence of domestic accidents among the elderly? Taking into consideration, Population (P), the elderly; Interest, area/Intervention (I), risk factors for falls; Context (Co), residences. To answer this question, complete articles were analyzed, published in the period from 2011 to 2021 that describe the risk factors for home accidents among the elderly related to the environment.

The search was conducted from March to April 2021, in the following databases: Scientific Eletronic Library Online (SciELO), Periódicos Capes, LILACS (Latin American and Caribbean Literature on Health Sciences) and Scopus. The descriptors used in the search were: older OR elderly AND domestic accidents AND extrinsic factors OR environmental risk OR environmental hazard. For this review, only articles in English, Portuguese and Spanish were analyzed. In addition to the language of publication, the search strategy was limited to texts available in full and the presence of descriptors in the title and abstract. For this review we selected studies with elderly people (older than 60 years, according to the World Health Organization) and that considered environmental factors as determinants of domestic accidents in their description. The articles selected according to the inclusion criteria were analyzed independently by two reviewers. Exclusion criteria were articles about elderly residents in long-stay institutions, symposium, congress and conference articles, and literature review articles.

The articles were selected by two independent reviewers, who independently evaluated the titles and abstracts. In case of disagreement between the two reviewers, a third reviewer evaluated the article. After this first selection of articles, the remaining articles were read in full, and those that did not meet the inclusion criteria were excluded. Studies were selected using Preferred Reporting Items for Systematic Reviews and Meta-Analyse (PRISMA) through identification, selection, and eligibility assessment.

3 Results

The initial search contained 113 articles, of which 41 in the Capes journals, 15 in LILACS, 6 in SciELO, and 51 in Scopus. Of these, 5 were eliminated for being repeated in the databases and 82 were excluded for not addressing the research theme by reading the title and abstract. Twenty-six articles were included for full reading; however, 20 of these articles did not address the environmental factors related to domestic accidents (Fig. 1).

In all the studies analyzed, the most prevalent domestic accident was falls. Unlike the other studies, Gautério et al. (2015), Neto et al. (2018), and Oliveira et al. (2018) researched only about falls, without discussing other types of accidents in the articles. Burns, poisoning, and sharps accidents were other types of accidents that occurred in elderly households (Camilloni et al. 2011; Santos et al. 2016).

Of the 6 articles, only Oliveira et al. (2018), evaluated the external environment of the homes. Camilloni et al. (2011), was the only author who described the places with the highest occurrence of accidents, which are: the living room, bedroom, and hallway. Regarding the circumstances of accidents, only Camilloni et al. (2011)

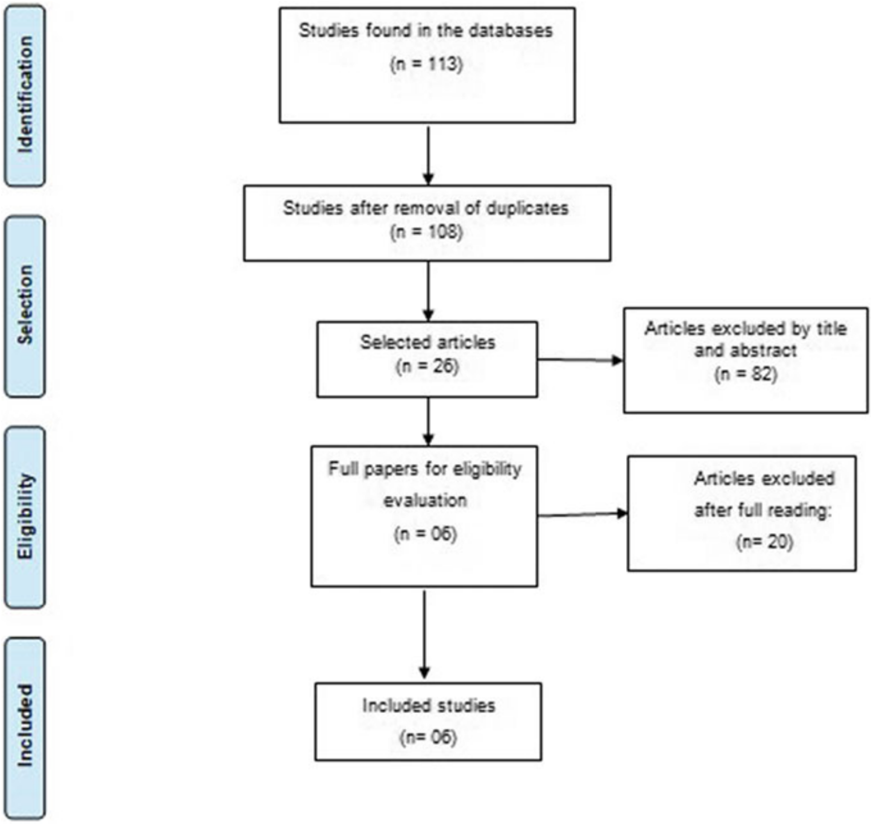

Fig. 1 Flowchart of the selected studies

described that most accidents occurred while performing physiological activities (drinking, eating) and housework.

To facilitate the understanding of the risk factors found in the articles included in the study, the analysis of the environmental determinants that contributed to the occurrence of domestic accidents in the home of the elderly is described in Table 1.

4 Discussion

Environmental risk factors were found in most domestic accidents that occurred with the elderly, however, only related risk factors were described in the articles (Aras et al. 2012; Camilloni et al. 2011; Gautério et al. 2015; Oliveira et al. 2018; Santos et al. 2016; Neto et al. 2018). In a study involving 50 elderly people, Cavalcante et al. (2012), showed that the causes of falls occurring inside homes were mainly related to

Table 1 Systematization of the environmental determinants of domestic accidents among the elderly

Environmental risk factors	Authors
Inadequate lighting	Aras et al. (2012), Camilloni et al. (2011), Gautério et al. (2015), Neto et al. (2018), Oliveira et al. (2018)
Slippery surfaces	Aras et al. (2012), Gautério et al. (2015), Neto et al. (2018)
Lack of handrails on the stairs	Aras et al. (2012), Neto et al. (2018), Oliveira et al. (2018)
Absence of support bars	Aras et al. (2012), Oliveira et al. (2018)
Uneven floors	Gautério et al. (2015), Neto et al. (2018), Oliveira et al. (2018)
Environments with too much furniture and objects	Gautério et al. (2015)
Mattress or high beds	Neto et al. (2018)
Loose carpets	Gautério et al. (2015), Oliveira et al. (2018)
Presence of unstable furniture	Oliveira et al. (2018)
Electrical wires scattered on the floor	Oliveira et al. (2018)
Poorly positioned furniture	Neto et al. (2018), Oliveira et al. (2018), Santos et al. (2016)
Inadequate height of the toilet bowl	Neto et al. (2018)
Obstacles inside the house	Neto et al. (2018)
Presence of stairs to access the dwelling	Oliveira et al. (2018)
Uneven sidewalk outside	Oliveira et al. (2018)

the inadequate home environment, among them, the most common was the presence of slippery surfaces.

Regarding the types of accidents found in the studies, burns, intoxication, accidents with sharp objects, and especially falls, which are the most prevalent accident in all studies, stand out. In the scientific literature, it is notorious the high academic production directed to falls, being found several reviews focused on this type of accident (Farias and Santos 2012; Medeiros et al. 2014; Sousa et al. 2016). According to the study of Camilloni et al. (2011), the place of higher occurrence of falls is the living room.

The most prevalent risk factors in the studies evaluated were: inadequate lighting, slippery surfaces, absence of handrails on the stairs, uneven floors, and poorly positioned furniture (Aras et al. 2012; Camilloni et al. 2011; Gautério et al. 2015; Oliveira et al. 2018; Neto et al. 2018). These extrinsic factors are considered by professionals, family members and caregivers as modifiable, however, the adequacy and adherence of guidelines and changes to make the residence safer is the most difficult to overcome (Medeiros et al. 2014).

On the other hand, most studies have pointed out that, although extrinsic factors are determinants of the occurrence of accidents, they do not determine the domestic accident in isolation, but rather, the combination of extrinsic and intrinsic factors are considered the most relevant cause for the occurrence of new accidents (Camilloni et al. 2011; Gautério et al. 2015; Oliveira et al. 2018; Santos et al. 2016).

In addition, studies also highlight that behavioral practices also influence the episodes of accidents, among them, not cleaning up water spills, walking on wet floors, and carpets spread on the floor of the house (Aras et al. 2012; Gautério et al. 2015; Oliveira et al. 2018). Habits such as exercising regularly have been found to be protective factors against accidents (Camilloni et al. 2011).

The use of safety measures/practices at home associated with awareness of necessary attitudes is important to prevent home accidents among the elderly (Aras et al. 2012). Checking the expiration dates of products and the wear and tear of electrical cords, periodic maintenance of home systems, the presence of rubber mats and support bars in the bathroom, switches near the doors, light accessible from the bed, lights on in the hallway, external leaf cleaning and even maintaining direct contact with a friend or neighbor were considered protective factors (Aras et al. 2012).

4.1 Limitations

The limitations of this study were the few databases and keywords used.

5 Conclusions

From this review, it was possible to describe, in a systematic way, the most prevalent risk factors related to the environment in domestic accidents among the elderly. These aspects can help design professionals and health professionals to direct strategies to prevent these accidents in the home environment, facilitating the construction of protocols that can guide the organization of homes, as well as the necessary guidelines and adjustments in the routine and actions of the elderly and their families.

References

Aras, R., Narayan, V., D'Souza, N., Veigas, I.: Assessment of accident risk among elderly in domestic environment: A cross-sectional study in rural south Karnataka, India. Ann. Trop. Med. Public Health **5**(6), 565 (2012)

Brasil. Ministério da Saúde, Secretaria de Vigilância em Saúde, Departamento de Análise de Situação de Saúde. Plano de ações estratégicas para o enfrentamento das doenças crônicas não transmissíveis (DCNT) no Brasil 2011-2022 (2011). Brasília, DF: MS; 2011 [acesso em 03mai. 2021]. Disponível em: bvsms.saude.gov.br/bvs/publicacoes/plano_acoes_enfrent_dcnt_2011.pdf

Camilloni, L. Farchi, S.; Rossi, P.G., Chini, F., Giorgio, M., Molino, N., Iannone, A., Borgia, P. & Guasticchi, G.: A case-control study on risk factors of domestic accidents in an elderly population. Int. J. Injury Control Saf. Promot. **18**(4), 269–276 (2011). https://doi.org/10.1080/17457300.2011.562615

Cavalcante, A.L.P., Aguiar, J.B., Gurgel, L.A.: Fatores associados a quedas em idosos residentes em um bairro de Fortaleza, Ceará. Revista Brasileira de Geriatria e Gerontologia **15**(1), 137–146 (2012). https://doi.org/10.1590/S1809-98232012000100015

Conforto, E.C., Amaral, D.C., Silva, S.L.D.: Roteiro para revisão bibliográfica sistemática: aplicação no desenvolvimento de produtos e gerenciamento de projetos. 8o Congresso Brasileiro de Gestão de Desenvolvimento de Produto - CBGDP. Anais, 1–12 (2011)

Degani, G.C., Júnior, G.A.P., Rodrigues, R.A.P., Luchesi, B.M., Marques, S.: Idosos vítimas de trauma: doenças preexistentes, medicamentos em uso no domicílio e índices de trauma. Revista Brasileira de Enfermagem **65**(5), 759–76 (2014). https://doi.org/10.1590/0034-7167.2014670513

Farias, R.G., Santos, S.M.A.: Influência dos determinantes do envelhecimento ativo entre idosos mais idosos. Texto & Contexto - Enfermagem **21**(1), 167–176 (2012). https://doi.org/10.1590/S0104-07072012000100019

Gautério, P., Zortea, D., Santos, B.C., Tarouco, S.S.S., Manoel José, B.L., and Cesar, J.F.: Risk Factors for new accidental falls in elderly patients at traumatology ambulatory center. Investigación y Educación en Enfermería, **33**(1), 35–43 (2015). Accessed from May 04, 2021, http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120530720150001000005&lng=en&tlng=en

Medeiros, K.K.A.S., Costa, G.M.C., Coura, A.S., Araújo, A.K.F., and Celino, S.D.D.M.: Perfil bibliométrico da produção científica (inter)nacional da Enfermagem Gerontogeriátrica. Revista Brasileira de Geriatria e Gerontologia (2014)

Neto, J.A.C., Brum, I.V., Braga, N.A.C., Gomes, G.F., Tavares, P.L., Silva, R.T.C. et al.: Percepção sobre queda como fator determinante desse evento entre idosos residentes na comunidade. Geriatr Gerontol Aging **11**(1), 25–31 (2017). Disponível em: http://www.ggaging.com/export-pdf/413/v11n1a05.pdf

Neto, J.A.C. et al. Percepç ao sobre queda e exposição de idosos a fatores de risco domiciliares. Ciência & Saúde Coletiva, **23**(4), 1097–1104 (2018)

Nóbrega, M.E., Lima, N.M.M., Farias, P.M.L., França, V.M.M., Vasconcelos, Guedes, P.M.S., Silva, P.M..M.: Determinants of risk of falls among elderly: a systematic study. Revista de Pesquisa Cuidado é Fundamental Online **6**(5),111–120 (2014). [fecha de Consulta 2 de Mayo de 2021]. ISSN: . Disponível em:https://www.redalyc.org/articulo.oa?id=505750772019

Oliveira, A.S., Trevizan, P.F., Bestetti, M.L.T., Melo, R.C.: Fatores ambientais e risco de quedas em idosos: revisão sistemática. Revista Brasileira de Geriatria e Gerontologia **17**(3), 637–645 (2014). https://doi.org/10.1590/1809-9823.2014.13087

Oliveira, T., Baixinho, C., Henriques, A.: Risco multidimensional de queda em idosos. Revista Brasileira em Promoção da Saúde. **31**, 1–9 (2018). https://doi.org/10.5020/18061230.2018.7058

Rubenstein. L.Z.: Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing 2006 **35**(Suppl 2), ii37-41 (2006). https://doi.org/10.1093/ageing/afl084.

Santos, A.M.R.D.O.S., Pereira, D.B.D., DE Carvalho, L.C.S., DE Madeira, M.Z., A., Andrade, E. M. L. R.: Acidentes domésticos em idosos atendidos em um hospital de urgência. Revista eletrínica de enfermagem **18**, 1–11 (2016)

Siqueira, F.V., Facchini, L.A., Piccini, R.X., Tomasi, E., Thumé, E., Silveira, D.S., Vieira, V., Hallal, P.C.: Prevalência de quedas em idosos e fatores associados. Rev Saude Publica **41**(5), 749–756 (2007). https://doi.org/10.1590/S0034-89102007000500009

Sousa, L.M.M, Marques-Vieira, C.M.A., Caldevilla, M.N.G.N., Henriques, C.M.A.D., Severino, S.P.P., Caldeira, S.M.A.: Risk for falls among community-dwelling older people: systematic literature review. Revista Gaúcha de Enfermagem, **37**(4), Acesso em: 03 de mai, 2021 (2016). https://doi.org/10.1590/1983-1447.2016.04.55030l

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Impacts of Nonstandard Work Schedules on Family and Social Life: The Children's Perspective

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Abstract Objective: This study aims to understand the impacts of nonstandard work schedules on family and social life from the perspective of workers' children. Background: The literature has shown that nonstandard work schedules, especially those involving rotating shifts and/or nights, have negative consequences for workers' families and social life. However, workers' perspective has been used mostly, being that literature recommends the inclusion of the perspective of third parties such as their family members. Method: Twelve children of workers working in nonstandard work schedules, aged between 14 and 20 years, participated in the study. Data were obtained using semi-structured interviews. Results: Negative impacts were reported on time spent with family, communication, school activities, extracurricular activities, and family management. The participants also reported disadvantages to the health of workers, such as fatigue and sleep problems. According to them, conventional working hours would be more beneficial for family and social life and workers' health. Application: The role that the organizational context can play in adapting to nonstandard working hours is discussed in order to minimize the impacts felt by workers and families, especially in the family and social spheres.

Keywords Working hours · Shift work · Work-family conflict · Family perspective

1 Introduction

The labor market is sensitive to the changes occurring in society. For example, the increase in the operational time of organizations arises as a response to the globalization of the economy, the competitiveness of markets, among others. Consequently,

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this reorganization of working time leads to nonstandard work schedules such as shift work, night work, or weekend work. Presser and Ward (2011) argued that defining nonstandard work schedules is somewhat problematic given the multiplicity of schedules practiced. However, this concept has been applied mostly to schedules that are different from the standard schedule (i.e. work on weekdays from 8 a.m. to 5 p.m.). According to the latest European Working Conditions Survey (Eurofound 2016), in 2015, 54% of workers in the 28 member states of the European Union worked at least one Saturday per month, 19% worked on the night shift, and 21% worked on rotating shifts.

Nonstandard working hours can bring advantages and disadvantages for workers. On the one hand, workers may have greater flexibility in working hours or economic benefits (i.e. typically, night work is associated with a shift allowance) (Agosti et al. 2015; Carneiro and Silva 2015). On the other hand, these working hours can cause several problems for workers in the health, organizational and social domains (Fonseca et al. 2020; Mauno et al. 2015). In terms of health, nonstandard working hours, especially those involving night work, have been associated with various complaints by workers, including sleep, gastrointestinal and/or psychological problems, among others (Bamonde et al. 2020; Chang and Peng 2021). For example, in the review by Bastos and Afonso (2020), negative effects of shift work on sleep, mental health, cognitive and work performance of workers were identified. On the other hand, the time lag that these schedules create between workers and other household members or with society can cause problems in the family, marital, parental or social spheres (Strazdins et al. 2006; Zhao et al. 2021). For example, in the systematic review by Wöhrmann et al. (2020), the authors found that shift workers had higher levels of work-family conflict (WFC) compared to conventional schedule workers, especially if this shift work involved nights and weekends.

At the parental level, the unconventional working hours practiced by parents can negatively influence relationships with children (Hook 2012; Prickett 2018). Other studies (e.g., Castillo et al. 2020; Kachi et al. 2021; Strazdins et al. 2006) have shown an association between parents' nonstandard work schedules and problems such as obesity, behavior problems, and well-being in children. Areas such as daily monitoring, school monitoring or responsibility for children's education have also been negatively associated with these schedules (Bolino et al. 2021; Cia et al. 2008; Gracia and Kalmijn 2016). For example, Pilarz et al. (2020) found a negative association between night shift and parental involvement with children. The authors suggest that low involvement may be due to parents missing important routines such as mealtimes and that they may be more stressed and tired to spend time with children.

The study of these consequences becomes even more important when authors such as Recuero and Segovia (2021), Silva-Costa et al. (2021) or Yildiz et al. (2021) argue that WFC can be a predictor of other problems such as burnout, turnover intentions or health problems. For example, night workers, to make up for the less time spent with family, give up their hours of sleep. Furthermore, most studies about the impact of working hours on family and social life have privileged the perspective of the workers themselves rather than the perspective of others, such as their family members. As several authors point out (e.g., Bolino et al. 2021; Molina 2020), it is necessary to include other methodologies and other perspectives in the study of this theme. In this sense, this study aims to contribute to understanding the impacts of nonstandard work schedules for workers, especially in family and social life and from their children's perspective. As previously mentioned, the integration of this perspective is scarce.

2 Materials and Methods

2.1 Participants

Twelve children of nonstandard work schedule workers aged 14–20 (M = 17.03; DP = 2.14) participated in the study. Two-thirds were female, and ten participants lived in the North region of Portugal. One-third of participants had completed the 2nd cycle of basic education, one-sixth had completed the 3rd cycle of basic education, five-twelfths had completed secondary education, and one-twelfth had completed a Higher Professional Technical Course. As for the workers (i.e. parents of participants submitted to nonstandard schedules), the average age was 47.25 years (SD = 4.51), and seven were female. Of the 12 workers, half worked in industry, one-sixth in the health sector, one-twelfth in the hospitality industry, one-twelfth in food service, one-twelfth in the social sector, and one-twelfth in the esthetics sector. As for working hours, one-fourth worked in rotating shifts (alternating between morning-afternoon-night), one-fourth in irregular hours (i.e. without defining start and end times) with nights and weekends, one-fourth on fixed afternoon shifts that included working on Saturday, one-third on fixed morning shifts that included working on Saturday and one-twelfth on night shift. One-fourth of the 12 participants had both parents working on nonstandard work schedules. Of the 12 employees, five-twelfths worked on their work schedule for more than 20 years, one-twelfth between 11 and 20 years, one-fourth between six and 10 years, and one-fourth between one and five years.

2.2 Instruments

Sociodemographic data of the participants (e.g., educational level), of their parents (e.g., age), and of their employment status (e.g., working hours) were collected using a sociodemographic and occupational questionnaire developed in the present study.

In turn, data regarding the impacts of nonstandard working hours were collected through semi-structured interviews. The interview guide was developed based on the literature review carried out (e.g., Cia and Barham 2005; Cia et al. 2008; Hook 2012; Root and Wooten 2008; Gracia and Kalmijn 2016) and in works previously developed in the research group (e.g., Costa and Silva 2019; Costa et al. 2017; Gonçalves et al. 2020). It consisted of the following areas that could be impacted by working hours:

time spent with family, time spent between father/mother and child, communication between father/mother and child, joint activities, school activities, and extracurricular activities.

2.3 Procedures

Initially, numerous Portuguese study centers and trade union organizations were contacted for further dissemination at the national level. However, given the low adhesion in this first phase of data collection, a convenience sampling method was used, with successive "snowball" dissemination among the participants. Data were collected through interviews conducted in a videoconference format (Zoom). Before conducting the interviews, the participants had to fill out an informed consent form as well as their guardians. In addition to explaining the objectives of the study, the consents reinforced the anonymity and confidentiality of the data. The interviews were recorded in audio and video format, with an average duration of 15 min. All interviews were transcribed in full by the principal researcher. The number of interviews was dependent on the theoretical saturation of the data (Nascimento et al. 2018). The present study integrates a Ph.D. Project, which was approved by the Ethics Committee of the University of Minho (CEICSH 098/2020).

2.4 Data Analysis

In the analysis of the interviews, Template Analysis (King 2004) was used. This technique allows to start the analysis with some themes defined a priori through the interview guide (initial template) and to modify/eliminate them based on the data obtained in the interviews (final template). Data analysis was performed by two independent judges (principal researcher and specialist external to the study) in order to compare the products obtained in both analyzes.

3 Results and Discussion

In this section, the results of the study will be presented together with the respective discussion. Table 1 presents the final template for the theme "Perception about nonstandard work schedules" and respective subthemes.

Regarding the first theme, "Perception about nonstandard work schedules", the main advantages listed by the participants were the economic benefits "The only advantage is the salary." (P11) and the flexibility of schedules "Have more time during the day to do things." (P4), what is supported by the literature as in the study by Carneiro and Silva (2015). On the other hand, the disadvantages focused on aspects

Table 1 Final template of the theme "Perception about nonstandard work schedules"

Final template
1. Perception about nonstandard work schedules
1.1. Advantages
1.1.1. Flexibility provided by the schedule
1.1.2. Time alone
1.1.3. Economic benefits
1.2. Disadvantages
1.2.1. Health
1.2.1.1. Tiredness
1.2.1.2. Sleep
1.2.2. Absence of the parent
1.2.3. Weekends
1.2.4. Little time with family
1.2.5. Little personal time
1.2.6. Not being able to plan activities in advance
1.2.7. Wake-up time
1.2.8. Worker does not like the schedule

related to the health of the worker "You can really notice my father's tiredness." (P10), with family and social life "She spends very little time with family." (P11) and with more individual aspects "She doesn't have time for herself, I think she should have more time for these things, not thinking so much about work." (P11). These results are consistent with the impacts reported by authors such as Bamonde et al. (2020) or Zhao et al. (2021) and that demonstrate the need to take into account worker health and family, and social life in the management of work schedules, in order to avoid/reduce such impacts.

As we can see in Table 2, participants reported time spent with family, communication, school activities, extracurricular activities, and family management/organization as the areas likely to be most impacted by nonstandard work schedules.

In the subtopic "*Time spent with family*", most participants emphasize the negative impacts that schedules could have in this subarea, for example, in terms of time spent together "*It complicates because we do not have any day that we can really be with her, spend time with her*. (P11) or at weekends "*It is weird because my friends went for a walk with their parents on Saturday and my parents were working.*" (P6), among others. These results point to the existence of less involvement of workers assigned to nonstandard working hours in family life and daily activities, as argued by Hook (2012) or Pilarz et al. (2020). If we think about the different temporal moments, most participants referred to weekends and evenings as the times most affected by their parents' schedules. In fact, it is in this temporal overlap between nonstandard work schedules and the most valued moments from the family point of view that

Table 2 Final template of the theme "Areas likely to be impacted by working hours"

Final template
2. Areas likely to be impacted by working hours
2.1. Time spent with the family
2.1.1. With perception of negative impact
2.1.1.1. Time spent together
2.1.1.2. Dinners
2.1.1.3. Evenings/nights
2.1.1.4. Weekend
2.1.1.5. Outputs together
2.1.1.6. Special occasions
2.1.2. No perception of impact
2.2. Communication
2.2.1. With perception of negative impact
2.2.2. No perception of impact
2.3. School activities
2.3.1. With perception of negative impact
2.3.1.1. Monitoring of school activities
2.3.1.2. Spouse's greater responsibility
2.3.1.3. Greater responsibility for another family member
2.3.2. No perception of impact
2.4. Extracurricular activities
2.4.1. With perception of negative impact
2.4.1.1. Greater responsibility for another family member
2.4.2. No perception of impact
2.5. Family management/organization
2.5.1. With perception of negative impact
2.5.1.1. Domestic activities
2.5.1.2. Spouse's greater responsibility
2.5.1.3. Greater responsibility for another family member
2.5.2. No perception of impact

WFC tends to appear. In this sense, for example, Wöhrmann et al. (2020) argue that the management of nonstandard working hours should take into account these periods. Workers must have a sufficient number of weekends and evenings/nights to enjoy with family and friends because "Parents want to see their children in the evenings, and friends often meet on Friday or Saturday evenings." (p. 21). However, two participants did not perceive any impact on the time spent with family "We managed to get out together and so." (P2).

Regarding the subtheme "*Communication*" between the participants and the father/mother, some mentioned that this was hindered by the working hours practiced by the parent "*The conversation time is shorter*" (P5), while others did not mention any kind of influence "*I still have a little time to talk to her.*" (P11). Sizane and Van Rensburg (2011) found that child-parent communication was perceived by teenagers as more efficient when mothers worked a standard schedule compared to a night shift. Although most participants reported "*School activities*" as an area affected by work schedules "*He was already tired from work, it was late, I was also tired, so I usually never asked anything, it was my mother who helped me*." (P6), others did not perceive any kind of impact "*She can help me.*" (P3). This impact at the school level takes on greater relevance when authors such as Han and Fox (2011) suggest a loss in children's school performance when parents work in nonstandard hours. Also, Cia et al. (2008) warn that the greater the communication between parents and children and the participation of parents in school activities, the better the children's academic performance. In the subtheme "*Extracurricular activities*", the responsibility of other members of the household to monitor the participants stood out, for example, "To take me it was always my grandfather that they were always working." (P7). In fact, Root and Wooten (2008) found that parents who worked in the evening and at night had more complaints about not being able to keep up with their children's activities such as sports. Finally, a subtheme that emerged in the interviews was "*Family management/organization", in which the majority of the participants mentioned that this management started to be done by other household members due to the schedule of one of the parents "It has to do with the overload from a family member*." (P6) or "I, on Saturdays, usually stay alone with my brother, so I am the one who has to take care of him (...)" (P9). In addition to these themes, the retrospective evaluation of the impact of working hours on family and social life, the adaptation strategies used, and the comparison with standard working hours were also analyzed (see Table 3).

In terms of "Retrospective evaluation", most participants reported that the impacts of nonstandard work schedules were greater when they were younger "Sometimes not having my mom is a bit complicated, especially when I was younger." (P1), which is in line with studies such as Allen and Finkelstein (2014) who found a negative relationship between the age of children and WFC. In terms of "Adaptation strategies", some were listed as practiced by the workers "For example, getting up earlier to get the work done earlier, to be able to pick me up." (P1) and by the family, "When we were at home, for example, we could not do housework because she was sleeping, we had to be much more careful." (P12). These listed strategies can help reflect about nonstandard working hours and the most appropriate management that organizations and workers should carry out. For example, Root and Wooten (2008) present three major recommendations for managing WFC in parents who work in shifts: (i) flexible working hours (e.g., flexible working arrangements taking into account the needs of workers); (ii) family-friendly policies and practices and (iii) informal approaches (e.g., relationship with coworkers). Also, Wöhrmann et al. (2020) consider that the more workers are satisfied with their working hours, the less WFC they report. In this sense, there should be flexibility in nonstandard hours, and the management/planning of these work schedules should be done in advance and with workers' participation. Lastly, the participants considered that working in a standard work schedule would be more beneficial for the family "I think it would

Table 3 Final template of other interview themes

Final template
3. Retrospective evaluation
3.1. Greater impact when younger
3.2. No perception of changes
4. Adaptation strategies
4.1. Worker
4.1.1. Work schedule management
4.1.2. Disclosure of working hours
4.2. Family
4.2.1. Noise reduction
5. Comparison with standard work schedule
5.1. Most beneficial standard work schedule
5.1.1. Time spent with family
5.1.2. Couple time
5.1.3. Domestic activities
5.1.4. Health
5.2. No perception of changes

be different, we were going to have more time with the family, we were going to do more things together, and we were going to have more communication because we were together, we were with the family (...)" (P6) and for the worker himself "It would also be good for her mental health." (P1). This perception of more free time in common among family members when everyone works on standard hours compared to nonstandard working hours is also supported by the literature (Wöhrmann et al. 2020; Zhao et al. 2021), as well as the health problems that nonstandard work schedules can cause for workers such as sleep or psychological problems (Bamonde et al. 2020). In fact, the tendency to implement work schedules different from the conventional has been increasing, making the management of these requirements even more pressing by organizations, workers and their families.

4 Limitations and Conclusions

Our results are in line with the literature that reports the existence of impacts of nonstandard work schedules on workers' health and family and social life, in this case, from their children's perspective. When analyzing these results, the heterogeneity of the work schedules practiced by the parents of the participants should be taken into consideration. In the future, one should try to standardize this characteristic in order to better understand the impacts of a certain nonstandard work schedule. It would also be interesting to compare the perspective of children of workers working in nonstandard work schedules with the perspective of children of workers working in standard work schedules. Despite the scarcity of studies that consider the perspective of children, it is important to continue exploring this theme in the future. The better the understanding of this issue and its impacts on family and social life, the better strategies can be planned to help reduce such conflict. In this sense, the ideal would be the extinction of these work schedules. However, given the impossibility of this measure, strategies such as the involvement of workers in the management of their work schedules, consider the ergonomic recommendations for these times (e.g., workers to be informed in advance of possible shift changes), greater flexibility or greater organizational support (e.g., the supervisor/organization responds to shift change requests) can help in the process of adapting to work schedules in general and in reducing health problems and conflict with the family and social spheres in particular.

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References

Agosti, M.T., Andersson, I., Ejlertsson, G., Janlöv, A.C.: Shift work to balance everyday life-a salutogenic nursing perspective in home help service in Sweden. BMC Nurs. **14**(2), 1–11 (2015). https://doi.org/10.1186/s12912-014-0054-6

Allen, T.D., Finkelstein, L.M.: Work-family conflict among members of full-time dual-earner couples: an examination of family life stage, gender, and age. J. Occup. Health Psychol. **19**(3), 376 (2014). https://doi.org/10.1037/a0036941

Bamonde, J., Pinto, C., Santos, P., Couto, G.: O impacto do trabalho por turnos na saúde dos enfermeiros: Revisão integrativa [The impact of shift work on nurse's health: Integrative review]. Revista de Investigação & Inovação em Saúde **3**(2), 101–110 (2020). https://doi.org/10.37914/riis.v3i2.85

Bastos, J., Afonso, P.: O impacto do trabalho por turnos no sono e na saúde psíquica [The impact of shiftwork on sleep and mental health]. Revista Portuguesa de Psiquiatria e Saúde Mental **6**(1), 24–30 (2020). https://doi.org/10.51338/rppsm.2020.v6.i1.101

Bolino, M.C., Kelemen, T.K., Matthews, S.H.: Working 9-to-5? A review of research on nonstandard work schedules. J. Organ. Behav. **42**(2), 188–211 (2021). https://doi.org/10.1002/job.2440

Carneiro, L., Silva, I.S.: Trabalho por turnos e suporte do contexto organizacional: Um estudo num centro hospitalar [Shift work and organizational support: A study in a hospital]. Int. J. Work. Cond. **9**, 142–160 (2015)

Castillo, B., Grogan-Kaylor, A., Gleeson, S.M., Ma, J.: Child externalizing behavior in context: associations of mother nonstandard work, parenting, and neighborhoods. Child. Youth Serv. Rev. **116**, 105220 (2020). https://doi.org/10.1016/j.childyouth.2020.105220

Chang, W.P., Peng, Y.X.: Differences between fixed day shift nurses and rotating and irregular shift nurses in work-related musculoskeletal disorders: a literature review and meta-analysis. J. Occup. Health **63**(1), e12208 (2021). https://doi.org/10.1002/1348-9585.12208

Cia, F., Barham, E.J.: A relação entre o turno de trabalho do pai e o autoconceito do filho [The relationship between fathers' workshift and their children's self-concept]. Psico **36**(1), 29–35 (2005)

Cia, F., Pamplin, R.C.D.O., Williams, L.C.D.A.: O impacto do envolvimento parental no desempenho acadêmico de crianças escolares [The impact of parental involvement on children's aca-

demic performance]. Psicologia em Estudo **13**(2), 351–360 (2008). https://doi.org/10.1590/S1413-73722008000200018
Costa, D., Silva, I.S.: Impactos na vida social e familiar do trabalho por turnos na perspectiva dos familiares [Social and family life impact of shift work from the perspective of family members]. Revista de Administração de Empresas **59**(2), 108–120 (2019). https://doi.org/10.1590/s0034-759020190204
Costa, D., Silva, I.S., Veloso, A.: Experience in working shifts: the spouses/partners vision of shift workers and day workers. In: Arezes, P.M., Baptista, J.S., Barroso, M.P., Carneiro, P., Cordeiro, P., Costa, N., Melo, R.B., Miguel, A.S., Perestrelo, G. (eds.) Occupational Safety and Hygiene V, pp. 369–373. Taylor & Francis Group (2017)
European Foundation for the Improvement of Living and Working Conditions [Eurofound].: Sixth European Working Conditions Survey - Overview report. Publications Office of the European Union (2016). https://doi.org/10.2806/518312
Fonseca, S., Queirós, C., Martins, V.: Saúde ocupacional na ferrovia: Trabalho por turnos, burnout, sono e interação trabalho-famlia [Occupational health on the railway: Shift work, burnout, sleep and work-family interaction]. Psicologia, Saúde & Doenças **21**(1), 221–228 (2020). https://doi.org/10.15309/20psd210132
Gonçalves, S.F., Silva, I.S., Veloso, A.L.: Trabalho por turnos e vida familiar e social na perspectiva dos/as filhos/as [Shift work and its impacts on family life and social life from children's perspective]. Psicologia Em Estudo **25** (2020). https://doi.org/10.4025/psicolestud.v25i0.48999
Gracia, P., Kalmijn, M.: Parents' family time and work schedules: the split-shift schedule in Spain. J. Marriage Fam. **78**(2), 401–415 (2016). https://doi.org/10.1111/jomf.12270
Han, W.J., Fox, L.E.: Parental work schedules and children's cognitive trajectories. J. Marriage Fam. **73**(5), 962–980 (2011). https://doi.org/10.1111/j.1741-3737.2011.00862.x
Hook, J.L.: Working on the weekend: fathers' time with family in the United Kingdom. J. Marriage Fam. **74**(4), 631–642 (2012). https://doi.org/10.1111/j.1741-3737.2012.00986.x
Kachi, Y., Abe, A., Eguchi, H., Inoue, A., Tsutsumi, A.: Mothers' nonstandard work schedules and adolescent obesity: a population-based cross-sectional study in the Tokyo metropolitan area. BMC Public Health **21**(1), 1–10 (2021). https://doi.org/10.1186/s12889-021-10279-w
King, N.: Using templates in the thematic analysis of text. In: Cassell, C., Symon, G. (eds.) Essential guide to qualitative methods in organizational research, pp. 256–270. Sage (2004)
Mauno, S., Ruokolainen, M., Kinnunen, U.: Work–family conflict and enrichment from the perspective of psychosocial resources: comparing finish healthcare workers by working schedules. Appl. Ergon. **48**, 86–94 (2015). https://doi.org/10.1016/j.apergo.2014.11.009
Molina, J.A.: The work-family conflict: evidence from the recent decade and lines of future research. J. Fam. Econ. Issues (2020). https://doi.org/10.1007/s10834-020-09700-0
Nascimento, L.C.N., Souza, T.V., Oliveira, I.C.S., Moraes, J.R.M.M., Aguiar, R.C.B., Silva, L.F.: Theoretical saturation in qualitative research: an experience report in interview with schoolchildren. Revista Brasileira de Enfermagem **71**(1), 228–233 (2018). https://doi.org/10.1590/0034-7167-2016-0616
Pilarz, A.R., Cuesta, L., Drazen, Y.: Nonstandard work schedules and father involvement among resident and nonresident fathers. J. Marriage Fam. **82**(2), 587–604 (2020). https://doi.org/10.1111/jomf.12627
Presser, H.B., Ward, B.W.: Nonstandard work schedules over the life course: a first look. Mon. Labor Rev. 3–16 (2011)
Prickett, K.C.: Nonstandard work schedules, family dynamics, and mother-child interactions during early childhood. J. Fam. Issues **39**(4), 985–1007 (2018). https://doi.org/10.1177/0192513X16684893
Recuero, L.H., Segovia, A.O.: Work-family conflict, coping strategies and burnout: a gender and couple analysis. J. Work Organ. Psychol. **37**(1), 21–28 (2021). https://doi.org/10.5093/jwop2021a5
Root, L.S., Wooten, L.P.: Time out for family: shift work, fathers, and sports. Hum. Resour. Manag. **47**(3), 481–499 (2008). https://doi.org/10.1002/hrm.20228

Silva-Costa, A., Toivanen, S., Rotenberg, L., Viana, M.C., Fonseca, M.D.J.M.D., Griep, R.H.: Impact of work-family conflict on sleep complaints: results from the longitudinal study of adult health (ELSA-Brasil). Front. Public Health **9** (2021). https://doi.org/10.3389/fpubh.2021.649974
Sizane, N.F., Van Rensburg, E.: Night shift working mothers: mutual perceptions with adolescent children. J. Psychol. Afr. **21**(1), 71–78 (2011). https://doi.org/10.1080/14330237.2011.10820431
Strazdins, L., Clements, M.S., Korda, R.J., Broom, D.H., D'Souza, R.M.: Unsociable work? Nonstandard work schedules, family relationships, and children's well-being. J. Marriage Fam. **68**(2), 394–410 (2006). https://doi.org/10.1111/j.1741-3737.2006.00260.x
Wöhrmann, A.M., Müller, G., Ewert, K.: Shift work and work-family conflict: a systematic review. Sozialpolitik.ch **3**(2), 3-2 (2020). https://doi.org/10.18753/2297-8224-165
Yildiz, B., Yildiz, H., Ayaz Arda, O.: Relationship between work-family conflict and turnover intention in nurses: a meta-analytic review. J. Adv. Nurs. **77**(8), 3317–3330 (2021). https://doi.org/10.1111/jan.14846
Zhao, Y., Cooklin, A.R., Richardson, A., Strazdins, L., Butterworth, P., Leach, L.S.: Parents' shift work in connection with work-family conflict and mental health: examining the pathways for mothers and fathers. J. Fam. Issues **42**(2), 445–473 (2021). https://doi.org/10.1177/0192513X20929059

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The Challenges of Automated Driving Contributions Towards a Human-Automation Research Agenda from the Lens of the Activity

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Abstract Objective: This paper aims to explore pivotal issues of today challenges regarding automated vehicles (AVs) and develop an integrative discussion evoking the activity-centred approach towards a research agenda on relations between human operators and automated systems. Background: Despite being an emerging technology, automated driving is forecast to contribute to the performance, safety, and comfort of road transport. In the advent of "mobility of the future" models, questions focused on how such technologies will modify drivers' activity and their relations with automation need further research. Method: Through an exploratory strategy, an interview study was carried out with four automated driving expert researchers to identify their perspectives and recommendations regarding the interaction with AVs. Results: Three primary themes were identified reflecting the new ways of mobilising the human activity when the operational conditions of automated systems are no longer met; and how the human-automation relationships could be apprehended in terms of technology appropriation. Application: The study highlights the need to consider "the activity" as a unit of analysis in the integration between human drivers and automation. A reflection is provided by debating the contributions of the activity-centred approach for supporting the development of representations and the appropriation of automated driving technology.

Keywords Automation · Activity approach · Technology · Safety · Human-machine integration

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1 Introduction

The confluence of accelerated developments in automation and artificial intelligence has made automated vehicles (AVs) a reality. The announced reinvention of mobility is grounded by the compelling promise automation technology holds for safer and more efficient road transport, leading to fewer accidents by eliminating the "human error" – often coded as behavioural deviations on the part of drivers and considered as the main cause of transport accidents. Different authors have recently contested this idea (Hancock 2020; ITF 2018; Noy et al. 2018), insofar it overlooks that road crashes have multiple causes. Also, work psychologists, by analysing work accidents, have emphasised the problem of "fundamental attribution error" resulting from a social judgment that focus more on the personal rather than the multiple and conflicting contextual factors (Nyssen and De Keyser 2001).

Thus, the increased transport safety and efficiency expectedly provoked by automation have two interdependent premises that deserve some scrutiny. The first assumption depicts automation as an error-free solution and, consequently, without operational design domains (or limitations). This assumption is not entirely new within the field of human-machine integration; in the past, it supported many strategies for producing error prevention tools in industrial contexts. Thereto, the rationale was the less human operators do, the fewer errors they commit (De La Garza and Fadier 2005; Nyssen and De Keyser 2001). This "derogatory view" on the degree of human reliability (Rabardel 1995) led to a strict delimitation of human activity at work.

A second assumption, perhaps even more insidious, regards the idea that automation means the obligatory, or the inevitable (Endsley 2019a), replacement of the human activity in driving. Such an assumption is now largely disseminated through lines of social discourse announcing the rise of "driverless vehicles", "autonomous vehicles", or "self-driving vehicles" (see Orfeuil and Leriche 2019). Despite its widespread uses, these terms are rooted in the concept of autonomy, which should be distinguished from the notion of automation, as it has been reiterated (Banks et al. 2019; Hancock et al. 2020; Silva and Cunha 2021a). Albeit technology is rapidly evolving, fully automated vehicles (i.e., vehicles operating in all conditions without human intervention) are some distance away from being a reality (Hancock et al. 2020). In the foreseeable future, the human will be a key component by managing the unpredictability of the driving environment, and thus the control of the driving task will be shifted between the human and automated system (Kyriakidis et al. 2019; Simões et al. 2020).

In terms of degrees of automation, the framework provided by the Society of Automotive Engineers is relatively ubiquitous, providing a common language, and it decomposes driving automation into six levels, from manual driving (level 0) to fully automated control (level 5) (SAE 2018). Founded more upon automation capabilities rather than on the human aspects (Hancock 2020; Navarro 2019; Navarro and Gabaude 2020), this classification defines that partial and conditional automated driving (levels 2–3) require drivers to take over control of the vehicle in a safe and timely way when necessary (e.g., in the presence of an unexpected event or to recover the automated system from failures). These control transitions have been flagged as sensitive driving situations from the perspective of the human operator (Cusanno et al. 2021; ITF 2018; Johansson et al. 2021; Navarro and Gabaude 2020).

The human activity in driving is radically transformed as automation increases, and new questions concerning human usage are raised. The role of human drivers, the required competences, and the consequences for safety that could be potentially generated remain poorly understood, or underestimated, particularly when a return to manual driving is required (Banks and Stanton 2016; Kyriakidis et al. 2019; Noy et al. 2018). What will compose the relationship between the human and an AV? What will be the impact of automated driving technologies on the human's role? And what safety issues concerning human usage and experience might raise with the most advanced automation technologies?

The primary purpose of our study was to examine these research questions through an interview study with researchers in the field of automated driving. Based on their visions and recommendations, the second goal was to provide an integrative discussion evoking evidence-based contributions derived from the work psychology field concerning the human-automation relationships. The purpose is to contribute to strengthening an activity-centred research agenda (Béguin 2007; Bobillier Chaumon 2021; Daniellou and Rabardel 2005; Darses 2016) while modern automation technologies are changing the intrinsic role of the human operator.

2 Materials and Methods

Following an exploratory strategy, data for our study was collected through semi-structured interviews with experts who are currently involved in research activities within the scope of the "Autodriving" project, a Portuguese research project dedicated to analysing the human driver's behaviour in safety-critical situations (Lobo et al. 2020; Simões et al. 2021). From a driver-centric approach, this research project inscribes a three-stage plan: (i) focus-group sessions with drivers; (ii) driving simulations using an AV prototype in level 3 of automation; and (iii) the design of decision-supporting tools for stakeholders engaged in the deployment of AVs.

The interview guideline was developed by two researchers in an iterative process, and it addressed the following topic groups: (1) potential benefits and concerns associated with AVs; (2) the human-automation relationships in the context of automated driving; (3) the expected role of human drivers in the "mobility of the future"; (4) safety challenges associated with AVs.

Four in-depth interviews were conducted, each lasting between 90 and 120 min. The participants were selected based on their expertise in transport and mobility systems engineering and human factors/ergonomics (HFE), with average work experience in the field over 15 years long (mean = 15.3 years). One of the participants is a senior researcher in the field of HFE, who is particularly dedicated to the domain of human-technology interaction and cooperation applied to the context of transports;

Table 1 Interview thematic analysis results

Theme 1. Human-as-backup architecture	Theme 2. Automation safety-related outcomes	Theme 3. Technology appropriation
Machine-to-human handovers are critical	Situation awareness and workload issues	Perpetuating a model of two-agent in isolation
New requirements for a human recovery ability ("an emergency driver")	Manual competences atrophy	Time for developing new representation schemes
	Operation in the public space (interaction with the road and other users)	Understanding the machine operation and its contextual reliability
		New driver-training programmes

two of the participants have a background in engineering (transport and mobility systems engineering) and, in the project, they are dedicated to the domains of road safety, driving behaviour, and transport data modelling; and the fourth participant is an ergonomist who is studying the expectations of the drivers with respect to AVs, considering demographic variables (age and gender), or prior attitudes on AVs (e.g., technology acceptance). The experts agreed to participate in this study after signing an informed consent form approved by the Ethics Committee of the FPCEUP.

2.1 Data Reduction and Analysis

The interviews were audio-recorded and transcribed verbatim. The transcripts were then imported into NVivo 12 for coding and analysis. After a reading dedicated to generating an initial narrative (in vivo codes) from each interview (Silva and Cunha 2021b), the second coding followed an inductive (data-driven) approach guided by emerging themes (Miles et al. 2014). Thereto, interviews data were then categorized using thematic analysis. After identifying the first pool of key themes, the final coding scheme was agreed between the two researchers following repeated iterations, and it encompassed three key themes (cf. Table 1).

3 Results

The most important findings gained from the interviews are summarised in Table 1, which provides an exploratory insight into researchers' perspectives. Each theme is discussed below with illustrative quotes provided.

3.1 Theme 1: Human-as-Backup Architecture

The interviewed experts agreed that one of the major challenges in the design and deployment of AVs is the management of unexpected events for which automated driving systems are not able to deal with. In this context, up to level 3 of automation, the automated driving concept is being developed based on the assertion that human operators will intervene upon a takeover request.

This challenge is even more critical in stage 3 of vehicle automation, in which the automated system monitors the driving environment, and the human could perform non-driving tasks. In these circumstances, there is an expectation that the human operator can remain aware and respond appropriately to the requests to intervene. The experts highlighted the need to define the optimal time requirements for human drivers to return back in control of the vehicle. "The main variable under analysis is the time that goes from when the system gives an alarm to when the driver initiates a certain action to deal with that sudden event (...) Beyond the time for re-engaging in the loop control, we are also interested in the quality of manoeuvres adopted, either braking actions or trajectory deviations".

In these scenarios in which the functioning of AVs is based on the human recovery ability in the presence of abnormalities or unexpected situations, the role of the human operator changes from an active driver to an "emergency driver". "Firstly, the driver will be a supervisor of automation, and then will act as an emergency driver to respond to critical events. In the highest level of automation [level 5], the driver will be a passenger".

3.2 Theme 2. Automation Safety-Related Issues

Vehicle automation was described as an opportunity to substantially improve road transport safety and efficiency. Yet, the interviewed researchers pointed the possible "unmet expectations" of the users (Hopkins and Schwanen 2021), which are underpinned by unrealistic visions around AVs operating in all environments without human intervention.

"Mobility is a human right, insofar as it articulates means of transport that make it possible for each of us to move for getting the needed goods and services. Therefore, we need safer transport, it's a living condition. Could today's levels of automation contribute for this goal?".

The doubts expressed by this participant are related to the consequences for human drivers resulting from the automation architectures made possible today by technological progress (stages 2 and 3 of automation). Two main issues were flagged with respect to the human-automation relationship: the drivers' reduced situation awareness and the possible loss of manual driving competences. The goal of safer road transport is not independent of the ability of human drivers to maintain a certain level of situation awareness that support the intervention in those circumstances that automation cannot handle. “When the driver is disengaged from active monitoring it dramatically decreases his/her understanding of what is going on (...) The more out of the loop of control the worse, because this will increase the reaction time for an action that needs to be consistent with the situation occurring”.

However, the process of situation awareness is not only about reacting to events (Endsley 2019b), as stated by an interviewed expert. It also regards the ability to constantly project ahead based on the human experience. “It is the driver who has the knowledge base to read the situation and project ahead, I mean, to infer the possible evolution of the situation and accordingly choose an alternative. The automated system perceives the reality according to the obstacles to avoid and the trajectory calculation, and the system does this very quickly, but then there is the problem of the knowledge base”.

The plausible degradation of manual competences and dexterity involved in manual driving due to disuse was also identified. This situation could be problematic particularly in those moments when the human operator is requested to intervene.

3.3 Theme 3. Technology Appropriation

It was noted as being particularly important to develop a critical analysis on the models providing predictions of human performances with automation. The design of AVs takes as a reference the SAE framework, a technology-centred taxonomy that defines a set of tasks that are assigned to each of the agents of the driving system (human and automation). However, such a “rigid” division of tasks has been questioned. “[The SAE taxonomy] presents the human and the automated system as two agents in isolation, as if there was a rigid separation. I think it doesn’t consider that the human interacts with technology, i.e., there is an interpenetration between the two agents”.

It was argued the fact that research should aim at ensuring that the human drivers understand the AV operation, what the machine is capable to do, and foremost what the human driver needs to perform for a safe automated driving situation. “In my opinion, the driver will have to understand what the automated system needs from him/her. If we want, the human and the system are two entities in co-evolution, because they are learning to know each other”.

In our interviewees, one of the participants with a background in HFE called this process the “technology appropriation”, during which the human learns about the automated functionalities and develops representations of the shared activity. “We need to learn about how technology works, about how we can manage the tasks we do while the technology controls the vehicle. This [learning] doesn’t happen overnight, it will take time. I think that all these technological innovations should be firstly understood, what technology is capable to do”.

Yet, the interviewed experts also highlighted the time required for appropriating technology. Learning how to operate an AV and understanding the machine’s behaviour implies a set of transformations in the representation schemes that were developed for “traditional” driving. “I believe that we need to appropriate the automated driving technology, and this takes time (...) This is why the development of AVs shouldn’t be a fast process, this process needs its maturity period. I am concerned that driving automation is being put into practice without the needed maturity”.

Finally, it was discussed the need to design new training programmes aiming at teaching the drivers about the automation functionalities, its reliability, and what to do when the machine’s behaviour is different from the expected.

4 Discussion

In line with recent works (Hancock et al. 2020; Kyriakidis et al. 2019), the results confirm some of the main pivotal issues of today challenges about driving automation. Regarding the relationship between the human and AVs (first research question) and the impact of automated driving technologies on the human’s role (second research question), it was argued that the role of the human driver is changing as vehicle automation increases, by removing the human from the active control of the vehicle and, at the same time, requiring the human agency to monitor and intervene whenever necessary. This new role could place the human operator in demanding and sensitive driving situations (Cusanno et al. 2021) due to restricted time periods (for regaining the manual control) and the loss of situation awareness. In these circumstances, both the mental workload and the stress experienced by drives could increase (Merriman et al. 2021).

The safety issues concerning human usage and experience (third research question) were addressed, and the participants suggest the importance to analyse how human drivers appropriate automated driving technologies. Haué et al. (2020) and Cusanno et al. (2021) have shown that automated driving requires the transformation of drivers’ representations schemes since certain schemes that were associated with the “traditional driving” must be inhibited (e.g., to inhibit the action on the steering wheel as the automated system is in charge of lateral control). According to Rabardel (1995), these schemes are (psychological) instruments for the organizing activity, and they are constituted in action (in and by the use of technology), while human develop experience with automation.

Considering the experience that humans constitute while performing their activities with technology implies an “epistemological conversion” (Bobillier Chaumon et al. 2005) in order to move from presumptive concepts of human work with automation to create more accurate characterizations focused on human usage. Quite often, the design of new technological systems takes the technological capabilities as the unit of analysis. This phenomenon gives rise to interpretations that assimilate the human and technology as two entities in separation, i.e., as if technology were a “crystalised artefact” that has an embedded model of the human and his/her activity. By viewing this restrictive model through the prism of the activity-centred approach, particularly developed within the fields of activity-centred ergonomics and work psychology, Bobillier Chaumon (2021) systematised three scenarios in which human operators experience difficulties while interacting with emerging technologies: (i) if technological systems are complex to use (designed with insufficient consideration of the human activity); (ii) if it is difficult to attribute meaning to technological artefacts to make them truly useful; and (iii) if it is difficult to anticipate the future of the activity and the competences required in these mediated (by automation) environments. These difficulties are not independent of the current dominant discourse and its accompanying theory of efficacy as the correspondence between the form and function of technology, depicting technological artefacts merely as tools at the service of tasks. In these circumstances, it prevails the "sumptuous opacity" of the technological world (Poizat 2015) as a form of de facto.

However, work psychology studies dedicated to analysing how human operators relate to technologies in work contexts have stressed the importance to adopt the point of view of the activity (Béguin 2007; Daniellou and Rabardel 2005), as the unit of analysis to grasp the human-technology relationships. Emphasis is placed on the person as an intentional agent with a set of competences based on his/her experience. Grounded in this frame, Móneger et al. (2018) analysed the experience of professional drivers operating with new automated shuttles. From the drivers' perspective, critical situations were identified as having mobilized, in the activity, new modes of usage of technology and the drivers' values to manage various situated arbitrations. The authors also put in evidence how this experience with technology favour the acceptance of the road transport system, by making it more reliable and developing a service relationship with the passengers (Móneger et al. 2018).

At a time when the human drivers' activity is more and more entangled within automated environments, this way of looking into the human-automation relationships could be particularly useful when it is underlined the need of not perpetuating the human driver as a "second-class citizen" (Norman 2015), only submitted to the laws of efficiency of the automation operation. Instead, by viewing automation technologies as embedded in a process of appropriation it will be possible to grasp them as objects undergoing even the slightest human transformation action (Rabardel 1995).

4.1 Limitations

This study has limitations that should be addressed in future research. The next steps of our work will be dedicated to collecting data from national and international researchers participating in other research projects on automated driving, seeking to explore strategies that are being developed to overcome the identified challenges. These additional interviews will contribute to enriching the diversity of contributions and mitigating the risk of unidimensionality of views. Thus, more three research projects will be analysed through interviewing the principal investigators and the researchers involved in the design of automated driving situations.

On the other hand, data from the future users of these vehicles will be collected in a view of gathering their perspectives and experience. Special attention will be devoted to professional drivers since driving vehicles in professional contexts is subject to determinants, demands, and conflicts of values quite different from those that take place in non-professional driving contexts (Cunha et al. 2021; Silva et al. 2019). To build up a broader empirical foundation, our research will be further developed in this way using different participant recruitment methods. Thus, the work plan of our study also includes: (i) focus-group sessions with professional drivers; and (ii) a round of interviews with public decision-makers engaged in the policy transition from traditional to automated driving in order to explore the main public challenges to accommodate the changes brought about by automated driving technologies.

5 Conclusions

Four interviews are not a representative sample for drawing general conclusions, but the interviews provided a consistent view with respect to the main safety issues of AVs, comparing with previous qualitative studies on this topic.

In terms of insights for the future, these findings, alongside the integrative discussion developed on the possible contributions of the activity-centred approach, will be complemented with other researchers' viewpoints. It is our goal to develop an aggregation matrix that allows contrasting the different options assumed in the design of future situations of automated driving, and thus identifying the commonalities between the Portuguese research project (in which the interviewed researchers participate) and other projects. Lastly, our study has the potential to support methodologies that includes a qualitative approach in future investigations about how human operators relate to automated driving technologies. The approach centred on work activity discussed here has a long scientific tradition in the work psychology domain, contributing to show that technology can positively or negatively affect the work resources (e.g., sense of control over the system operation) and demands (e.g., mental workload), but also the human does not remain as a passive agent. On the contrary, he/she transforms technical objects by performing his/her activity, developing new competences, resources, and significations, and thus constructing experience.

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References

Banks, V., Stanton, N.: Keep the driver in control: automating automobiles of the future. Appl. Ergon. **53**, 389–395 (2016). https://doi.org/10.1016/j.apergo.2015.06.020

Banks, V., Shaw, E., Large, D.: Keep the driver in the loop: the "other" ethics of automation. In: Bagnara, S., Tartaglia, R., Albolino, S., Alexander, T., Fujita, Y. (eds.) 20th Congress of the International Ergonomics Association. IEA 2018, pp. 70–79. Springer (2019). https://doi.org/10.1007/978-3-319-96074-6_8

Béguin, P.: Taking activity into account during the design process. Activités **4**(2), 1–8 (2007). https://doi.org/10.4000/activites.1727
Bobillier Chaumon, M.-E.: Technologies émergentes et transformations digitales de l'activité: enjeux pour l'activité et la santé au travail. Psychologie du Travail et des Organisations **27**(1), 17–32 (2021). https://doi.org/10.1016/j.pto.2021.01.002
Bobillier Chaumon, M.-E., Carvallo, S., Tarpin-Bernard, F., Vacherand-Revel, J.: Adapter ou uniformiser les interactions personnes-systèmes? Revue d'Interaction Human-Machine **6**(2), 91–129 (2005)
Cunha, L., Barros, C., Baylina, P., Silva, D.: Work intensification in road transport industry: an approach to new working scenarios with automated vehicles. Work J. Prev. Assess. Rehabil. **69**(3), 1–11 (2021)
Cusanno, H., Vidal-Gomel, C., Le Bellu, S.: Comment guider les genèses instrumentales pour la prise en main d'un véhicle automatisé? In: Actes du 55ème Congrès de la Société d'Ergonomie de Langue Française (SELF): L'activité et ses frontières: penser et agir sur les transformations de nos sociétés, pp. 336–341. SELF, Paris (2021)
Daniellou, F., Rabardel, P.: Activity-oriented approaches to ergonomics: some traditions and communities. Theor. Issues Ergon. Sci. **6**(5), 353–357 (2005). https://doi.org/10.1080/14639220500078351
Darses, F.: Activity analysis: not what it was. Le Travail Humain **79**(3), 193–208 (2016). https://doi.org/10.3917/th.793.0193
De La Garza, C., Fadier, E.: Towards proactive safety in design: a comparison of safety integration approaches in two design processes. Cogn. Technol. Work **7**, 51–62 (2005). https://doi.org/10.1007/s10111-005-0173-7
Endsley, M.: The limits of highly autonomous vehicles: an uncertain future. Ergonomics **62**(4), 496–499 (2019a). https://doi.org/10.1080/00140139.2019.1563330
Endsley, M.: Situation awareness in future autonomous vehicles: beware of the unexpected. In: Bagnara, S., Tartaglia, R., Albolino, S., Alexander, T., Fujita, Y. (eds.) 20th Congress of the International Ergonomics Association. IEA 2018, pp. 303–309. Springer (2019b). https://doi.org/10.1007/978-3-319-96071-5_32
Hancock, P.: Driving into the future. Front. Psychol. **11**, 1–13 (2020). https://doi.org/10.3389/fpsyg.2020.574097
Hancock, P., Kajaks, T., Caird, J., Chignell, M., Mizobuchi, S., Burns, P., (...) Vrkljan, B.: Challenges to human drivers in increasingly automated vehicles. Hum. Factors J. Hum. Factors Ergon. Soc. **62**(2), 310–328 (2020). https://doi.org/10.1177/0018720819900402
Haué, J.-B., Le Bellu, S., Barbier, C.: Le véhicule autonome: se désengager et se réengager dans la conduite. Activités **17**, 1–26 (2020). https://doi.org/10.4000/activites.4987
Hopkins, D., Schwanen, T.: Talking about automated vehicles: what do levels of automation do? Technol. Soc. **64**, 1–10 (2021). https://doi.org/10.1016/j.techsoc.2020.101488
ITF - International Transport Forum: Safer roads with automated vehicles? Paris: OECD/ITF (2018). https://www.itf-oecd.org/safer-roads-automated-vehicles-0
Johansson, M., Soderholm, M., Novakazi, F., Rydstrom, A.: The decline of user experience in transition from automated driving to manual driving. Information **12**(3), 126 (2021). https://doi.org/10.3390/info12030126
Kyriakidis, M., de Winter, J., Stanton, N., Bellet, T., van Arem, B., Brookhuis, K., (...) Happee, R.: A human factors perspective on automated driving. Theor. Issues Ergon. Sci. **20**(3), 223–249 (2019). https://doi.org/10.1080/1463922X.2017.1293187
Lobo, A., Ferreira, S., Silva, D., Cunha, L., Simões, A., Couto, A.: On the road to automated vehicles: from perception to use. In: Lusikka, T. (ed.) Proceedings of the 8th Congress of the Transport Research Arena (TRA 2020). Traficom, Helsinki (2020)
Merriman, S., Plant, K., Revell, K., Stanton, A.: Challenges for automated vehicle driver training: a thematic analysis from manual and automated driving. Transp. Res. Part F: Traffic Psychol. Behav. **76**, 238–268 (2021). https://doi.org/10.1016/j.trf.2020.10.011

Miles, M., Huberman, A., Saldana, J.: Qualitative Data Analysis: A Methods Sourcebook. Sage, California (2014)
Moneger, F., Coutarel, F., Moták, L., Chambers, P., Izaute, M., Dhome, M.: L'expérience vécue et les valeurs en acte des accompagnants pour la conception d'un service de transport par navettes destinées à être autonome. Activités **15**(1), 1–35 (2018). https://doi.org/10.4000/activites.3077
Navarro, J.: A state of science on highly automated driving. Theor. Issues Ergon. Sci. **20**(3), 366–396 (2019). https://doi.org/10.1080/1463922X.2018.1439544
Navarro, J., Gabaude, C.: Human factors perspectives on highly automated driving. Le Travail Humain **83**(4), 285–295 (2020). https://doi.org/10.3917/th.834.0285
Norman, D.: The human side of automation. In: Meyer, G., Beiker, S. (eds.) Road vehicle automation 2. Lecture Notes in Mobility, pp. 73–79. Springer (2015). https://doi.org/10.1007/978-3-319-19078-5_7
Noy, I., Shinar, D., Horrey, W.: Automated driving: safety blind spots. Saf. Sci. **102**, 68–78 (2018). https://doi.org/10.1016/j.ssci.2017.07.018
Nyssen, A-S., De Keyser, V.: Prevention of human errors in the frame of the activity theory. In: Anderson, N., Ones, D., Sinangil, H., Viswesvaran, C. (eds.) Handbook of Industrial, Work & Organizational Psychology, pp. 348–362. Sage, London (2001). https://doi.org/10.4135/9781848608320.n17
Orfeuil, J.-P., Leriche, Y.: Piloter le véhicule autonome au service de la ville. Descartes & Cie, Paris (2019)
Poizat, G.: Learning through the interaction with technical objects: from the individuality of the technical object to human individuation. In: Filliettaz, L., Billet, S. (eds.) Francophone perspectives of learning through work: conceptions, traditions and practices, pp. 119–143. Springer (2015). https://doi.org/10.1007/978-3-319-18669-6_6
Rabardel, P.: Les hommes et les technologies: approche cognitive des instruments contemporains. Armand Colin, Paris (1995)
SAE - Society of Automotive Engineers: Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. SAE Int. (2018). https://doi.org/10.4271/J3016_201806
Silva, D., Cunha, L.: "Automated but not alone": how the possible forms of future human activity are analyzed in the advent of automated vehicles? In: Russo, D., Ahram, T., Karwowski, W., Di Bucchianico, G., Taiar, R. (eds.), Intelligent Human Systems Integration 2021, pp. 90–96. Springer (2021a). https://doi.org/10.1007/978-3-030-68017-6_14
Silva, D., Cunha, L.: . Automation and the future of human work: an everlasting debate renewed by the work activity. In: Black, N., Neumann, W., Noy, I.: (eds.) 21st Congress of the International Ergonomics Association (IEA 2021). Lecture Notes in Networks and Systems, pp. 273–281. Springer (2021b). https://doi.org/10.1007/978-3-030-74602-5_40
Silva, D., Cunha, L., Barros, C., Baylina, P.: Preparing the future scenario of automated vehicles: recommendations drawn from the analysis of the work activity of road transport workers. In: Cotrim, T., Serranheira, F., Sousa, P., Hignett, S., Albolino, S., Tartaglia, R. (eds.) Health and Social Care Systems of the Future: Demographic Changes, Digital Age and Human Factors, pp. 301–310. Springer (2019). https://doi.org/10.1007/978-3-030-24067-7_35
Simões, A., Cunha, L., Ferreira, S., Carvalhais, J., Tavares, J., Lobo, A., Couto, A., Silva, D.: The user and the automated driving: a state-of-the-art. In: Stanton, N. (ed.) Advances in Human Factors of Transportation. AHFE 2019, pp. 190–201. Springer (2020). https://doi.org/10.1007/978-3-030-20503-4_17
Simoes, A., Cunha, L., Silva, D., Ferreira, S., Lobo, A., Couto, A., Tavares, J., Cotrim, T., Neto, C.: A focus group research in the frame of the Autodriving project under lockdown conditions. In: Santon, N. (ed.), Advances in Human Aspects of Transportation. AHFE 2021, pp. 339–347. Springer (2021). https://doi.org/10.1007/978-3-030-80012-3_40

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The Role of the Quality Principles on the Integration of Multiple Management Systems

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Abstract The International Organisation for Standardization (ISO) established the Quality Management Principles (QMP) as the foundation values aiming at drive the performance improvement of management systems (MS). Since the QMP are transversal to any ISO standard, they also may support the integration of multiple MS (the IMS) and act as the basis for achieving a higher maturity level. The literature reviewed suggests an urgency in developing strategies to handle performance shortcomings of IMS and to facilitate organisations to achieve and operate on high performance levels. Intending to contribute to this matter, the goals of this paper embrace to establish the specific common requirements (SR) amidst ISO 9001, ISO 14001 and ISO 45001 standards, and to determine the quantitative efficiency of the QMP for the requirements integration. The data collection was carried out via an online survey, which was designed to be answered by representative experts in the MS and IMS field, and through literature review. Supported on the data collected, the pivotal QMP and the correlated SR were established and their scores: metrics to treat more efficiently the detected non-conformities (i.e. the shortcomings of the integration performance). Further, the results comprise the disclosure of the significant role of the QMP 'Process Approach' (in addition to the 'Leadership') for the integration. Therefore, the QMP efficiency scores might be adopted as a strategy by any organisation holding an IMS, to efficiently handle the performance limitations.

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Keywords Environment · Health and safety · Integrated management systems · Quality · Performance measurement

1 Introduction

Pursuing to effectively create customer value, in recent years, organisations have implemented the certified Quality Management System (QMS), the Environmental MS (EMS) and the Occupational Health and Safety MS (OHSMS) according to the ISO's standards: an inevitable circumstance for integration. The ISO 9001 standard specifies requirements for implementing a QMS and points out their potential benefits to the organisation, such as the improvement of overall performance, the fulfilment of the customers' requirements (by foreseeing their future needs and expectations), altogether culminating on enhancement of the customer satisfaction. Seven Quality Management Principles (QMP) were established as the basis of the ISO 9001 for a QMS: Customer focus, Leadership, Engagement of People, Process Approach, Improvement, Evidence-based Decision Making and Relationship Management. According to the ISO, these principles are the foundation values to drive performance improvement and organisational excellence (ISO - Quality Management Principles 2015a), i.e., a "fundamental rule" for continuously improve performance focussing on the long term (Dordević 2018, p. 35). Furthermore, the principles act as the pillars of excellence management and are common features in any ISO standard that may comprise an IMS (Integrated Management System) (Domingues 2013) therefore, might be the basis for the integration of other MS (Sampaio et al. 2012).

Zeng et al. (2011) posit that "the objective of the IMS is to achieve continuous improvements" (p. 184) thus, the adoption of the QMP might feed a purpose synergy for the IMS whilst the QMS adoption might be the first step on this pursuit for continuous improvement. However, the MS certification according to the ISO standards does not assure undoubtedly the establishment of continual improvement practices, culture and organisational climate, and improved performance (Boiral 2008; Dordević 2018). The organisation's awareness for continuous improvement, clarity of purpose and directness that will determine the release of the substantive results according to the propositions embedded in the standards' requirements. It is an organisation role to assure the directives are not merely procedures to be addressed as well the presence of a motivation to reach added value to the organisation' outcomes. According to Boiral (2008) the gains are a corollary in which manner the standards are implemented and the extent of consistency of the policies adopted than on whether or not one is certified.

The ISO standards share a same structural pattern, i.e., the ISO high-structure level (Annex SL (normative) n.d.) which is in turn coupled with the PDCA (Plan-Do-Check-Act) cycle. These attributes provide compatibility between the standards and turn them well suited for integration. Beyond these common features, the ISO domain can present other kind of similarities that may facilitate the integration and can be interpreted as capabilities beyond the common implementation factors (Tarí and Molina-Azorí-n 2010). Furthermore, Sampaio et al. (2012) reported a high compatibility between the EMS and OHSMS standards in the surveyed companies.

Based on the above mentioned, this paper aims to address the contribution of each QMP for the integration and performance of an IMS. For that, main objectives were outlined: (i) ascertaining the most integrable MS' requirements among ISO 9001 (ISO 2015b), ISO 14001 (ISO 2015c) and ISO 45001 (ISO 2018) standards (i.e., the synergistic requirements); (ii) determining the quantitative efficiency of the QMP for the requirements integration (i.e., the QMP efficiency scores).

2 Materials and Methods

This topic presents the methodological strategy selected and performed to collect data and achieving the objectives of this study. The survey is a quantitative research strategy and questionnaires a structured approach of extracting reliable information (Saunders et al. 2009). Thus, the quantitative data was collected via an online survey through the development of a questionnaire, which was designed for leadership professionals, industrial and academic experts that are representative in the MS and IMS field. It is also important to highlight that an exploratory and comprehensive literature review was carried out in order to map the relevant literature and getting a deep understanding of the subject.

The questionnaire development was oriented for correlating the synergistic aspects (the SR) of the ISOs for QMS (9001:2015), EMS (14001:2015) and OHSMS (45001:2018) with the QMPs, whereby the experts should rank each QMP according to levels of relevance. Hence, aiming to achieve the objectives of this paper several steps were performed: (i) the identification of the most integrable requirements (the SR) between the three mentioned standards and through a transversal analysis, and (ii) the selection of the key ones; (iii) the SR's contextualisation, mandatory to draw up the questions-statements. The questionnaire holds nine questions and the QMP presented as sub-questions for each one. The experts should deliberate about the information offered in the statements and then rate each QMP in a scale of 'not relevant', 'relevant' or 'totally relevant'.

It was intended to capture from the respondents the sense of adoption and implementation of the requirements in an integrated approach in the businesses, further, the experts could infer around the application of the QMP and measure their relevance in the exposed circumstances. The choice of the measure scale (three points) aims at a more precise answer about relying on QMP as guiding principles and, if so, to evaluate whether it would be relevant or mandatory for the requirements integration. Furthermore, it was expected that respondents, as skilled specialists, would be able to access their experiences, recall past actions and behaviours, judge the questions, and make decisions based on those experiences. They were also expected to be motivated in benchmarking their own knowledge moreover, contributing to the state of the art regarding the topic.

The diagrams and statistical analysis were supported by the IBM Statistical Package for the Social Science (SPSS) version 27 and the Microsoft Excel. Therefore, to enable an exploratory statistical analysis of the survey results in SPSS, a variable transformation of the answers was executed aiming to recode the qualitative relevance scale (i.e., the questionnaire measure scale) into quantitative data as following: 'not relevant' = value 1; 'relevant' = value 2; 'totally relevant' = value 3.

3 Results

As part of the results obtained, the specific common requirements, or SR, between ISO 9001, 14001 and 45001 are established and described hereinafter:

- SR1 Scope and Boundaries – 4.3 Determining the scope of the QMS/EMS/OHSMS;
- SR2 Leadership – 5.1 Leadership and commitment; 5.2 Policy; 5.3 Organizational roles, responsibilities, and authorities;
- SR3 Interested Parties – 4.2 Understanding the needs and expectations;
- SR4 Management of changes, risks and opportunities – 6.1 Actions to address risks and opportunities;
- SR5 Documented Information Control – 7.5 Documented information;
- SR6 Strategic Direction, Strategic Objectives and Policy – 5.2 Policy; 6.2 QMS/EMS/OHSMS objectives and planning to achieve them;
- SR7 Performance Measurement System – 9.1 Monitoring measurement, analysis, and evaluation;
- SR8 Internal Audit – 9.2 Internal audit;
- SR9 PDCA Cycle and Continual Improvement – 0.4 PDCA and 0.3.2 PDCA (this last in ISO 9001); 10.3 Continual improvement.

Concerning the survey, a total amount of 55 experts were chosen to participate on the online survey and selected as beacons in the subject under study. This set of individuals was contacted and 13 agreed to take part. Hence, 13 valid answers were collected, a response rate of approximately 24%. The respondents are located in three continents and in nine different countries namely Brazil, Denmark, Ghana, Macedonia, Portugal, Romania, Spain, Sweden, and Switzerland; diversity, that in addition with their expertise, enriches the knowledge that is the foundation of this study. Altogether, they account for 365 years of experience (199 in academia; 166 in industrial context, considering them as distinct types of experience) in the MS or IMS field. A proportion of 62% (eight experts) holds both academic and industrial experience and 62% holds more than 20 years of experience in at least one of these fields.

The next step focused on the exploratory statistical analysis of the survey results. The experts' answers for the Question 9, i.e. SR 9, are graphically presented (as an example) in Fig. 1. The boxplots depict quantitatively the relevance ascribed by the respondents for every QMP. By adopting this type of chart is possible to establish a

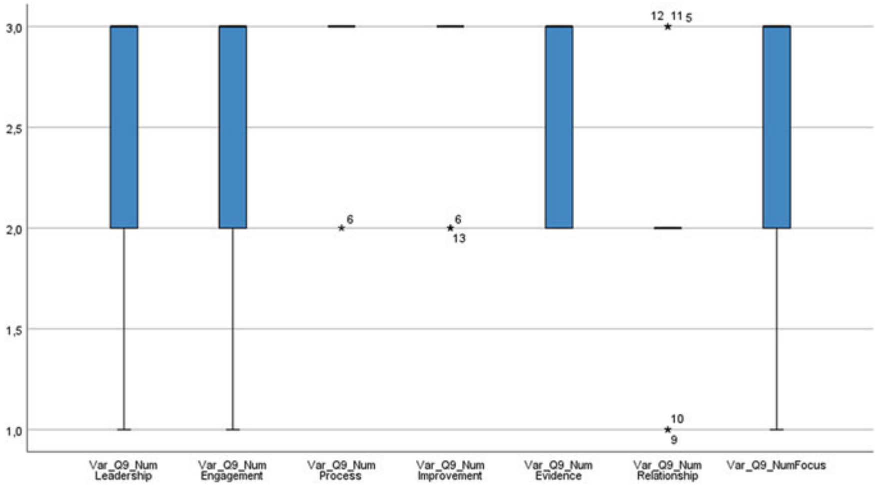

Fig. 1 Results from Question 9

comparison between the several data sets, and inferring about their distribution, such as: identifying the degree of dispersion and concentration of the data, the extreme values (outliers) and how far they are from the most of the data. It is possible to observe that there is a strong concentration of responses since the interquartile ranges not always can be well distinguished. Taking into account the shape of the boxplots, there are quartiles coincident and overlapped. Therefore, it is reasonable to affirm the data are mostly concentrated on the highest value of the relevance scale, on the response 'totally relevant' (value 3). It is also possible to characterize the data sets as asymmetrically distributed and skewed left (so, the median, on this case, will be the proper and more robust measure). This negative asymmetry asserts the low dispersion of the data and, therefore, a high consensus among respondents.

However, despite the high consensus among the respondents, it is possible to observe the presence of outliers meaning there are answers outside the predominant pattern. By analysing the experts' answers for all questions, a similar data pattern described was observed.

Based on the outcomes of the survey, a hierarchical analysis holding a set of criteria was developed to establish a ranking and relative weights/priorities to be ascertained for each QMP (correlated to each SR). The descriptive statistics, the boxplots and the dendrogram (used to verify the proximity between the set of QMP so, as a measure of relevance) were the metrics and source of information chosen so that the hierarchy criteria were underlined. For example, the SR 9, i.e., Question 9, presented the QMP 'Process approach' with the highest score values of median (the median is the central tendency measure, thus, the most robust for asymmetric distributions), sum, and frequency (i.e., number of times the QMP was evaluated as 'Totally relevant'). Hence, on the hierarchical criteria, the QMP 'Process approach' was defined as the most relevant QMP for the successful implementation and integration of the requirements 0.4/0.3.2 Plan-Do-Check-Act cycle and 10.3 Continual improvement, followed by 'Leadership' and 'Engagement of people'. This hierarchical process was adopted for every QMP and each SR.

The next step embraced ascribing quantitative weights (scores) to each QMP. These weights were calculated based on their ranking and according to Eqs. 1 and 2:

$$w1 > w2 > ...w7 \,|\, w1 = 7;\ w2 = 6;\ ...w7 = 1 \tag{1}$$

$$Ws = wp, s \cdot Fp, s \tag{2}$$

where: Ws: weight of the QMP. s: the related SR. wp, s: is the weighting coefficient based on the QMP ranking; it can assume values [1 – 7] (Eq. 1) p : position ranking based on the hierarchical criteria. Fp, s: is the frequency of the 'totally relevant' response (value 3).

Table 1 displays the weights (i.e., the efficiency scores) of the QMPs that assume the first three positions on the relevance ranking, by each SR.

4 Discussion

The concentration of data responses on the highest value of the relevance scale ('totally relevant') and, so far, ascribed by the beacons in the field, corroborates the pivotal role of the QMP for the integration process. Furthermore, that is an evidence of the importance of adopting this set of principles as a strategy for evaluating an IMS.

Table 1 provides the QMP that hold the greatest impact, upon specific common requirements, the SR, whereby it is possible to observe that 'Leadership' owns a pivotal role once is the one that most assumes the first position (four times), followed by 'Process Approach' (three times). Hence, these two QMP, together, hold 78% of relevance for the integration whilst the others QMP hold 22% (Pareto principle).

The IMS audit reports register non-conformities and reveal the shortcomings around the capability of IMS operation and requirements implementation. Now, since the pivotal QMP and the correlated SR are established (and the scores of their contribution), the detected non-conformities (i.e., limitations in terms of performance) can be better managed which constitutes a shift for handling improvement opportunities. Therefore, Table 1 might be considered as a road map for that, which holds non-conformities as input into a cause-and-effect relation with the QMP (Fig. 2).

Furthermore, the requirement's scopes of PDCA Cycle and Continual Improvement; Internal Audit; Performance Measurement System; Strategy, Objectives and Policy; Documented Information; Risk Based-thinking; Interested Parties; Leadership, and Scope and Boundaries were established and validated by the experts as the key ones whose are common to the ISO 9001, 14001 and 45001 standards. They

Table 1 The QMP ranking (position) and their efficiency scores assigned, by each SR

SR1_SCOPE and BOUNDARIES	Ranking	Weight	Score
(L) Leadership	1ª	7,00	30,60 %
(CF) Customer focus	2ª	5,08	22,20%
(EP) Engagement of people	3ª	4,23	18,40%
SR2_LEADERSHIP	Ranking	Weight	Score
(L) Leadership	1ª	6,46	31,11%
(EP) Engagement of people	2ª	5,08	24,44%
(IM) Improvement	3ª	3,08	14,80%
SR3_INTERESTED PARTIES	Ranking	Weight	Score
(CF) Customer focus	1ª	6,46	36,05%
(RM) Relationship management	2ª	4,61	25,75%
(EP) Engagement of people	3ª	2,69	15,00%
SR4_RISK BASED-THINKING	Ranking	Weight	Score
(L) Leadership	1ª	5,38	25,92%
(IM) Improvement	2ª	4,61	22,21%
Evidence-based decision making	3ª	3,85	18,51%
SR5_DOCUMENTED INFORMATION	Ranking	Weight	Score
(PA) Process approach	1ª	5,92	35,95%
(ED) Evidence-based decision making	2ª	5,08	30,81%
(EP) Engagement of people	3ª	1,93	11,70%
SR6_STRATEGY, OBJECTIVES and POLICY	Ranking	Weight	Score
(L) Leadership	1ª	6,46	33,90%
(EP) Engagement of people	2ª	4,61	24,18%
(CF) Customer focus	3ª	3,08	16,12%
SR7_PERFORMANCE MEASUREMENT SYSTEM	Ranking	Weight	Score
(PA) Process approach	1ª	6,46	30,10%
(ED) Evidence-based decision making	2ª	5,54	25,80%
(IM) Improvement	3ª	3,85	17,91%
SR8_INTERNAL AUDIT	Ranking	Weight	Score
(EP) Engagement of people	1ª	5,92	30,56%
(PA) Process approach	2ª	5,08	26,20%
(IM) Improvement	3ª	3,08	15,86%
SR9_PDCA and CONTINUAL IMPROVEMENT	Ranking	Weight	Score
(PA) Process approach	1ª	6,46	31,35%
(IM) Improvement	2ª	5,08	24,65%
(ED) Evidence-based decision making	3ª	3,46	16,78%

Ranking Matrix

SR 1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9
L	L	CF	L	PA	L	PA	EP	PA
CF	EP	RM	IM	ED	EP	ED	PA	IM
EP	IM	EP	ED	EP	CF	IM	IM	ED

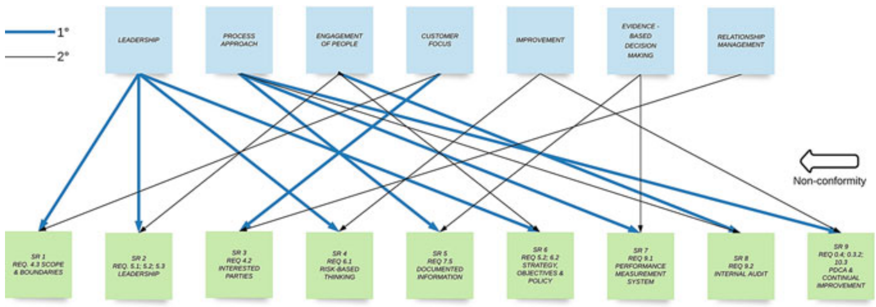

Fig. 2 The cause-and-effect relation between the requirements integration and the QMP

might be the standards' references for integration that can be used by organisations as a starting point.

Research Limitations The online survey was conducted among a limited sample of leadership professionals, industrial and academic experts which may have restricted the results obtained. It arises as an opportunity for future research, in terms of conducting a new survey among a broader number of experts and thus, for analysing whether the QMP efficiency scores are sustained.

5 Conclusions

The correlation between the QMP with the defined SR was established quantitatively. Since the QMP are transversal to the three ISO standards, the supportive role of these pillars goes beyond just over the standards: they support the operation and maturity of an IMS. In practice, these weights represent quantitatively the contribution of the QMP for the IMS performance and its efficiency therefore, the score of their contribution throughout the integration process. Another distinctive contribution of this project is the disclosure of the potentially significant role of the 'Process Approach' QMP for the requirements integration (added to the pivotal role of the 'Leadership' already pointed out by the mainstream literature). The QMP efficiency scores is a strategy idealised to be employed as an independent tool, by any organisation, to efficiently handle performance deficiencies of its IMS.

Accordingly, to Wiengarten et al. (2018) the technical efficiency pursuit by organisations figures among the expectations on adopting an ISO standard, moreover, the increasing pressure for organisations beckoning the compliance concerning OHS and environmental constraints (while assuring a minimum level) can be a powerful driver towards certification. In this sense, it is essential that an organisation gets a holistic perspective of its organisational processes' capabilities and maturity therefore, identifying opportunities for change, for prioritising investments and targeting efforts meant for continuous improvement (Asah-Kissiedu 2019; Dragomir et al. 2017). The literature reviewed also suggested an urgency in improving strategies to diagnose and to improve capabilities, thus, to facilitate organisations to achieve and operate on high performance levels.

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References

Annex SL (normative).: Proposals for management system standards. ISO/IEC Directives, Part 1 – Consolidated ISO Supplement – Procedures specific to ISO (n.d.). Retrieved from https://www.iso.org/sites/directives/current/consolidated/index.xhtml#_idTextAnchor535
Asah-Kissiedu, M.: Development of an integrated safety, health and environmental management capability maturity model (SHEMCMM) for Ghanaian construction companies. [Ph.D. Thesis, Faculty of Environment and Technology, University of the West of England, Bristol] (2019). Retrieved from: https://uwe-repository.worktribe.com/output/2982246
Boiral, O.: Les pays du sud à l'épreuve des normes ISO: vers un sous-développement durable? Manag. Int. **12**(2), 49–63 (2008)
Domingues, J.P.T.: Sistemas de gestão integrados: Desenvolvimento de um modelo para avaliação da maturidade [Ph.D. thesis, Systems and Production Department, University of Minho, Portugal] (2013). Retrieved from: http://hdl.handle.net/1822/28830
Dordević, L.P.V.: The management system integration on the production process level. J. Econ. Manag. Inform. **9**(1), 31–45 (2018). https://doi.org/10.5937/bizinfo1801031D
Dragomir, M., Popescu, S., Neamtu, C., Dragomir, D., Bodi, S.: Seeing the immaterial: a new instrument for evaluating integrated management systems' maturity. Sustainability **9**(9), 1–14 (2017). https://doi.org/10.3390/su9091643
ISO - Quality Management Principles (2015a). ISBN 978-92-67-10650-2. Retrieved from https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100080.pdf
ISO: ISO 9001:2015 Quality Management Systems – Requirements (2015b)
ISO: ISO 14001:2015 Environmental Management Systems – Requirements with Guidance for Use (2015c)
ISO: ISO 45001:2018 Occupational health and safety management systems: Requirements with guidance for use (2018)
Sampaio, P., Saraiva, P., Domingues, P.: Management systems: integration or addition? Int. J. Qual. Reliab. Manag. **29**(4), 402–424 (2012). https://doi.org/10.1108/02656711211224857
Saunders, M., Lewis P., Thornhill, A.: Research Methods for Business Students (5h ed). Pearson Education Limited (2009)
Tari, J.J., Molina-Azorin, J.F.: Integration of quality management and environmental management systems similarities and the role of the EFQM model. TQM J. **22**(6), 687–701 (2010). https://doi.org/10.1108/17542731011085348
Wiengarten, F., Onofrei, G., Humphreys, P., Fynes, B.: A supply chain view on certification standards: does supply chain certification improve performance outcomes? In: Heras-Saizarbitoria, I. (ed.) ISO 9001, ISO 14001, and New Management Standards. Springer Publishing (2018)
Zeng, S.X., Xie, X.M., Tam, C.M., Shen, L.Y.: An empirical examination of benefits from implementing integrated management systems (IMS). Total Qual. Manag. Bus. Excell. **22**(2), 173–186 (2011). https://doi.org/10.1080/14783363.2010.530797

Occupational Health and Safety in the Brazilian Sector of Cargo Transportation: A Systematic Review on the Category of Self-Employed Drivers

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Abstract Objective: To analyze the main aspects of Occupational Health and Safety that affect the category of self-employed drivers. Background: Self-employed drivers in Brazil are not covered by Labor Laws to protect them against strenuous days of work. Method: Our exploratory method intends to bring up the problem and present hypotheses. It is a Systematic Literature Review, in which a structured process was used, including planning, execution and analysis of the researched data. Results: Sleep-deprived driving or signs of fatigue is one of the main risk factors for accidents in the world. Among truck drivers it is very common to use chemical substances to reduce sleep and decrease tiredness. Conclusion: The findings corroborate with the discussions brought about the increasing informality of work in the self-employed category. Long working hours, the absence of rest breaks, the risk of robberies and accidents affect the health of drivers. Application: To add the category of self-employed drivers in Labor Laws thus reducing the main cause of traffic accidents and meet a minimum working condition.

Keywords Safety · Health · Working conditions self-employed · Truck driver

1 Introduction

Brazil is the country that has the highest concentration of road transportation in the main world economies (Wolff and Caldas 2018), accounting for about 61% of cargo and 95% of passenger in the country (CNT 2019). This scenario shows the importance of the category of truck drivers for the country, affecting the county's economy and politics. The national government estimates that the stoppage of truck

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drivers in 2018 had a negative impact on the economy of about R$ 15.9 billion, approximately 0.2% of GDP (Brazil 2018).

Occupational Health and Safety (OHS) concerns about the cargo transportation sector include risks of road accidents, physical risks, violence, dangerous operational situations and exposure to harmful substances (Hege et al. 2016). Drivers are in a unique situation, as OHS sees the transportation sector can have a direct impact on third parties, such as road users, urban traffic and public safety (Crizzle et al. 2017). According to data from the National Transportation Confederation (CNT 2019), considering all accidents recorded on the Brazilian federal highways between the years 2007 and 2018, 570,029 accidents involving at least one truck were recorded.

Several studies present fatigue, drowsiness, physical and mental fatigue, drug use and payment for production among the main factors that lead to occupational accidents with professional drivers (Sinagawa et al. 2014; Gonçalves et al. 2015; Junior et al. 2015, 2016; Nazari et al. 2017; Junior and Garcia 2019).

Road freight transportation has different models of freight contracting, a factor that negatively impacts the working conditions offered to drivers. The working hours of truck drivers in Brazil are, as a rule, linked to the labor relationship of the driver with the carrier responsible for transporting the cargo (Junior and Garcia 2019). Self-employed drivers are individuals and owners, co-owners or tenants of one to three trucks. They can be hired directly by the applicant for the transportation service or provide services to a carrier, which is the most common form of action for the self-employed (Silva et al. 2016).

The job of a truck driver is one of the most demanding in relation to the need to have good physical and mental conditions. Exhaustive journeys cause truck drivers to reverse their sleep cycle, and this inversion results in an excessive physical, cognitive and psychic burden (Narciso and Mello 2017). The difference between employed drivers and self-employed drivers may include: negotiating debts, managing finances, attracting new services or ensuring regular transportation. The group of self-employed drivers is under greater pressure at work, as they themselves need to be responsible for issues outside the driving. The demand for cargo, the payment of tolls, the lack of resources to replace the cargo in the event of an assault, are among the possible sources of stress for this group of professionals (Wanke 2012).

The Brazilian road freight transport sector needs urgent attention. This study aims to identify and analyze, through a literature review, the main aspects of occupational health and safety related to the category of self-employed drivers.

2 Materials and Methods

The methodology adopted for the development of this study, according to Gil (2019), is qualitative in its approach to the problem, since it has a dynamic relationship between the real world and the subject, through interpretation without numerical representation; for its purpose, it is exploratory, since it intends to familiarize itself with the problem and present hypotheses; and by technical procedures, it is a Sys-

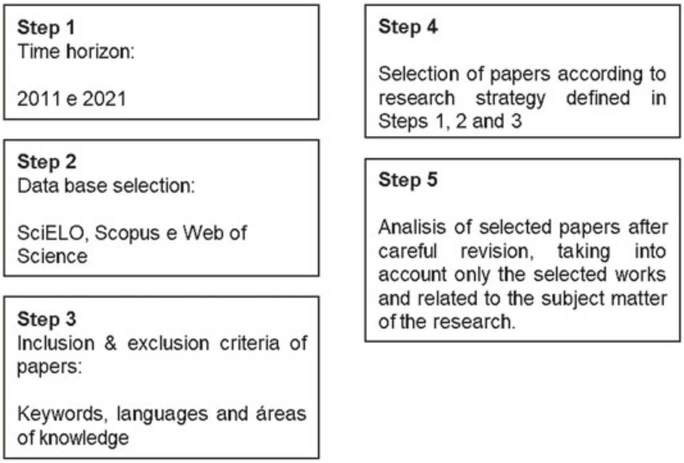

Fig. 1 Methodology for systematic literature review. (Soni and Kodali 2011; Saenz and Koufteros 2015)

tematic Literature Review, in which a structured review process was used, including planning, execution and analysis of the researched data (Saenz and Koufteros 2015). Figure 1 presents the set of five steps (Soni and Kodali 2011; Saenz and Koufteros 2015) that allow the verification and replicability of the procedures adopted and the conclusions obtained by the researcher.

We used SciELO, Scopus and Web of Science databases to collect articles, and for the search for articles aligned with the proposed theme, we adopted the following keywords: “Safety” or “Health” or “Truck Driver”; “Occupational Risks” or “Occupational Health” or “Professional Driver”; “Working Conditions” or “Self-employed” or “Truck Driver”. These words were used in all databases, in English and Portuguese, in the areas of knowledge of Engineering, Health, Administration, and the articles should have in the title, abstract or throughout the text, any of the keywords- key used. We used only articles published within the past ten years, in full text. Through the pre-selected documents, other approaches were sought in the bibliographic references in order to insert them in the research. After this survey, the research sought to relate the information available and their contributions to the discussion on the main aspects of the working conditions of self-employed drivers in road freight transportation.

3 Results and Discussion

Based on the systematic literature review carried out, a total of 43 articles were obtained. Applying the exclusion criteria (area of knowledge, language, period of publication and complete format for analysis), 20 articles were selected for the study, presented in Fig. 2.

Authors	Main Results
Araújo, Bandeira & Campos, 2014.	It was determined the value of the final freight price that would be enough to remunerate all the expenses.
Cerqueira-Santos & Santana, 2014.	It was identified that the informality and precariousness present in this profession, configured by outsourcing, compromise the working conditions and health of drivers.
Coelho, 2015.	It was concluded that limits should be imposed on collective agreements, aiming to maintain the objectives of the law and improve the working conditions of the driver.
Crizzle et al., 2017.	The findings show that long-haul truck drivers have multiple risk factors that can lead to various medical conditions.
Di Milia et al., 2011.	The findings show that fatigue has been implicated in a range of impairments.
Fonseca, 2016.	The findings show that professional drivers and professional soccer athletes suffered precariousness of labor rights by special legislation.
Gonçalves et al., 2015.	This research demonstrates that drowsy driving is a major safety hazard throughout Europe.
Hege et al., 2016.	It was identified that there has been a lack of comprehensive and integrated safety and health attempts to the health and safety of truck drivers.
Junior et al., 2016.	It was noted that the combined use of drugs exposes drivers at risk of accidents, problems with laws and spread of diseases.
Junior & Garcia, 2019.	The findings show that it is necessary to increase the number of inspections and in addressing the contributing factors for fatal work accidents among truck drivers.
Lan et al., 2020.	Work-related transmission is considerable in early Covid-19 outbreaks, and the elevated risk of infection was not limited to healthcare workers.
Malinga et al., 2021.	This review highlights the countries response to mitigate the impact of the pandemic by implementing measures to facilitate safe cross-border trade.
Narciso & Mello, 2017.	To restrict and reduce accidents, deaths, and injuries in traffic, appropriate legislation is essential, aiming at the safety of workers and users of highways.
Nazari; Moradi & Rahmani, 2017.	Results showed various interventions in different parts of the world have been used to decrease drowsy driving.
Oliveira & Carlotto, 2020.	The study results reveal a risk profile consisting of occupational, psychosocial and occupational stressors variables in truck drivers.
Santos et al., 2020.	As the pandemic is still evolving, workers must be a priority target of attention in the control and spread of the disease.
Silva et al., 2016.	Both contractors and self-employed drivers mentioned the precarious labor relations and short delivery timeframes were related to use of drugs.
Sinagawa et al., 2014.	Truck drivers who reported driving more than 270 km had higher frequencies of urine samples positive for amphetamine than those who reported shorter driving distances.
Wank, 2012.	The results point to three large groups of shippers, in which the perceived quality of service depends on the intensive use of self-employed workers.
Wolff; Caldas, 2018.	The model proposed includes tem variables that count from the initial investment in the road to air emissions of carbon dioxide.

Fig. 2 List of articles selected for the study (Authors 2021)

Self-employed drivers are characterized by owning their own truck and working on their own, establishing their own working hours. They do not receive the same benefits as registered workers, such as vacation, 13th salary, among others. Therefore, they have no bond or guarantee of rights under the terms of the Brazilian labor law known as Consolidation of Labor Laws (CLT), which comprises Self-Employed Cargo Carriers, being subcontracted by the carriers and remunerated for the number of trips they take (Brazil 2007).

It should be noted that, even for the employed drivers, governed by the CLT, through Law 13.103/2015, there is a certain doctrinal discussion about the constitutionality of the devices that govern this category, since the said law has made rights considered essential for work safety. In this sense, the aforementioned law foresaw that the waiting time (loading/unloading or inspection of the goods) is not considered working time, even though it is necessary for the driver to remain in the place in the employer's interest (Coelho 2015).

The discrepancy in rights between the driver and among the other employees governed by the CLT is evident, and the overlap between the economic interest of the employer and that of the employees becomes clear. In the case of the self-employed driver, the exploitation of the category is even greater, as there is no legal minimum for this category (Fonseca 2016).

A current example of the precarious working conditions of the self-employed is the exposure of these workers to the risks of contagion from COVID-19, since this category of drivers has personal habits, such as bathing, eating and staying overnight, which are carried out in shared environments and in locations in varied regions in a short period of time (Malinga et al. 2021).

Lan et al. (2020) conducted a study on the impact of the pandemic on different professional categories, carried out in six Asian countries, identifying that the five occupational groups with the highest frequency of cases were health workers (22%), drivers and transport workers (18%), service sector workers (18%), cleaning professionals and domestic workers (9%), and public security employees (7%). In Brazil, the data available on the notification of cases among groups of workers are still incipient and have significant underreporting (Santos et al. 2020).

Many carriers choose to hire self-employed truck drivers to transport their cargos, thus reducing their operating costs (vehicle maintenance, fuel and other related expenses), as well as responsibilities and commitments to employment relationships (Wanke 2012). These drivers accept inadequate working conditions, such as long working hours, face great difficulty to change vehicles, carry out regular maintenance or meet safety standards. The low freight rates in the Brazilian market are the result of the excessive offer of transport services offered by self-employed drivers, which are mostly contracted by large carriers. Well-being itself becomes a secondary concern, since fuel costs represent a much larger part of freight than of your own profit obtained from the trip (Araújo et al. 2014).

The study by Cerqueira-Santos and Santana (2014), when analyzing the perception of satisfaction with the work of 342 truck drivers, self-employed and employees, from several states in Brazil, showed that drivers who had an employment relationship indicated greater satisfaction with the job when compared to freelancers. Silva et al. (2016) state that among the self-employed drivers studied, recurrent reports were observed about anxiety and constant concern in relation to meeting the deadlines set by the company and to be able to make new trips, due to their monthly income depending exclusively on the number of commissioned transported loads. In addition, self-employed drivers mentioned discontent in relation to their working conditions, such as helplessness, insecure wages and labor rights (such as time off and health care).

Fatigue and drowsiness are considered a major OHS problem in the transport sector, not only because they affect the well-being of drivers, but also because they negatively impact performance when driving the vehicle and, consequently, on safety (Oliveira and Carlotto 2020). Fatigue and drowsiness can occur due to several endogenous and exogenous factors, such as sleep disorders, poor physical and mental health, old age, long working hours, poor diet, alcohol and illicit drug use or habits that are harmful to health, as poor sleep quality; long driving periods, with times that conflict with the organism's natural rhythms; monotony; permanent night shifts and excess overtime (Di Milia et al. 2011).

Sleep-deprived driving is one of the main risk factors for accidents, accounting for between 20% and 30% of all traffic accidents in the world (Nazari et al. 2017). A study carried out in 19 European countries identified that 17% of the interviewed drivers had ever slept at the wheel in the past two years, and the most frequent reasons they pointed out were poor sleep the night before (42.5%) and inadequate sleep habits in general (34.1%) (Gonçalves et al. 2015).

Among Brazilian truck drivers, it is very common to use chemical substances to reduce sleep and reduce tiredness, as a result of lack of sleep and little time for rest, due to the long journeys made to meet deadlines and delivery times. In the study by Junior et al. (2016), it was identified among the 114 drivers interviewed, 64% use alcohol and 25.8% used drugs. Stimulants are the drug most consumed by 87.5%, followed by 75% of cocaine and 62.5% of crack. Of these, 55.6% use drugs in combination, 50% consume alcohol on the roads and 45% have already driven after drinking.

Long working hours, absence of rest breaks, poor diet, risk of robberies and accidents at work affect the health of self-employed drivers. In addition, the short delivery times not only make it difficult to take rest breaks, but also push many workers towards the consumption of chemical substances, such as amphetamines and alcohol, since they need to stay awake to meet the urgencies of the deadlines set by the companies (Sinagawa et al. 2014).

4 Conclusions

Based on this systematic literature review, it is observed that the road cargo transportation sector in Brazil, as well as in other countries, uses the hiring of self-employed drivers as a way to reduce costs and avoid the existence of costly labor relations. The lack of labor rights adds to the transfer of operating costs (fuel, tires, maintenance, etc.), so, in addition to not having a fixed income, drivers have to cover the costs inherent in the transportation activity, compromising their safety.

Sleep-deprived driving or signs of fatigue is one of the main risk factors for accidents in the world. Among Brazilian truck drivers, it is very common to use chemical substances to reduce sleep and decrease tiredness. Long working hours, the absence of rest breaks, the risk of robberies and accidents at work affect the health of self-employed drivers.

Depending on the above, the lack of legal regulation stipulating minimum safety conditions for self-employed drivers, compromises the health of both drivers and population. Self-employed workers do not have the protections provided for in the CLT, such as working hours, benefits and vacation, as employed drivers have.

Truck drivers are an important category of workers for the economy of many countries, especially for Brazil, which handles a large part of its cargo movements through roads. However, the working conditions to which these professionals are subjected, especially the self-employed, do not reflect this highlight. The improvement of the driver's working conditions is of interest not only to the category, but to the whole of society.

References

Araújo, M.P.S., Bandeira, R.A.M., Campos, V.B.G.: Custos e fretes praticados no transporte rodoviário de cargas: uma análise comparativa entre autônomos e empresas. J. Transp. Lit. (2014). https://doi.org/10.1590/2238-1031.jtl.v8n4a8

Brazil: Lei n° 11.442, de 5 de janeiro de 2007. Casa Civil (2007)

Brazil: Greve dos caminhoneiros impacta a economia em cerca de R$ 15,9 bilhões. Secretaria Especial de Fazenda (2018)

Cerqueira-Santos, E., Santana, M.: Work satisfaction among truck drivers: a comparative study of self-employed and employees. Revista de Psicologia da UFC (2014). https://doi.org/10.17652/rpot/2016.2.675

CNT: Pesquisa CNT de Rodovias 2019. Confederação Nacional do Transporte (2019)

Coelho, L.A.T.: As Leis 12.619/2012 e 13.103/2015 e flexibilização da jornada de trabalho do motorista em transporte rodoviário de passageiros e de cargas. Revista eletrônica [do] Tribunal Regional do Trabalho da 9 Região (2015)

Crizzle, A.M., Bigelow, P., Adams, D., Gooderham, S., Myers, A.M., Thiffault, P.: Health and wellness of long-haul truck and bus drivers: a systematic literature review and directions for future research. J. Transp. Health (2017). https://doi.org/10.1016/j.jth.2017.05.359

Di Milia, L., Smolensky, M.H., Costa, G., Howarth, H.D., Ohayon, M.M., Philip, P.: Demographic factors, fatigue, and driving accidents: an examination of the published literature. Accid. Anal. Prev. (2011). https://doi.org/10.1016/j.aap.2009.12.018

Fonseca, E.P.R.: Motoristas profissionais e atletas profissionais de futebol: quando a legislação especial precariza o trabalho. Revista do Curso de Direito da UNIFOR (2016)

Gil, A.C.: Métodos e Técnicas de Pesquisa Social. Editora Atlas, 7 edição (2019)

Gonçalves, M., Amici, R., Lucas, R., Akerstedt, T., Cirignotta, F., Horne, J., Léger, D., Mcnicholas, W.T., Partinen, M., Téran-Santos, J., Peigneux, P.: Sleepiness at the wheel across Europe: a survey of 19 countries. J. Sleep Res. (2015). https://doi.org/10.1111/jsr.12267

Hege, A., Perko, M., Apostolopoulos, Y., Sönmez, S., Strack, R.: US long-haul truck driver health demands integrated approach. Int. J. Workplace Health Manag. (2016). https://doi.org/10.1108/ijwhm-12-2014-0058

Junior, A.F., Garcia, E.G.: Road freight transport: fatal work accidents and labor inspection. Revista Brasileira de Saúde Ocupacional (2019). https://doi.org/10.1590/2317-6369000018317

Junior, G.A., Melo, H.C.S., Mendes, D.F., Silva, M.L.A., Oliveira, R.F.S., Gaya, C.M.: O uso de drogas por motoristas caminhoneiros e o comportamento de risco nas estradas. Revista de Epidemiologia e Controle de Infecção (2016). https://doi.org/10.17058/reci.v6i4.7968

Lan, F.Y., Wei, C.F., Hsu, Y.T., Christiani, D.C., Kales, S.N.: Work-related Covid-19 transmission. medRxiv (2020). https://doi.org/10.1101/2020.04.08.20058297

Malinga, T., Wiysonge, C.S., Ndwandwe, D., Okeibunor, J.C., Talisuna, A.O.: A scoping review of the impact of long-distance truck drivers on the spread of COVID-19 infection. Pan Afr. Med. J. (2021). https://doi.org/10.11604/pamj.2021.38.27.26691

Narciso, F.V., Mello, M.T.: Safety and health of professional drivers who drive on Brazilian highways. Revista Saúde Pública (2017). https://doi.org/10.1590/S1518-8787.2017051006761

Nazari, S.S.H., Moradi, A., Rahmani, K.: A systematic review of the effect of various interventions on reducing fatigue and sleepiness while driving. Chin. J. Traumatol. (2017). https://doi.org/10.1016/j.cjtee.2017.03.005

Oliveira, M.E.T., Carlotto, M.S.: Factors Associated with Common Mental Disorders in Truck Drivers. Teoria e Pesquisa, Psicologia (2020). https://doi.org/10.1590/0102.3772e3653

Saenz, M.J., Koufteros, X.: Special issue on literature reviews in supply chain management and logistics. Int. J. Phys. Distrib. Logist. Manag. (2015). https://doi.org/10.1108/IJPDLM-12-2014-0305

Santos, K.O.B., Fernandes, R.C.P., Almeida, M.M.C., Miranda, S.S., Mise, Y.F., Lima, M.A.G.: Labor, health and vulnerability in the COVID-19 pandemic. Cadernos de Saúde Pública (2020). https://doi.org/10.1590/0102-311x00178320

Silva, L.G., Luz, A.A., Vasconcelos, S.P., Marqueze, E.C., Moreno, C.R.C.: Vínculos empregatícios, condições de trabalho e saúde entre motoristas de caminhão. Organizações e Trabalho, Revista Psicologia (2016). https://doi.org/10.17652/rpot/2016.2.675

Sinagawa, D.M., Carvalho, H.B., Andreuccetti, G., Prado, N.V., Oliveira, K.C.B.G., Yonamine, M., Muñoz, D.R., Gjerde, H., Leyton, V.: Association Between Travel Length and Drug Use Among Brazilian Truck Drivers. Traffic Injury Prevention (2014). https://doi.org/10.1080/15389588.2014.906589

Soni, G., Kodali, R.: A critical analysis of supply chain management content in empirical research. Bus. Process Manag. J. (2011). https://doi.org/10.1108/14637151111122338

Wanke, P.F.: Fatores de satisfação com o uso de autônomos no transporte rodoviário de cargas. Produção (2012). https://doi.org/10.1590/S0103-65132012005000046

Wolff, M.G.C., Caldas, M.A.F.: A model for the evaluation of brazilian road transport: a sustainable perspective. J. Adv. Transp. (2018). https://doi.org/10.1155/2018/5274789

R. Soliani Federal Institute of Acre (IFAC), Doctor in Environmental Technology (2020), University of Ribeirão Preto (UNAERP), Brazil

L. Bueno Federal University of Paraíba (UFPB), Doctor in Production Engineering (2001), Federal University of Santa Catarina (UFSC), Brazil

A Short Review on the Usage of Online Surveys Among Health Professionals

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Abstract Background: Surveys are an established tool within health services, allowing to recruit large and diverse cross-sections of the population and offer rapid data collection and cost-effectiveness. Various methods for conducting surveys exist, being the web-based method the one with increasing applicability. Despite its advantages, specific concerns might affect their validity and, therefore, require special attention. Objective: To characterise the methods and good practices of online surveys applied explicitly to health professionals. Method: The databases Scopus and PubMed were searched throughout the last five years and were screened in parallel by to two authors. Studies addressing the application of web-based surveys among health professionals were selected and, data regarding survey characteristics, response rates and applied methodologies were extracted. Results and discussion: Outcomes evidenced that the use of web surveys has increased significantly. Email is the most used method for disseminating questionnaires, with Google Forms and Survey Monkey as the most preferred platforms. As for the methodology applied for the development of the questionnaires, the most mentioned was CHERRIES. Conclusion: The use of online questionnaires proved to be a facilitator in collecting responses. However, some resistance from participants remains. This resistance may be associated with the sample's difficulty using online platforms or its unavailability to answer the questionnaires. Application: This review found limited but helpful information regarding the procedures and good practices to follow when applying and presenting

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surveys. It can be used as a reference for future studies for an overall perspective on the up-to-date methodologies and remaining challenges when conducting these surveys.

Keywords Web surveys · Survey platforms · Survey research · Web-based survey · Health services.

1 Introduction

Surveys are an essential tool in health services, providing cost-effective sources of information on physicians' attitudes, knowledge, and practices related to care delivery (VanGeest et al. 2007). They have been used to assess a range of issues, from routine subjects like knowledge of and compliance with evidence-based practice recommendations to more specific topics such as improving medical practices in treating patients (Miró et al. 2021) and collecting patients' opinions on undertaking specific treatments (Kaiser et al. 2019), among others. There are various methods for conducting surveys. Traditionally, paper-based or telephone systems have been used as the methods of choice, while more recently, there has been a surge in web-based surveys (Harrison et al. 2020).

Web-based surveys are increasing acceptance within research fields, as they are easy to apply and allow to cover more expansive geographic areas while being cost and time effective (Eysenbach and Wyatt 2002; Manfreda et al. 2008). Despite their advantages, however, their findings' validity and generalisability are often subject to concerns due to the low response rates or the lack of control to the population and sample sizes, among other reasons. Authors point to some issues that compromise their efficacy, including the sample's unavailability to participate in the study and the difficulties individuals encounter with unfamiliar tools used in the online questionnaires (Couper 2000).

The emergence of new tools for conducting these surveys, specifically online survey platforms and new data processing procedures, can help face these reported weaknesses. As a result, up-to-date research needs to be systematised and examined to identify these new tools and, more importantly, potential procedures or methodologies used to guarantee their validity, their limitations, and opportunities for improvement in their application. Thus, this review aimed to collect and analyse the procedures and good practices of studies addressing web-based surveys and online surveys, focusing on those applied explicitly to health professionals.

2 Materials and Methods

A systematic search of the literature was performed following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement (Page et al.

2021). The electronic databases Scopus and PubMed were searched throughout the last five years and were screened in parallel by to two authors for relevant studies. Initially, the electronic databases were accessed, and selected combinations of keywords were inserted. The terms "e-survey" and "web-based survey" were combined with the "healthcare"keyword by using the Boolean connector "AND". Then, restrictions of date (records published between 2016 and 2021), document type (only research articles, excluding reviews, conference papers and case reports), source type (articles published in peer-reviewed journals) and language (only English written items) were applied.

Retrieved papers were screened (examining title, abstract and keywords) and excluded if they did not refer to web-based or online surveys or did not consider a sample of health professionals. The remaining articles were full text assessed and were selected if they addressed survey results from a homogeneous health profession group. Articles resulting from this last stage were analysed according to the sought goals of this review. Data regarding survey characteristics, response rates and applied methodologies were extracted by using a customised table. Specifically, the studies' scope, used survey platform, and their adherence to any method or guidelines (if mentioned) were individually examined. Due to the diversity found among studies, a comparison of their results could not be performed, and their respective findings were described narratively.

3 Results and Discussion

Following the PRISMA Statement procedures, 116 articles were initially found in the databases. Then, by analysing the title, abstract and keywords, 60 items were eliminated due to non-compliance with the eligibility criteria, leaving a total of 56 articles. From them, six were eliminated (after a full-text assessment) for not complying with the requirements for indicating the survey platform and the response rate. From this process, 50 were left and included in the review, and are presented in Table 1. Articles were classified according to the platforms in which they conducted their surveys and the applied methodologies or procedures.

3.1 General Findings

Regarding their publishing year, our 50 included studies evidence an increasing trend over the years. Specifically, investigations show a significant increase from the year 2018–2019, from which 15 studies were retrieved. On the other hand, a slight decrease was also observed in the year 2020, where a total of 11 articles were identified. Finally, during the year 2021 (until the date this research was performed), only five published articles were included.

Table 1 Included studies according to identified survey platforms and methods

Survey platform	Methodologies/Guidelines	Studies references
Google Forms	CHERRIES	Lisi et al. (2020)
	Guidelines of the Nurses Early Exit Study (Hasselhorn et al. 2005)	Gea-Caballero et al. (2019)
	Not reported	Abu Arja et al. (2019); Amerio et al. (2020); Kadoya et al. (2021); Kanmounye et al. (2020); Ojha et al. (2020)
Survey Monkey	STROBE (Von Elm et al. 2007)	Necknig et al. (2020)
	Not reported	Arnadottir and Gudjonsdottir (2016); Bushati et al. (2018); Chapman et al. (2017); Choo et al. (2019); Fels et al. (2019); Pradhan et al. (2020); Saugel et al. (2018)
Decipher online survey platform	CHERRIES	Salam et al. (2020)
(FocusVision, New York, NY, USA)	Not reported	Coleman et al. (2020)
Facebook	Not reported	Riccò et al. (2020)
FluidSurveys (Ottawa, Ontario, Canada)	Modified Dillman approach	Lau et al. (2016)
	CHERRIES	Lau et al. (2016)
	Not reported	Sharma et al. (2017)
Google Docs	Not reported	Ferhatoglu et al. (2020); Vascellari et al. (2017)
https://www.thesistools.de	Not reported	Azizi and Schouten-van Meeteren (2018)
LimeSurvey GmbH, Hamburg, Germany	Not reported	Krug et al. (2016)
QuestionPro	Not reported	Lee et al. (2018)
RAMatters.eu website	Not reported	Alten et al. (2019)
REDCap (Research Electronic Data Capture)	Not reported	Boyne et al. (2017); Humer et al. (2020)
So Jump	Not reported	Xu et al. (2019)
Survey Force Deluxe 3	CHERRIES	Suppan et al. (2020)
Weblink	Not reported	Gramegna et al. (2018); Zhang et al. (2019b)
Webropol	STROBE checklist (Von Elm et al. 2007)	Sparud-Lundin et al. (2017)
WeChat	Not reported	Zhang et al. (2019a)

(continued)

Table 1 (continued)

Survey platform	Methodologies/Guidelines	Studies references
WeChat and Tencent QQ	Not reported	Ouyang et al. (2019)
Wenjuanxing (wjx.cn)	Not reported	Yi et al. (2021)
www.onlineanketler.com	Not reported	Ates et al. (2016)
Not reported	KSID's recommendation with reference to the Centers for Disease Control and Prevention in the United States	Ko et al. (2017)
Not used (sent directly via email)	CHERRIES	Felice et al. (2020)
	Recommendations from (Edwards et al. 2009)	Sebo et al. (2017)
	Not reported	Beck et al. (2016, 2017); Brod et al. (2019); Kriss et al. (2019); Palanica et al. (2019); Peiffer-Smadja et al. (2019); Sahashi et al. (2020); Shoham et al. (2019); Vidal-Alaball et al. (2020); Wojcieszek et al. (2019)

As it was observed, there has been a significant increase in the use of web-based surveys over time. Several authors report the benefits of online questionnaires as they are easy to apply and quick to answer (Crawford et al. 2001; Edwards et al. 2009; Fricker and Schonlau 2002; Schmidt 1997). However, between paper and web-based questionnaires, there are still errors that result in low response rates. These errors are generally related to the difficulty reported by some participants in using the online platforms in which the questionnaires are developed or their unavailability to answer (Fricker and Schonlau 2002).

Finally, concerning the way by which the surveys were conducted, several online platforms were identified. Google Forms and Survey Monkey were the ones that evidenced the greatest applicability among the studies (Cobanoglu et al. 2001; Wright 2019). Survey Monkey was included in 6 studies, while Google Forms was identified in 7. On the other hand, few studies were found addressing So jump (Xu et al. 2019) and We Chat (Zhang et al. 2019b) platforms.

3.2 Identified Methodologies and Good Practices

As already demonstrated within our wide variety of included articles, web-based surveys are becoming more common among health professionals related research. However, these surveys' quality varies widely, and the need to educate consumers of surveys regarding quality indicators is already apparent. As Hagan et al. (2017) state, researchers administering surveys (paper or web-based) must seek to balance data quality, sources of error, and practical concerns associated with every survey administration mode. Their adherence to standardised methodologies when developing, conducting, and reporting them could improve the quality and validity of obtained results.

Considering this, we aimed to identify existing methodologies to conduct and report the results from web-based surveys. The application of any guideline, procedure, or reference methodology was examined among our selected papers. As Table 1 reports, nine different methodologies were found. From them, the CHERRIES checklist (Eysenbach 2004) was the most predominant. This method encompasses recommendations for both conducting and reporting web-based surveys. A paper elaborated according to the CHERRIES statement is aimed to describe aspects related to the survey design, an institutional review board approval and informed consent process, the development of pre-testing procedures, the recruitment process and survey administration, response rates, developed strategies to prevent multiple entries from the same individual and the respective analysis of results. From all the identified methodologies, this was the only one explicitly addressing web-based surveys.

The second most preferred methodology was the STROBE Statement (Knottnerus and Tugwell 2008; Von Elm et al. 2007), in which a checklist to report observational studies in epidemiology is provided. Although its purpose differs from this review's goals, it offers valuable criterions to increase the quality of surveys conducted within the epidemiology area. Other guidelines with less common application included those suggested by Edwards et al. (2009). These authors developed a review in which different strategies to overcome bias sources identified among studies, such as inadequate allocation concealment, methodological quality and questionnaire topic, were suggested.

Despite the identification of procedures and guidelines within some of the papers, it was observed that most of them did not mention their adherence to any specific methodology. They just indicated the measures they followed to overcome some typical biases associated with web-based surveys and traceability of results. 37 out of the 50 final selected group did not provide details in this regard, representing more than 70% of our sample.

Overall, common measures and good practices included principles applied to the question design, namely, keeping the questions simple, requiring intuitive answers, and avoiding controversial issues by referring to universally accepted medical guidelines or procedures. Additionally, many studies assured respondents had a unique survey link or restricted IP access to prevent duplicate responses. Finally, some authors indicated to have validated their questionnaire first within a small sample before conducting the actual study, which allowed them to make the necessary improvements and guarantee better results.

On the other hand, challenges and limitations identified through the conducted surveys were mainly related to the low obtained response rates or the impossibility of determining them. In some cases, it was not possible to estimate whether the proportion of participating health personnel was representative of their professional group or target study population, compromising the generalisability of their results. Lastly, as reported by some authors, using a web-based survey also implied a possible bias in obtaining answers from those with better technology management.

3.3 Final Considerations

In general, the central goals of surveys are to include the broadest possible sample from the population of interest and to create generalisable results, minimising error in responses. Survey research, therefore, must ensure that the survey can be accessed and completed by a representative sample of the target population and can be easily administered, accurately completed, and seamlessly collected. To fulfill these goals, this review was able to find limited but helpful information regarding the procedures and good practices to follow when applying and presenting surveys. Further studies validating new methodologies for standardised application or suggesting improvements on previous ones are recommended.

3.4 Limitations

In this work, some limitations were registered. Although intentional, only English-based studies conducted since 2016 were included, excluding investigations written in other languages or published before that period. In addition, limited evidence was found on the application of some platforms and methodologies, which did not allow a deeper analysis of their effectiveness and applicability. Thus, further studies in this area are recommended, researching their benefits and disadvantages. Finally, it was not possible to make a statistical analysis of the response rates of the different studies since they included different sample sizes and target populations.

4 Conclusions

E-surveys and web-based surveys are a relatively inexpensive and effective way to collect information from people for research purposes. Finding ways to overcome their associated bias sources would improve the quality of health research. This review summarised up-to-date studies conducting these surveys among health professionals and characterised their main methodological and reporting aspects. Our review found that few studies have been published addressing their adherence to methodologies or procedures to conduct web-based or online surveys. Despite this limited evidence, it was verified the application of various platforms for distributing questionnaires online. However, even with the easy use and applicability of these platforms, there is still the implication of a decrease in response rates. These response rates can be affected by different factors. First, it should be noted that, although the questionnaires are sent more frequently by email, it is not always easy to restrict and control target population sizes. Second, participants do not always have time to respond to online questionnaires. The fact that they are distant from the research team makes the sample more indifferent to the study they were invited to participate in. As a result, we consider that the present study allows evaluating the advantages and disadvantages of using online questionnaires in health professionals. It verifies the application of different methodologies and platforms and examines their response rates. However, we believe it is necessary to carry out more studies, increasing the number of investigations included and assessing the use of other work platforms and methodologies applied to online questionnaires.

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References

Abu Arja, M.H., Stanek, J.R., Morales La Madrid, A.E., Lassaletta, A., Bartels, U., Qaddoumi, I., Finlay, J.L., Osorio, D.S.: The Latin American Brain Tumor Board teleconference: results of a web-based survey to evaluate participant experience utilising this resource. Child's Nerv. Syst.: ChNS: Off. J. Int. Soc. Pediatr. Neurosurg. **35**(2), 257–265 (2019). https://doi.org/10.1007/s00381-018-4000-x

Alten, R., van de Laar, M., De Leonardis, F., Tietz, N., Guerreiro, M., van Vollenhoven, R.: Physical and emotional burden of rheumatoid arthritis: data from RA matters, a web-based survey of patients and healthcare professionals. Rheumatol. Ther. **6**(4), 587–597 (2019). https://doi.org/10.1007/s40744-019-00179-2

Amerio, A., Bianchi, D., Santi, F., Costantini, L., Odone, A., Signorelli, C., Costanza, A., Serafini, G., Amore, M., Aguglia, A.: Covid-19 pandemic impact on mental health: a web-based cross-sectional survey on a sample of Italian general practitioners. Acta Bio-Med.: Atenei Parm. **91**(2), 83-88 (2020). https://doi.org/10.23750/abm.v91i2.9619

Arnadottir, S.A., Gudjonsdottir, B.: Icelandic physical therapists' attitudes toward adoption of new knowledge and evidence-based practice: cross-sectional web-based survey. Phys. Ther. **96**(11), 1724–1733 (2016). https://doi.org/10.2522/ptj.20150428

Ates, F., Zor, M., Yılmaz, O., Tuncer, M., Ozturk, M., Gurbuz, C., Atis, G., Koca, O., Yildirim, A., Eryildirim, B., Kucuk, E.V., Narter, F., Senkul, T., Sarica, K.: Management behaviors of the urology practitioners to the small lower calyceal stones: the results of a web-based survey. Urolithiasis **44**(3), 277–281 (2016). https://doi.org/10.1007/s00240-015-0825-x

Azizi, A.A., Schouten-van Meeteren, A.Y.N.: Current and emerging treatment strategies for children with progressive chiasmatic-hypothalamic glioma diagnosed as infants: a web-based survey. J. Neuro-Oncol. **136**(1), 127–134 (2018). https://doi.org/10.1007/s11060-017-2630-6

Beck, M., Michel, B., Rybarczyk-Vigouret, M.-C., Levêque, D., Sordet, C., Sibilia, J., Velten, M.: Rheumatologists' perceptions of biosimilar medicines prescription: findings from a french web-based survey. BioDrugs: Clin. Immunother., Biopharm. Gene Ther. **30**(6), 585–592 (2016). https://doi.org/10.1007/s40259-016-0202-5

Beck, M., Michel, B., Rybarczyk-Vigouret, M.-C., Levêque, D., Sordet, C., Sibilia, J., Velten, M.: Knowledge, behaviors and practices of community and hospital pharmacists towards biosimilar

medicines: results of a French web-based survey. mAbs, **9**(2), 383–390 (2017). https://doi.org/10.1080/19420862.2016.1267087
Boyne, P., Billinger, S., MacKay-Lyons, M., Barney, B., Khoury, J., Dunning, K.: Aerobic exercise prescription in stroke rehabilitation: a web-based survey of US physical therapists. J. Neurol. Phys. Ther.: JNPT **41**(2), 119–128 (2017). https://doi.org/10.1097/NPT.0000000000000177
Brod, M., Basse, A., Markert, M., Pfeiffer, K.M.: Post-basal insulin intensification and healthcare resource use in type 2 diabetes: a web-based physician survey in the United States and United Kingdom. Diabetes Ther.: Res., Treat. Educ. Diabetes Relat. Disord. **10**(4), 1323–1336 (2019). https://doi.org/10.1007/s13300-019-0636-0
Bushati, M., Rovers, K.P., Sommariva, A., Sugarbaker, P.H., Morris, D.L., Yonemura, Y., Quadros, C.A., Somashekhar, S.P., Ceelen, W., Dubé, P., Li, Y., Verwaal, V.J., Glehen, O., Piso, P., Spiliotis, J., Teo, M.C.C., González-Moreno, S., Cashin, P.H., Lehmann, K., Deraco, M., Moran, B., de Hingh, I.H.J.T.: The current practice of cytoreductive surgery and HIPEC for colorectal peritoneal metastases: results of a worldwide web-based survey of the Peritoneal Surface Oncology Group International (PSOGI). Eur. J. Surg. Oncol.: J. Eur. Soc. Surg. Oncol. Br. Assoc. Surg. Oncol. **44**(12), 1942–1948 (2018). https://doi.org/10.1016/j.ejso.2018.07.003
Chapman, S., Fitzpatrick, R., Aladul, M.: Knowledge, attitude and practice of healthcare professionals towards infliximab and insulin glargine biosimilars: result of a UK web-based survey. BMJ Open **7**, e016730 (2017). https://doi.org/10.1136/bmjopen-2017-016730
Choo, S.H., Nishiyama, H., Kitamura, H., Chen, C.-H., Pu, Y.-S., Lee, H.-L., Jeong, B.C., Kim, I.S.: Practice pattern of non-muscle invasive bladder cancer in Japan, Korea and Taiwan: a web-based survey. Int. J. Urol.: Off. J. Jpn. Urol. Assoc. **26**(12), 1121–1127 (2019). https://doi.org/10.1111/iju.14105
Cobanoglu, C., Warde, B., Moreo, P.: A comparison of mail, fax and web-based survey methods. Int. J. Mark. Res. **43**,(2001). https://doi.org/10.1177/147078530104300401
Coleman, C., Salam, T., Duhig, A., Patel, A.A., Cameron, A., Voelker, J., Bookhart, B.: Impact of non-medical switching of prescription medications on health outcomes: an e-survey of high-volume medicare and medicaid physician providers. J. Mark. Access Health Policy **8**(1), 1829883 (2020). https://doi.org/10.1080/20016689.2020.1829883
Couper, M.P.: Review: web surveys: a review of issues and approaches*. Public Opin. Q. **64**(4), 464–494 (2000). https://doi.org/10.1086/318641
Crawford, S.D., Couper, M.P., Lamias, M.J.: Web surveys: perceptions of burden. Soc. Sci. Comput. Rev. **19**(2), 146–162 (2001). https://doi.org/10.1177/089443930101900202
Edwards, P., Roberts, I., Clarke, M., Diguiseppi, C., Wentz, R., Kwan, I., Cooper, R., Felix, L., Pratap, S.: Methods to increase response to postal and electronic questionnaires (Review). Cochrane Database Syst. Rev. (Online) **3**, MR000008 (2009). https://doi.org/10.1002/14651858.MR000008.pub4
Eysenbach, G.: Improving the quality of web surveys: the checklist for reporting results of internet E-surveys (CHERRIES). J. Med. Internet Res. **6**(3), e34 (2004). https://doi.org/10.2196/jmir.6.3.e34
Eysenbach, G., Wyatt, J.: Using the internet for surveys and health research. J. Med. Internet Res. **4**(2), E13 (2002). https://doi.org/10.2196/jmir.4.2.e13
Felice, C., Di Tanna, G.L., Zanus, G., Grossi, U.: Impact of COVID-19 outbreak on healthcare workers in Italy: results from a national E-survey. J. Community Health **45**(4), 675–683 (2020). https://doi.org/10.1007/s10900-020-00845-5
Fels, J., Pigorsch, S., Vorwerk, H., Engenhart-Cabillic, R., van Oorschot, B.: Palliative care in everyday practice of radiation oncologists: results from a web-based survey among medical members of the German society for radiation oncology (DEGRO). Strahlentherapie und Onkologie: Organ der Deutschen Rontgengesellschaft, et al. **195**(7), 659-667 (2019). https://doi.org/10.1007/s00066-018-1403-2
Ferhatoglu, S.Y., Ferhatoglu, M.F., Gurkan, A.: Approach of the clinicians practicing in intensive care units to brain death diagnosis and training expectations in Turkey: a web-based survey. Transplant. Proc. **52**(10), 2916–2922 (2020). https://doi.org/10.1016/j.transproceed.2020.05.023

Fricker, R.D., Schonlau, M.: Advantages and disadvantages of internet research surveys: evidence from the literature. Field Methods **14**(4), 347–367 (2002). https://doi.org/10.1177/152582202237725

Gea-Caballero, V., Castro-Sánchez, E., Díaz-Herrera, M.Á., Sarabia-Cobo, C., Juárez-Vela, R., Zabaleta-Del Olmo, E.: Motivations, beliefs, and expectations of spanish nurses planning migration for economic reasons: a cross-sectional, web-based survey. J. Nurs. Sch.: Off. Publ. Sigma Theta Tau Int. Honor. Soc. Nurs. **51**(2), 178–186 (2019). https://doi.org/10.1111/jnu.12455

Gramegna, A., Dellafiore, S., Contarini, M., Blasi, F., Aliberti, S., Tosatto, R., Mantero, M.: Knowledge and attitudes on influenza vaccination among Italian physicians specialised in respiratory infections: an Italian Respiratory Society (SIP/IRS) web-based survey. J. Prev. Med. Hyg. **59**(2), E128–E131 (2018)

Hagan, T. L., Belcher, S. M., Donovan, H.S.: Mind the mode: differences in paper vs. web-based survey modes among women with cancer. J. Pain Symptom Manag. **54**(3), 368–375 (2017). https://doi.org/10.1016/j.jpainsymman.2017.07.005

Harrison, S., Alderdice, F., Henderson, J., Redshaw, M., Quigley, M.: Trends in response rates and respondent characteristics in five national maternity surveys in England during 1995–2018. Arch. Public Health **78** (2020). https://doi.org/10.1186/s13690-020-00427-w

Hasselhorn, H., Tackenberg, P., Müller, B.: Nurses early exit study: scientific report July 2005. University of Wuppertal. Accessed 23 April 2008. In (2005)

Humer, E., Stippl, P., Pieh, C., Pryss, R., Probst, T.: Experiences of psychotherapists with remote psychotherapy during the covid-19 pandemic: cross-sectional web-based survey study. J. Med. Internet Res. **22**(11), e20246 (2020). https://doi.org/10.2196/20246

Kadoya, Y., Zen, K., Wakana, N., Yanishi, K., Senoo, K., Nakanishi, N., Yamano, T., Nakamura, T., Matoba, S.: Knowledge, perception, and level of confidence regarding COVID-19 care among healthcare workers involved in cardiovascular medicine: a web-based cross-sectional survey in Japan. J. Cardiol. **77**(3), 239–244 (2021). https://doi.org/10.1016/j.jjcc.2020.07.029

Kaiser, F., Vehling-Kaiser, U., Hermes-Moll, K., Walawgo, T., Baumann, W.: Feasibility of nurse consultation in oral tumor therapy: a web-based survey among physicians and nonmedical specialists. Oncol. Res. Treat. **42**(9), 448–457 (2019). https://doi.org/10.1159/000501725

Kanmounye, U.S., Mbonda, A.N., Djiofack, D., Daya, L., Pokam, O.F., Ghomsi, N.C.: Exploring the knowledge and attitudes of Cameroonian medical students towards global surgery: a web-based survey. PloS one **15**(4), e0232320 (2020). https://doi.org/10.1371/journal.pone.0232320

Knottnerus, A., Tugwell, P.: STROBE—a checklist to STrengthen the reporting of OBservational studies in epidemiology. J. Clin. Epidemiol. **61**, 323 (2008). https://doi.org/10.1016/j.jclinepi.2007.11.006

Ko, K., Kim, S., Kim, S.-H., Son, K.Y., Lee, J., Lee, D.R.: Knowledge, current status, and barriers toward healthcare worker vaccination among family medicine resident participants in a web-based survey in Korea. Korean J. Fam. Med. **38**(1), 21–27 (2017). https://doi.org/10.4082/kjfm.2017.38.1.21

Kriss, J.L., Grant, G.B., Moss, W.J., Durrheim, D.N., Shefer, A., Rota, P.A., Omer, S.B., Masresha, B.G., Mulders, M.N., Hanson, M., Linkins, R.W., Goodson, J.L.: Research priorities for accelerating progress toward measles and rubella elimination identified by a cross-sectional web-based survey. Vaccine **37**(38), 5745–5753 (2019). https://doi.org/10.1016/j.vaccine.2019.02.058

Krug, D., Baumann, R., Rieckmann, T., Fokas, E., Gauer, T., Niyazi, M.: Situation of young radiation oncologists, medical physicists and radiation biologists in German-speaking countries : results from a web-based survey of the Young DEGRO working group. Strahlentherapie und Onkologie: Organ der Deutschen Rontgengesellschaft, et al., **192**(8), 507–515 (2016). https://doi.org/10.1007/s00066-016-1003-y

Lau, C., Chitussi, D., Elliot, S., Giannone, J., McMahon, M.-K., Sibley, K.M., Tee, A., Matthews, J., Salbach, N.M.: Facilitating community-based exercise for people with stroke: cross-sectional e-survey of physical therapist practice and perceived needs. Phys. Ther. **96**(4), 469–478 (2016). https://doi.org/10.2522/ptj.20150117

Lee, J.Y., Kersten, D.D., Mines, P., Beltran, T.A.: Regenerative endodontic procedures among endodontists: a web-based survey. J. Endod. **44**(2), 250–255 (2018). https://doi.org/10.1016/j.joen.2017.09.010

Lisi, L., Ciaffi, J., Bruni, A., Mancarella, L., Brusi, V., Gramegna, P., Ripamonti, C., Quaranta, E., Borlandelli, E., Gallo, G., Garofalo, E., Chiaravalloti, A., Viola, P., Ruscitti, P., Caio, G., D'Onghia, M., D'Amuri, A., Cimellaro, A., Facchini, G., La Regina, M., Spinardi, L., De Giorgio, R., Giacomelli, R., Landini, M. P., Berardi, D., Meliconi, R., Ursini, F.: Levels and factors associated with resilience in italian healthcare professionals during the COVID-19 pandemic: a web-based survey. Behav. Sci. (Basel, Switzerland) **10**(12) (2020). https://doi.org/10.3390/bs10120183

Manfreda, K., Bosnjak, M., Berzelak, J., Haas, I., Vehovar, V.: Web surveys versus other survey modes: a meta-analysis comparing response rates. Int. J. Mark. Res. **50**, 79–104 (2008). https://doi.org/10.1177/147078530805000107

Miró, J., Micó, J.A., Reinoso-Barbero, F.: The management of pediatric chronic pain in Spain: a web-based survey study. Curr. Med. Res. Opin. **37**(2), 303–310 (2021). https://doi.org/10.1080/03007995.2020.1854208

Necknig, U., Wolff, I., Bründl, J., Kriegmair, M.C., Marghawal, D., Wülfing, C., Burger, M., May, M.: Gender-specific variations in professional and personal aspects among senior urology physicians at german centers: results of a web-based survey. Urol. Int. **104**(3–4), 309–322 (2020). https://doi.org/10.1159/000503869

Ojha, S., Debnath, M., Sharma, D., Niraula, A.: Knowledge of Handling the Personal protective equipment (PPE) by frontline Allied Health professionals in COVID-19 outbreak—a web-based survey study. J. Radiol. Nurs. (2020). https://doi.org/10.1016/j.jradnu.2020.1012.1012

Ouyang, Y.-Q., Zhou, W.-B., Xiong, Z.-F., Wang, R., Redding, S.R.: A web-based survey of marital quality and job satisfaction among Chinese nurses. Asian Nurs. Res. **13**(3), 216–220 (2019). https://doi.org/10.1016/j.anr.2019.07.001

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D.: The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ **372**, n71 (2021). https://doi.org/10.1136/bmj.n71

Palanica, A., Flaschner, P., Thommandram, A., Li, M., Fossat, Y.: Physicians' perceptions of chatbots in health care: cross-sectional web-based survey. J. Med. Internet Res. **21**(4), e12887–e12887 (2019). https://doi.org/10.2196/12887

Peiffer-Smadja, N., Bauvois, A., Chilles, M., Gramont, B., Maatoug, R., Bismut, M., Thorey, C., Oziol, E., Hanslik, T.: The french society of internal medicine's top-5 list of recommendations: a national web-based survey. J. Gen. Intern. Med. **34**(8), 1475–1485 (2019). https://doi.org/10.1007/s11606-019-05050-2

Pradhan, A., Ganguly, A., Naik, M.N., Nair, A.G., Desai, S., Rath, S.: Thyroid eye disease survey: an anonymous web-based survey in the Indian subcontinent. Indian J. Ophthalmol. **68**(8), 1609–1614 (2020). https://doi.org/10.4103/ijo.IJO_1918_19

Riccò, M., Vezzosi, L., Gualerzi, G., Bragazzi, N.L., Balzarini, F.: Pertussis immunisation in healthcare workers working in pediatric settings: knowledge, attitudes and practices (KAP) of occupational physicians: preliminary results from a web-based survey. J. Prev. Med. Hyg. **61**(1), E66–E75 (2017). https://doi.org/10.15167/2421-4248/jpmh2020.61.1.1155

Sahashi, Y., Endo, H., Sugimoto, T., Nabeta, T., Nishizaki, K., Kikuchi, A., Matsumoto, S., Sato, H., Goto, T., Hasegawa, K., Matsue, Y.: Worries and concerns among healthcare workers during the coronavirus 2019 pandemic: a web-based cross-sectional survey (2020). https://doi.org/10.1101/2020.06.09.20126045

Salam, T., Duhig, A., Patel, A.A., Cameron, A., Voelker, J., Bookhart, B., Coleman, C.I.: Physicians' perspectives regarding non-medical switching of prescription medications: results of an internet e-survey. PloS One **15**(1) (2020). https://doi.org/10.1371/journal.pone.0225867

Saugel, B., Reese, P.C., Wagner, J.Y., Buerke, M., Huber, W., Kluge, S., Prondzinsky, R.: Advanced hemodynamic monitoring in intensive care medicine: a German web-based survey study. Medizinische Klinik, Intensivmedizin und Notfallmedizin **113**(3), 192–201 (2018). https://doi.org/10.1007/s00063-017-0302-0

Schmidt, W.C.: World-wide web survey research: benefits, potential problems, and solutions. Behav. Res. Methods, Instrum., Comput. **29**(2), 274–279 (1997). https://doi.org/10.3758/BF03204826

Sebo, P., Maisonneuve, H., Cerutti, B., Fournier, J.P., Senn, N., Haller, D.M.: Rates, delays, and completeness of general practitioners' responses to a postal versus web-based survey: a randomised trial. J. Med. Internet Res. **19**(3), e83 (2017). https://doi.org/10.2196/jmir.6308

Sharma, G.K., Sofferman, R.A., Armstrong, W.B.: Evaluation of the American college of surgeons thyroid and parathyroid ultrasound course: results of a web-based survey. Laryngoscope **127**(8), 1950–1958 (2017). https://doi.org/10.1002/lary.26335

Shoham, G., Levy-Toledano, R., Leong, M., Weissman, A., Yaron, Y., Shoham, Z.: Oncofertility: insights from IVF specialists-a worldwide web-based survey analysis. J. Assist. Reprod. Genet. **36**(5), 1013–1021 (2019). https://doi.org/10.1007/s10815-019-01419-8

Sparud-Lundin, C., Berghammer, M., Moons, P., Bratt, E.-L.: Health care providers' attitudes towards transfer and transition in young persons with long term illness- a web-based survey. BMC Health Serv. Res. **17**(1), 260 (2017). https://doi.org/10.1186/s12913-017-2192-5

Suppan, L., Chan, M., Gartner, B., Regard, S., Campana, M., Chatellard, G., Cottet, P., Larribau, R., Sarasin, F.P., Niquille, M.: Evaluation of a prehospital rotation by senior residents: a web-based survey. Healthcare (Basel, Switzerland) **9**(1) (2020). https://doi.org/10.3390/healthcare9010024

VanGeest, J.B., Johnson, T.P., Welch, V.L.: Methodologies for improving response rates in surveys of physicians: a systematic review. Eval. Health Prof. **30**(4), 303–321 (2007). https://doi.org/10.1177/0163278707307899

Vascellari, A., Grassi, A., Combi, A., Tomaello, L., Canata, G.L., Zaffagnini, S.: Web-based survey results: surgeon practice patterns in Italy regarding anterior cruciate ligament reconstruction and rehabilitation. Knee Surg., Sport. Traumatol., Arthrosc.: Off. J. ESSKA **25**(8), 2520–2527 (2017). https://doi.org/10.1007/s00167-016-4007-3

Vidal-Alaball, J., López Seguí, F., Garcia Domingo, J.L., Flores Mateo, G., Sauch Valmaña, G., Ruiz-Comellas, A., Marín-Gomez, F.X., García Cuyàs, F.: Primary care professionals' acceptance of medical record-based, store and forward provider-to-provider telemedicine in catalonia: results of a web-based survey. Int. J. Environ. Res. Public Health **17**(11), 4092 (2020). https://doi.org/10.3390/ijerph17114092

Von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gøtzsche, P.C., Vandenbroucke, J.P.: The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Ann. Intern. Med. **147**(8), 573–577 (2007)

Wojcieszek, A.M., Heazell, A.E., Middleton, P., Ellwood, D., Silver, R.M., Flenady, V.: Research priorities and potential methodologies to inform care in subsequent pregnancies following stillbirth: a web-based survey of healthcare professionals, researchers and advocates. BMJ Open **9**(6),(2019). https://doi.org/10.1136/bmjopen-2018-028735

Wright, K.B.: Web-based survey methodology BT—handbook of research methods in health social sciences. In: Liamputtong, P. (ed.) pp. 1339–1352 (2019). https://doi.org/10.1007/978-981-10-5251-4_18

Xu, Y., Wang, W., Zhao, J., Wang, J., Zhao, T.: Knowledge, attitude, and practice of healthcare professionals toward clinically applying graduated compression stockings: results of a Chinese web-based survey. J. Thromb. Thrombolysis **47**(1), 102–108 (2019). https://doi.org/10.1007/s11239-018-1749-4

Yi, H., Yang, Y., Zhang, L., Zhang, M., Wang, Q., Zhang, T., Zhang, Y., Qin, Y., Peng, Z., Leng, Z., Yang, W., Zheng, J., Liang, X., Feng, L.: Improved influenza vaccination coverage among healthcare workers: evidence from a web-based survey in China, 2019/2020 season. Hum. Vaccines Immunother. **1–5** (2021). https://doi.org/10.1080/21645515.2020.1859317

Zhang, Y., Li, X., Luo, S., Liu, C., Xie, Y., Guo, J., Liu, F., Zhou, Z.: Use, Perspectives, and Attitudes Regarding Diabetes Management Mobile Apps Among Diabetes Patients and Diabetologists in

China: National Web-Based Survey. JMIR mHealth uHealth **7**(2), e12658 (2019). https://doi.org/10.2196/12658

Zhang, Z., Xu, P., Fang, Q., Ma, P., Lin, H., Fink, J.B., Liang, Z., Chen, R., Ge, H.: Practice pattern of aerosol therapy among patients undergoing mechanical ventilation in mainland China: a web-based survey involving 447 hospitals. PloS One **14**(8) (2019). https://doi.org/10.1371/journal.pone.0221577

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Mask Use During the COVID-19 Pandemic: A Study with Civil Servants of Education

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Abstract Objective: investigate the respiratory protection care of civil servants at the Instituto Federal de Educação, Ciência e Tecnologia (IFRN), in Brazil, during the COVID-19 pandemic. Background: it is of fundamental importance to study the respiratory protection of workers and the use of adequate masks in the context of the COVID-19 pandemic. Method: Data collection was carried out with civil servants through an online survey containing questions about the use of masks and behavior related to Respiratory Protection. Results: the 525 survey respondents showed little knowledge about the investigated aspects related to the use of masks. Until the period of data collection, there was little contaminated with COVID-19 among the research participants. Conclusion: the importance of carrying out training on respiratory protection was verified, including the use of behavioral change strategies with a focus on collective benefit, recommended for this pandemic context. Application: reflections and technical knowledge about respiratory protection for society in general.

Keywords Coronavirus infections · SARS-CoV-2 · Respiratory protective devices · Disposable half mask · Filtering facepiece (FFP)

1 Introduction

Since the first centuries of the Christian Era, there is a need to protect the airways, according to records by Gaius Plinius Secundus (23—79 AD) (TORLONI; VIEIRA, 2019). Nowadays, many workers wear breathing apparatus or respirators to protect their health in the workplace all around in the world (HSE 2013).

Breathing apparatus (BA) provides clean air for the worker to breathe while the Respirators filter the air to remove harmful substances. The BA's can be of the types:

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Fresh air hose, Constant flow airline, and Demand valve. Respirators can be of the types: Powered hoods/helmets, Powered mask, Full face mask—gas/vapour filter, Full face mask—particle filter, Reusable half mask—gas/vapour filter, Reusable half mask–particle filter, and Disposable half mask—particle filter (HSE 2013; TORLONI; VIEIRA, 2019). These Personal Protective Equipment (PPE) are known as Respiratory Protective Equipment (RPE) (HSE 2013).

The most used RPE's are the disposable half masks or disposable masks. They are designed to be discarded when they become unfit for use due to hygiene limitations, excessive breathing resistance or physical damage (NIOSH 2018b).

In Brazil, disposable half mask are called Peça Semifacial Filtrante (PFF). They are classified according to their contaminant filtration efficiency. Through laboratory tests with NaCl certification aerosols, the masks are classified as PFF1 (80% filtration efficiency), PFF2 (94% filtration efficiency) and PFF3 (99% filtration efficiency) (ABNT 2011). The Brazillian PFF2 disposable half mask is equivalent to the North American N95 disposable half mask (FUNDACENTRO 2020; TORLONI; VIEIRA, 2019).

For the use of BA's and Respirators it is necessary to carry out a user seal check whenever the respirator is used to ensure that a proper seal is obtained. Because people come in different sizes and shapes, so these facial differences will mean that one type of equipment probably won't fit all (NIOSH 2018a). According to Health and Safety Executive (HSE), the differences are even more significant between women, men and people of different ethnicities, and if the equipment does not fit, it will not protect the user (HSE 2013).

The RPE‘s are designed for protection against chemical, biological, radiological, and nuclear (CBRN) agents (CDC 2012). Specifically regarding biological agents, they can disperse in the air and be transmitted by bioaerosols (INSST 2021a). Bioaerosols are airborne particles composed of living organisms or their derivatives (ACGIH 2019).

The use of RPE‘s to protect workers from bioaerosols is recent. This need to use RPE emerged with the outbreak of tuberculosis in the 1990s and was reinforced by the Ebola virus epidemic between 2014 and 2016 in the United States (NIOSH 2019).

After COVID-19, caused by the SARS-CoV-2 virus, became a pandemic in March 2020 (WHO 2020a), the entire world population was required to acquire new patterns of behavior: social distancing (Anderson et al. 2020; WHO 2020b), use of alcohol and constant hand washing (WHO 2020a) and one of the most necessary: the use of respiratory protection (CCOHS 2021; CDC 2020; FUNDACENTRO 2020; INSST 2021b; WHO 2020c).

Therefore, the objective of this study is to investigate the respiratory protection care of civil servants at the Instituto Federal de Educação, Ciência e Tecnologia (IFRN), in Brazil, during the COVID-19 pandemic.

2 Materials and Methods

Civil servants from the Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte (IFRN), in Brazil, participated in this study, being Teachers and Administrative Technicians.

Data collection was carried out in September 2020 through an online survey. The survey contained 16 questions that investigated behavior related to respiratory protection during the COVID-19 pandemic.

In addition, the survey also collected information about the participants' knowledge in the area of Occupational Safety and Health (OSH) and Respiratory Protection, such as: types of masks and respirators used, work way, and whether they had already been diagnosed with COVID-19.

Before applying the survey, the participants answered an written informed consent form (WICF), in which they were informed about the research objectives and asked for their agreement.

The results were analyzed using descriptive statistics. At the end of this study, guidance is provided on respiratory protection and behaviors favorable to the use of respirators.

3 Results

The sample included a total number of 525 participants, with a balanced number of respondents: 50.9% of Teachers and 49.1% of Administrative Technicians. IFRN civil servants from 19 cities in Rio Grande do Norte participated in this study.

Of the total number of participants, 76.8% were working online, 21.5% in a hybrid way and 1.35% in a face-to-face way. Most survey respondents (81%) do not have formal training in Occupational Health and Safety (OSH) (Fig. 1) and 93.7% do not have specific training in Respiratory Protection (Fig. 2).

Only 4% of survey respondents do not wear the mask when leaving home and 16.8% partially wear the mask while away from home. Regarding the types of masks used by the participants, it is observed in Fig. 3 that 76.6% use only the cloth mask, 3.0% use only the surgical mask, 1.5% use only the PFF2 Respirator, 0.8% use only the PFF1 Respirator and 18.1% use more than one type of mask.

Of all survey respondents, 45 (8.6% of the total) use a respirator exclusively or alternately with cloth masks and surgical masks. Of those who use a respirator, 21 (46.7%) do not perform or do not know what the user's seal check; 9 (20%) perform the verification of positive or negative pressure user seal check; 11 (24.4%) perform the verification of the positive pressure user seal check; and 4 (8.9%) perform the verification of the negative pressure user seal check (Fig. 4).

The number of times the 45 PFF users reuse (donned) their disposable half masks before disposing of them are: 21 (46.7%) people donnings less than 5 times; 5 (11%)

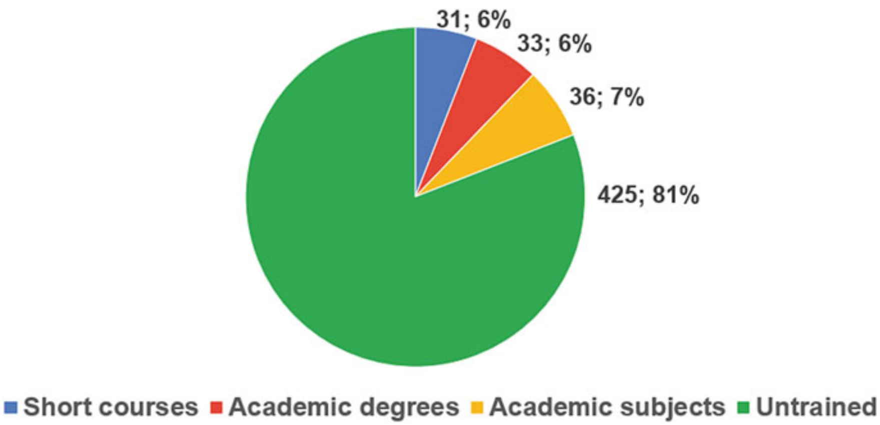

Fig. 1 OSH training

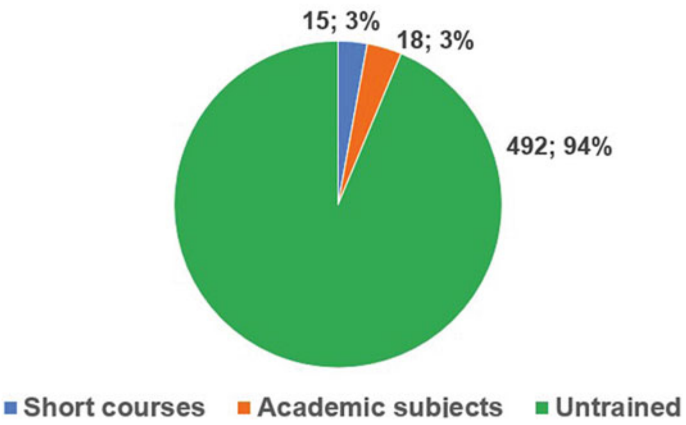

Fig. 2 Respiratory protection training

people donnings it 5 times; 12 (26.7%) people donnings over 5 times; and 7 (15.6%) people were unable to answer this question (Fig. 5).

Of the entire sample, 20 survey participants (3.8% of the total) were diagnosed with COVID-19 (Fig. 6). Regarding the type of mask used, 75% (15) of those diagnosed with COVID-19 make exclusive use of a cloth mask; 10% (2) of those diagnosed wear a cloth mask or surgical mask; 5% (1) of those diagnosed use a cloth mask or PFF1 Respirator; 5% (1) of those diagnosed use a surgical mask or PFF1 Respirator; and 5% (1) of those diagnosed exclusively use the surgical mask.

The behavior regarding the use of respiratory protection, of the 20 survey participants diagnosed with COVID-19, 75% (15) use respiratory protection during the entire period they are out of their home and 25% (5) use it part-time. Only 1 (5%) diagnosed claim to no longer use respiratory protection when leaving home. Regard-

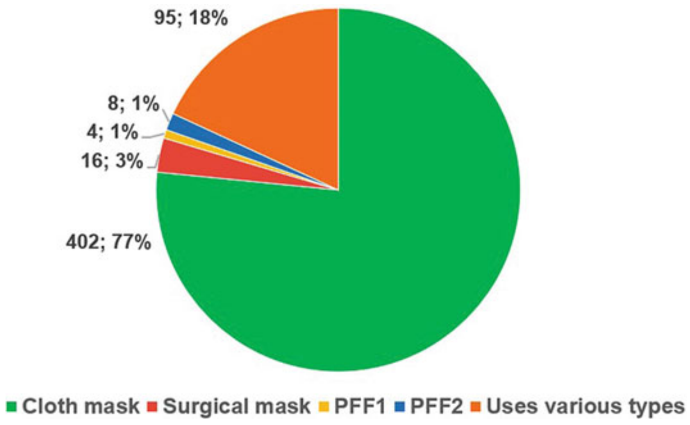

Fig. 3 Types of masks used

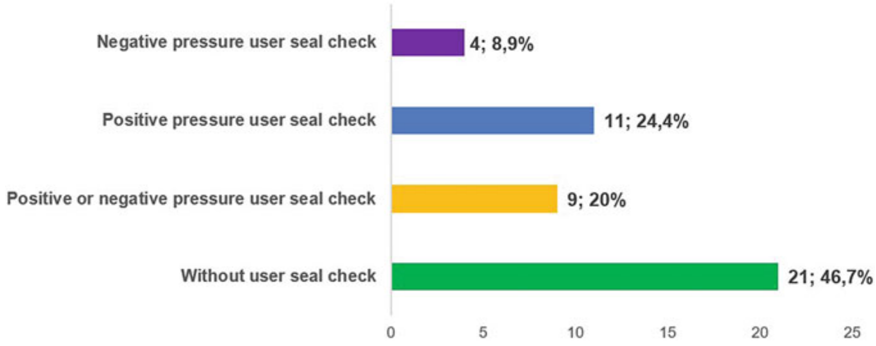

Fig. 4 User seal check

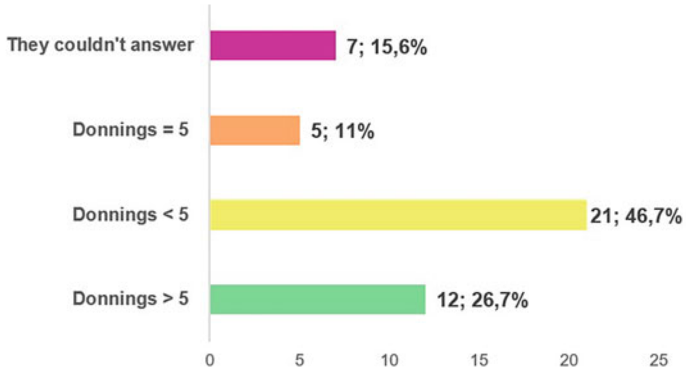

Fig. 5 Number of donnings

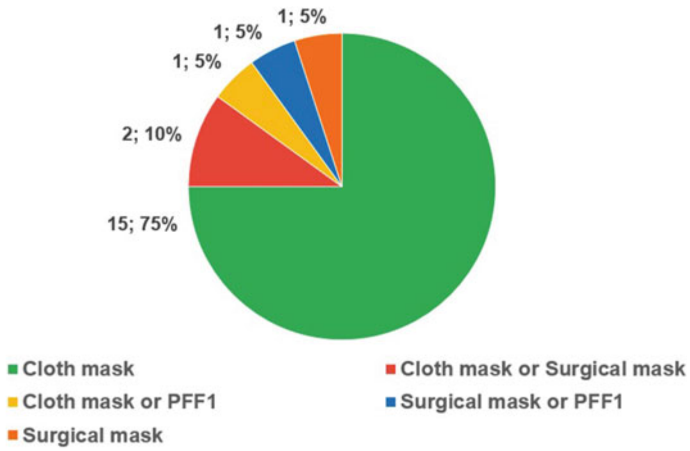

Fig. 6 Respiratory protections used by those diagnosed with COVID-19

ing the way of working, of the 20 participants diagnosed with COVID-19, 80% (16) of them work exclusively online and only 20% (4) work in a hybrid way (online and face-to-face).

4 Discussion

According to the results obtained, most respondents do not have knowledge in the area of Occupational Health and Safety (OHS) or in the area of Respiratory Protection.

Associated with this fact, the results also show that the majority (77%) of respondents use cloth masks. Considering that the surgical mask (3%), the PFF1 (1%) and the use of various types of masks (18%) used are also considered inadequate for protection against bioaerosols, 99% of the participants use a protection inadequate respiratory function for COVID-19. The cloth mask helps to limit the spread of droplets and saliva (CCOHS 2021), the surgical mask is a barrier to the spread of droplets and saliva (CCOHS 2021), whereas only PFF2 Respirators (CCOHS 2021; CDC 2020; FUNDACENTRO 2020; INSST 2021b) or PPF3 Respirators (HSE 2021; INSST 2021b) protect from exposure to airborne particles, including bioaerosols containing SARS CoV 2.

Of the participants who use PFF's, 46.7% still need to improve the way the Respirator is used by checking the seal. The User Seal Check is required to ensure a proper seal every time the respirator is used (CDC 2020; NIOSH 2018a).

Still on the participants who use PFF's, the majority (57.7%) reuse correctly, that is, they donnings it 5 or less than 5 times (CDC 2020; Fisher and Shaffer 2014).

For participants infected with COVID-19, the mistaken behavior regarding the use of masks is repeated, where all of them use inappropriate masks. That is, none of those infected with COVID-19 used PFF2 Respirators (CCOHS 2021; CDC 2020; FUNDACENTRO 2020; INSST 2021b) or PFF3 Respirators (HSE 2021; INSST 2021b).

These results suggest the need for training in Occupational Health and Safety (OHS) and specifically on the subject of Respiratory Protection, especially during the COVID-19 pandemic, for all IFRN civil servants.

In addition to disseminating correct information about masks, respirators and their correct use, it is also important to discuss how to make people adhere to a new behavior, as it requires a certain flexibility in behavior and the need for change. In other words, make sure that protective measures, and in this case, use of a mask, are used regularly and correctly. Our results showed that some changes still need to be made at the behavioral level. Behavioral sciences can contribute to public policies to promote behaviors conducive to disease prevention, such as COVID-19 (Lunn et al. 2020). The use of Respirators, if thought of from an individual perspective, is relatively costly, and needs to be related to a motivation to act beyond the benefit for oneself, but also for the collective. Studies show that in situations where there is a need for cooperation, most people tend to conform to the collective, driven by the needs of: belonging, understanding the world around them, creating trusting relationships with people and self-improvement (Van Vugt 2009). This compliance tends to increase given the perception that other people are also cooperating and there is also a concern if any action that generates social disapproval or punishment becomes public (Chaudhuri 2011). Therefore, an important aspect in the communication of cooperative behavior is to make evident the feeling of belonging and identity to a group (Van Vugt 2009), and together they will manage to overcome any threat, which must be done through a clear communication of the factors of risk and protection, increasing the group's compliance with the recommended behaviors (Carter et al. 2013), always considering the local culture and the important role of local authorities in shaping the behavior of the public, always keeping up-to-date information on the actions it will take and recommendations to the population (Carter et al. 2018).

These results point to a need to expand this research with a greater number of participants, especially those diagnosed with COVID-19, in order to obtain more robust results.

Another study that could be carried out is training on respiratory protection for a group of civil servants, and then evaluating the impacts of this training, comparing behavior and knowledge with untrained civil servants.

4.1 Limitations

Data analysis was performed using only descriptive statistics, which can reduce the impact of the results obtained. The survey was conducted on a specific group of workers, which does not allow for extrapolation to society in general.

5 Conclusions

Therefore, it is concluded that there is a need to implement trainings for IFRN civil servants with information on the purpose of different masks and respirators, correct way of User Seal Check, maximum amount of times a respirator can be reused and basic principles on the dissemination of bioaerosols.

In addition, to awaken a collective motivation for using the respirator, we can make use of robust findings from behavioral research that indicate solutions for this type of situation: the importance of continuously reinforcing the discourse of benefits for all, clear and updated communication of risk and protective factors, strengthen a group identity and create a signal of punishment or social disapproval if the individual presents contrary conduct.

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References

ABNT: ABNT NBR 13698: Equipamento de proteção respiratória - Peça semifacial filtrante para partículas (2011)

ACGIH: TLVs® and BEIs® Baseados na Documentação dos Limites de Exposição Ocupacional (TLVs®) para Substâncias Químicas e Agentes Físicos & Índices Biológicos de Exposição (BEIs®). Translate from Associação Brasileira de Higienistas Ocupacionais (ABHO) (2019)

Anderson, R.M., Heesterbeek, H., Klinkenberg, D., Hollingsworth, T.D.: How will countrybased mitigation measures influence the course of the COVID-19 epidemic? The lancet, Published online. (2020). https://doi.org/10.1016/S0140-6736(20)30567-5

Carter, H., Drury, J., Rubin, G.J., Williams, R., Amlôt, R.: Communication during mass casualty decontamination: highlighting the gaps. Int. J. Emerg. Serv. **2**, 29–48 (2013). https://doi.org/10.1108/IJES-06-2012-0026

Carter, H., Gauntlett, L., James Rubin, G., Russell, D., Genereux, M., Lemyre, L., Blain, P., Byers, M., Amlôt, R.: Psychosocial and behavioural aspects of early incident response: outcomes from an international workshop. Global Sec.: Health, Sci. Policy **3**(1), 28–36 (2018). https://doi.org/10.1080/23779497.2018.1556112

CCOHS: Get the Facts on Masks: Respirators, Surgical Masks, and Non-Medical Masks (2021). https://www.ccohs.ca/covid19/facts-on-masks/

CDC: NIOSH Interim Guidance on the Use of Chemical, Biological, Radiological and Nuclear (CBRN) Full Facepiece, Air-Purifying Respirators/Gas Masks Certified Under 42 CFR Part 84 (2012). https://www.cdc.gov/niosh/npptl/guidancedocs/interapr070805.html

CDC: Implementing Filtering Facepiece Respirator (FFR) Reuse, Including Reuse after Decontamination, When There Are Known Shortages of N95 Respirators (2020). https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html

Chaudhuri, A.: Sustaining cooperation in laboratory public goods experiments: a selective survey of the literature. Exp. Econ. **14**(1), 47–83 (2011). https://doi.org/10.1007/s10683-010-9257-1

Fisher, E.M., Shaffer, R.E.: Considerations for recommending extended use and limited reuse of filtering facepiece respirators in health care settings. J. Occup. Environ. Hyg. **11**(8), D115–D128 (2014). https://doi.org/10.1080/15459624.2014.902954

FUNDACENTRO: Prevenção à Covid-19: orientações para prevenção e controle da Covid-19 nos locais de trabalho (2020)

HSE: Respiratory protective equipment at work: a practical guide (2013). https://www.hse.gov.uk/pubns/priced/hsg53.pdf
HSE: Fit testing face masks to avoid transmission during the coronavirus pandemic (2021). https://www.hse.gov.uk/coronavirus/ppe-face-masks/face-mask-ppe-rpe.htm
INSST: ¿Cómo se transmiten los agentes biológicos y entran en contacto con el trabajador (2021a)? https://www.insst.es/-/-como-se-transmiten-los-agentes-biologicos-y-entran-en-contacto-con-el-trabajador-1/2
INSST: Procedimiento de actuación para los servicios de prevención de riesgos laborales frente a la exposición al SARS-CoV-2 (2021b). https://www.mscbs.gob.es/profesionales/saludPublica/ccayes/alertasActual/nCov/documentos/Proteccion_Trabajadores_SARS-CoV-2.pdf
Lunn, P.D., Belton, C.A., Lavin, C., McGowan, F.P., Timmons, S., Robertson, D.: Using behavioural science to help fight the Coronavirus: A rapid, narrative review. J. Behav. Public Adm. **3**(1), 1–15 (2020). https://doi.org/10.30636/jbpa.31.147
NIOSH: Filtering out Confusion: Frequently Asked Questions about Respiratory Protection, User Seal Check. Publication 2018 130 (2018a). https://doi.org/10.26616/NIOSHPUB2018130
NIOSH: Filtering out Confusion: Frequently Asked Questions about Respiratory Protection, Respirator Reuse and Extended Use. Publication 2018-128 (2018b). https://doi.org/10.26616/NIOSHPUB2018128
NIOSH: 100 Years of Respiratory Protection History (2019). https://www.cdc.gov/niosh/npptl/Respiratory-Protection-history.html
Torloni, M., Vieira, A.V.: Manual de Proteção Respiratória, 2nd edn. ABHO, São Paulo (2019)
Van Vugt, M.: Averting the tragedy of the commons: using social psychological science to protect the environment. Curr. Dir. Psychol. Sci. **18**(3), 169–173 (2009). https://doi.org/10.1111/j.1467-8721.2009.01630
WHO: Coronavirus disease 2019 (COVID-19). WHO-situation report-51. March 11 (2020a). https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200311-sitrep-51-covid-19.pdf?sfvrsn=1ba62e57_10
WHO: Coronavirus disease 2019 (COVID-19). WHO-situation report-11. January, 31 (2020b). https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200131-sitrep-11-ncov.pdf?sfvrsn=de7c0f7_4
WHO: Mask use in the context of COVID-19 (2020c). https://apps.who.int/iris/rest/bitstreams/1319378/retrieve

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Workers' Lifestyle, Occupational Workload and Their Relation to Work Fatigue: A Short Review

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Abstract Objective: This systematic review aims to analyse physical fatigue and the main causes. Background: Fatigue results from physical and psychological overload, mainly due to daily stress and lack of time to recover energy. Method: The review was performed according to the Prisma Statement. It was accessed Scopus, Web of Science, Science Direct, Pubmed. 26 keywords were screened using Boolean operators. The first articles' selection was made by abstract analysis. Articles that considered interventions in healthy human beings were included. Results: Studies have concluded that a great cause of fatigue is sleep deprivation, and it was observed that shift workers have commonly felt excessive tiredness. The assumption is that shift work disrupts circadian rhythm and impairs sleep quality. Conclusion: Bad sleeping quality can increase the possibility of physical fatigue. The risk can be minimised with well-planned strategies. Application: The review article raises awareness of the importance of a healthy lifestyle and precautions in carrying out activities.

Keywords Physical exhaustion · Circadian rhythm · Shift-work · Healthy habits · Diet

1 Introduction

Fatigue is a physiological state of reduced mental and physical capability (Lock et al. 2018). It reflects the disability for the continuity of activity and also for the performance of physical efforts (Huang et al. 2018). The tiredness felt before the onset of fatigue usually results from lack of sleep, mental or physical overload,

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and stress. Repetitive work, monotonous activity, and especially disrupted sleep can increase the risk of fatigue (Caldwell et al. 2019).

The first symptoms of fatigue are physical exhaustion and muscular pain. Pain can be defined as an unpleasant phenomenon associated with actual or potential damage (Tang et al. 2020).

Physical fatigue can be recovered with adequate rest, which permits energy restoration (Litwiller et al. 2016). Insufficient rest can be damaging for health since it results in harmful consequences such as degradation of cognitive performance (Caldwell et al. 2019) and cumulative trauma disorders (Kulkarni and Devalkar 2019), directly affecting productivity private life. Other important symptoms are reduced physical workability (Skovlund et al. 2020), loss of productivity, and sickness absence (Silva et al. 2018).

Healthy diet habits are also vital to restore energy. According to Moore (2015), carbohydrates and protein are essential macronutrients to provide substrates to enhance glycogen resynthesis and repair the skeletal muscle (Moore 2015).

Each person has a different response to the same stimulus, depending on personal factors and individual conditions. However, for almost all of them, a prolonged period of demanding physical, cognitive, or emotional activity leads to feelings of physical and mental failure (Guan et al. 2017).

Tiredness has harmful consequences for workers' health and generates a great economic burden (Nagata et al. 2018). Factors leading to drowsiness should be known by companies, as well as strategies to mitigate the risk must be implemented to guarantee an efficient and productive workplace (Lock et al. 2018).

Corroborating the investigations against the negative consequences of fatigue, studies have shown that insufficient sleep is the leading cause of fatigue since it directly interferes with physical and psychological detachment. The importance of the theme has been justified due to the costs concerning the harmful consequences of physical fatigue. This systematic review aims to confront the relation between circadian rhythm alteration and physical fatigue; and assess the causes of such a harmful consequence for workers' health.

2 Materials and Methods

This systematic review was performed according to the PRISMA Statement (Moher et al. 2009), and the research was updated to March 2021. The research strategy included the top electronic databases in the health and manufacturing industry, which provided access to databases: Scopus, Web of Science, Science Direct, Pubmed.

The research was restricted to the following databases: Science Direct: only the area of "Engineering" was accepted; Web of Science: the areas of "Engineering", "Engineering Biomedical", and "Ergonomics" were considered; Pubmed: only "Humans" subject was recognised. The limitation avoided articles in unrelated areas.

The terms used in the search strategy were: activity AND measure AND physiological AND variables; fatigue AND chronic AND "work shift"; fatigue AND "repetitive work"; "fatigue recovery" AND methods; fatigue + recovery AND shift + work; "fatigue recovery" AND breaks; "fatigue recovery" AND sleep; gait AND "motion analysis" AND reliable; "muscle glycogen depletion" AND recovery; muscular AND fatigue AND recovery; recovery AND fatigue AND "after work"; "sleep loss" AND fatigue; "task rotation" AND fatigue; "work capacity" AND tiredness; "work capacity evaluation" AND fatigue.

This literature review was done by analysing articles, which could be systematic reviews and individual research. The analysis of each evaluated survey was verified, on the first moment, by the title and abstract. If the abstract fulfills the goal, then a careful reading was performed. The inclusion criteria for this review are limit articles that considered healthy human beings; select works that included fatigue definition; the main causes that increase fatigue, its consequences, and recovery methods. They were also focused on experimental articles. Articles before 2015 were used due to their importance in the subject (Fig. 1).

For the design of Figs. 2 and 3, the results exhibited in the articles were considered. The percentage illustrated in the graphs was taken from the sum of all analysed reports and was achieved by the following paths: (a) reading of each assessed article; (b) isolate all the results obtained in each article; (c) organise by topics; (d) insert all the results in excel; (e) subdivide in tables separately considering for each topic one value; (f) design the figure; (g) calculate the percentage using the sum of each unit value.

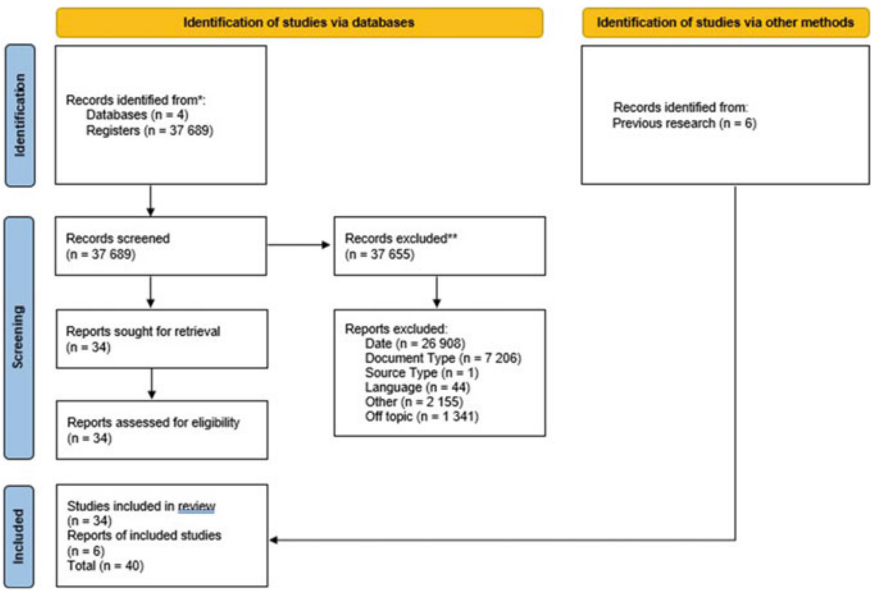

Fig. 1 Flow diagram of research, adopted from (Moher et al. 2009)

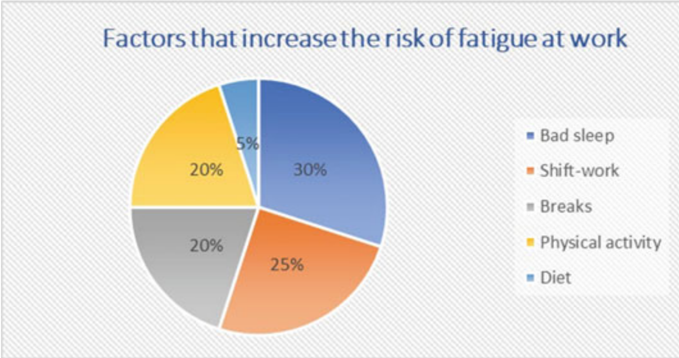

Fig. 2 Factors that can generate fatigue in workers

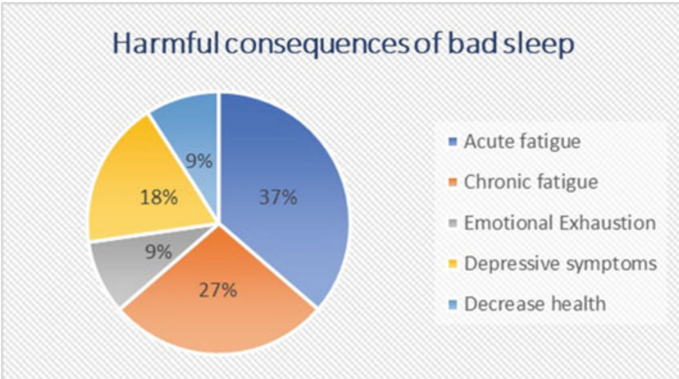

Fig. 3 Harmful consequences of lack of sleep

For a better understanding, it must be emphasised that only one value was considered for each topic, i.e., the article concluded that insufficient sleep and shift-work are directly related to fatigue; it was added one value to bad sleep and one value to shift-work. Since most of the analysed articles did no exhibited the outcomes in percentages, it was thought to be the best path to illustrate global research results.

3 Results

The investigation of the articles resulted in: summary of the collected articles with 37 689 articles pre-selected. Applying the exclusion criteria, 26 908 papers were excluded by "date" (articles published in the period between 2015 and 2021 were included); 7 206 were rejected by "document type" (only articles and systematic reviews were accepted); 1 article was excluded by "source type" (Journal was considered); 44 texts were refused due to "language" (only English was accepted).

The imposed limitations on the databases Science Direct, Web of Science and Pubmed. excluded 2 155 articles. 1 341 articles were excluded because they are not consistent with the goal of this short review. Finally, disregarding repeated articles found in more than one database, 34 articles were used for analysis in this work. Records identified from previous research relevant to the topic are considered in this brief review.

This short review was done by analysing research articles that measured real context (workers and environment). The evaluated articles measured the physical exhaustion felt by the nurses, its schedules, naps and sleep routine, time for recovery, as well as the main consequences of overwork and lack of proper rest. The results can eventually differ from other professionals and work conditions.

Table 1 summarizes the assumptions of the 19 articles mentioned in Prisma Statement, which allowed the illustration of Fig. 2. Table 2, condenses the statements of 25 surveys used to demonstrate the Fig. 3. Figures 2 and 3 exhibit the results achieved in the analysed articles. The percentage demonstrated in the figures reflects the sum of each unit value comparing to the totality. The articles cited in Tables 1 and 2 were also used to support this systematic review.

According to the analysed articles, the causes of fatigue are greatly due to lack of proper rest, which is increased due to bad sleep quality and 12-hour shift work. Improper relaxation can cause adverse consequences to the worker's health. Tables 1 and 2 summarises the evaluated articles used to realize the risk factor of fatigue and harmful consequences, illustrated in Figs. 2 and 3.

Assumptions of 19 articles mentioned in Table 1 mainly summarize the harmful consequences of bad sleep, shift-work, and benefits of diet and physical activity. Also highlight the consequences of unhealthy habits, as obesity. Table 2 underscore 25 articles that assess the causes and damaging effects of fatigue, acute and chronic; and the importance of physical and psychological detachment. It is also emphasized the effectiveness of occupational health and safety practices. The assess of the articles allowed to design Figs. 2 and 3, which gives an overview of some factors that can be detrimental to the workers' health.

Figure 2 was designed using the results of the articles cited in Table 1. The assumptions of those surveys allowed to validate some factors that may increase the risk of fatigue: bad sleep quality and length; long shift work; lack of inter-shift breaks; physical activity; unhealthy diet. Recent studies agree that these factors raise the risk of harmful conditions for health.

According to the results, physical fatigue can be associated with a lack of proper rest and shift work, especially night shift work that impairs a good night's sleep. Approximately 20% of European workers perform shift work during the day or night. The schedule with extensive hours, especially by night, harms worker's health. Detrimental consequences are due to circadian cycle, sleep disruption, diet and exercise habits (Brum et al. 2015) and lack of control over work (Johnston et al. 2019).

Shift workers tend to adopt damaging lifestyle habits (Brum et al. 2015), consuming more unhealthy food, which increases the risk of overweight (Ulhôa et al. 2015).

Table 1 Summary of the articles analysed in Prisma Statement, and used to illustrate Fig. 2

Sleep and shift-work	Relaxation	Healthy habits	Obesity
Sleep deprivation, circadian desynchronization, behavioral changes in diet and physical activity are associated to night work and metabolic disorders (Brum et al. 2015) Promote better sleep can mitigate the impact of fatigue and sleep loss. (Caldwell et al. 2019) Sleep quality is associated with health and physical capacity (Litwiller et al. 2016) Shift work negatively affect sleep and contribute to sedentarism, unhealthy eating habits, and stress (Ulhôa et al. 2015) The prevalence of shift work disorders is higher among night-shift workers (Vanttola et al. 2019) Shift workers are susceptible to shift work disorder, which is a circadian rhythm sleep disorder characterized by excessive sleepiness and insomnia (Wickwire et al. 2017) 12-hour shifts increase the risk of fatigue (Johnston et al. 2019)	Decreased sleep duration have relation to fatigue (Lock et al. 2018) Workers who reported feeling refreshed after sleep had significantly less chronic and acute fatigue and more intershift recovery (Sagherian et al. 2017) Nocturnal work is associated with a reduction in attention and concentration and delayed response to stimuli It may compromise health and quality of life (Sanches et al. 2015) A scheduled nap provides an effective countermeasure against the negative consequences of night-time shift work (Zion and Shochat 2019)	The ingestion of carbohydrate and protein have the potential to accelerate muscle glycogen resynthesis and increase functional capacity (Alghannam et al. 2018) Dietary carbohydrate and protein provide the substrates to enhance glycogen resynthesis and remodel skeletal muscle proteins (Moore 2015) Diet rich in protein has the potential to be used as a fatigue-preventing and recovery-promoting (Huang et al. 2018) Protein and carbohydrates supplementation did not have positive effect compared to only carbohydrates supplementation, although this one increase the risk of fat (Kephart et al. 2016) Physical activity is negatively associated with long term sick-absence (Gupta et al. 2020) Factors related to health, work, and lifestyle were associated with good work ability (Pensola et al. 2016)	Shift work can increase the ingestion of unhealthy food. Increasing the risk of obesity, metabolic syndrome, diabetes, sleep deprivation (Brum et al. 2015) Workers are more susceptible to fatigue in high-stress work environments, particularly those with higher body mass index, which can increase the risk of musculoskeletal injuries (Mehta 2015)

Table 2 Summary of the articles analysed in Prisma Statement, and used to illustrate Fig. 3

Fatigue	Acute and chronic fatigue	Psychological detachment	Physical detachment	Interventions and economic burden
Fatigue is related to reduced cognition, occupational accidents, and injury (Lock et al. 2018) Repetitive work have impact on fatigue, which reduce the physical capacity (McDonald et al. 2019) A total of 86.24% of workers reported musculoskeletal discomfort, and 43% presented fatigue. There are association between fatigue and reduction of work ability (Silva et al. 2018) Workers impaired by fatigue and lack of sleep are not aware of the risk of accident and injury (Dawson et al. 2021)	Acute fatigue is directly related to job demand, job control, support at work, and exposure to hazards. Sleep quality has direct effect on acute fatigue (Fang et al. 2012) Shift work, job demands, and exposure to hazards are direct predictors of chronic fatigue. Job satisfaction, job control, and acute fatigue are indirect predictors (Li et al. 2019) Sleepiness and chronic fatigue inhibited full functioning both at work and at home (Wolf et al. 2017) Physical activity and sleep quality are negatively associated with fatigue (Frone and Blais 2019) Workers with acute and chronic fatigue decrease physical performance (Sagherian et al. 2017)	Lack of sleep and higher daytime dysfunction increase depression and anxiety (Bullock et al. 2019) Job stressors are related to health-related productivity losses (Brunner et al. 2019) High-job strain level is related to burnout, mental fatigue and incidence of chronic diseases (Guan et al. 2017) Cardiometabolic stress and cognitive impairments are increased by shift work, and sleep loss (Kecklund and Axelsson 2016) Psychological detachment and relaxation with adequate sleep restore physical energy (Burke et al. 2009)	Disrupted sleep results in accidents and adverse mental and physical health (Caldwell et al. 2019) Repetitive work, without proper muscle rest, increases the risk of the injuries and strains (Kulkarni and Devalkar 2019) Physical detachment after work decrease concentration problems, emotional exhaustion and physical problems (Jonge 2019) Health consequences of shift work and insufficient sleep are very similar to health (Kecklund and Axelsson 2016) Work involving high demands are detrimental to work ability (Skovlund et al. 2020) Pain impact workers' health and should be addressed due to its impact on reducing work ability (Vieira et al. 2020)	Prevention and management is recommended to minimise unnecessary costs (Azevedo et al. 2016) Musculoskeletal disorders are the leading cause of work disability. There is limited consensus on use of occupational health and safety practices (Svendsen et al. 2020) Pain affects physical and psychological well-being and work performance. Programs can help to address the critical problem of pain (Tang et al. 2020) Interventions can be effective in reducing absenteeism and presenteeism (Brunner et al. 2019) Strategies can increase health and job satisfaction (Baral et al. 2018) Interventions may prolong work careers (Nielsen and Midtsundstad 2020) Cost burdens from chronic illness is related to mental health conditions and musculoskeletal disorders (Nagata et al. 2018)

Obesity, in its turn, increases stress-related neuromuscular fatigue and consequently musculoskeletal disorders (Mehta 2015).

It must be highlighted that the main causes of fatigue are related to each other. Lack of proper rest is increased by shift-work, which reduces the quality of sleep. Inadequate relaxation reduces energy, which impairs physical activity and increases unhealthy habits. Interventions are vital to minimise the risk (Nielsen and Midtsundstad 2020), as a well-planned work schedule ensures proper rest (Litwiller et al. 2016). Suitable relaxation is achieved mainly with adequate sleep, which is crucial to ensure the well-being and efficient body function (Burke et al. 2009).

To minimise risk factors, companies must adopt procedures to raise awareness of security and increase healthy habits (Brum et al. 2015) since stress, sleep deprivation, and obesity increases the risk of fatigue (Mehta 2015). It has been proven that interventions improve the quality of life (Tang et al. 2020) and minimise harmful consequences (Svendsen et al. 2020). There are effective measures that must be evaluated according to the possibility and the reality of each establishment. In this sense, Svendsen et al. (2020) conclude that an effective measure is to make field observations; develop a pilot test; and workshop with occupational health safety professionals. It could minimise the risk of harmful conditions in the workplace.

According to the articles cited in Table 2, can be assumed that the bad sleep can lead to harmful inconveniences. Figure 3 illustrate the damaging consequences described in the surveys.

Regarding physical health, sleep is vital to recovery energy and musculoskeletal strength (Burke et al. 2009; Caldwell et al. 2019).

In terms of sleep length and sleep quality, adequate sleep is crucial to ensure psychological well-being and efficient body function. It is recommended eight hours of sleep per day. Otherwise, lack of sleep can affect normal activity caused by weariness. Fatigue, in its turn, is a significant predictor of higher depression and anxiety levels (Bullock et al. 2019), which makes good sleep the foremost path to achieve adequate rest and minimise the eventual damaging consequences of work and daily stress (Litwiller et al. 2016).

The causes of fatigue, analysed in this short review, are related to each other since most causes impair proper rest and reduce life quality. These causes can result in harmful consequences for the worker, related to physical and psychological illnesses.

4 Discussion

4.1 Fatigue Risk Factors

According to the results, bad sleep, quality and length, is an important cause to lead to fatigue. However, it must be highlighted that the main causes of fatigue are all related to each other and can be damaging to the workers' health. Sleep is a biological need for survival, ensuring physical and mental well-being. During sleep, regeneration of neurons and formation of new synapses occur (Sanches et al. 2015). Adequate rest with a good night's sleep minimises the incidence of fatigue, increases alertness and levels of physical activity, and restores energy, improving performance and well-being (Caldwell et al. 2019).

Daily stress and increased responsibilities can cause insomnia. Unfortunately, it is not unusual in the working population, leading to private and professional life consequences. Short sleep duration, poor sleep quality, and prolonged wakefulness also compromise cognitive functioning (Zion and Shochat 2019). It is noteworthy that adequate sleep is vital to ensure physiological well-being and efficient body function and is a great ally to reduce the incidence of excessive tiredness.

Shift-work is one of the main causes of bad sleep quality and length in the working population. Especially night shift workers suffer from sleep deprivation and circadian desynchronization (Brum et al. 2015), which increase the risk of fatigue. It is owing to disruption of the normal sleep-wake cycle (Kecklund and Axelsson 2016), also called shift work disorder (SWD). It can be characterised by sleepiness and insomnia, particularly those who work at night or on early-morning shifts (Wickwire et al. 2017). Approximately one-fifth of the European population performs shift work (Brum et al. 2015). This way of working harms workers' health due to the circadian cycle, sleep disorders, diet, and exercise habits.

Jobs that demand 12 h shift-work should be scrutinised because it leads to many consequences, such as disruption of circadian rhythm, inter-shift (leisure and rest time), bad sleep, especially night and rotating shift work, unhealthy diet. These factors decrease energy and reduce vitality in physical activity.

Despite eventual damaging outcomes, long periods at work have been adopted in many companies due to productivity and profit. To minimise this negative effect, industries can implement the possibility of taking a nap. Besides the importance of effective rest after the workday, a nap also has benefits especially considering circadian rhythms (Caldwell et al. 2019). Studies have demonstrated the beneficial effects of a scheduled rest and its efficacy against the adverse effects of night work and shift work, reducing sleepiness and improving cognitive performance (Zion and Shochat 2019).

Shift-work can be damaging for human health as it prevents adequate sleep, increases the prevalence of various pathologies, and is aggravated by overwork (Litwiller et al. 2016). Otherwise, shift workers who reported feeling refreshed after sleep had significantly less chronic and acute fatigue (Sagherian et al. 2017). It highlights the importance of a good night's sleep.

It was verified that shift workers tend to adopt unhealthy lifestyle habits, consuming more fatty foods. Long hours at work also result in low energy to physical exercise, which can be due to sleep deprivation, especially by night and rotating shift work (Brum et al. 2015).

To minimise harmful effects of 12-h shift-work, breaks are important to restore energy. A scheduled nap is especially beneficial for night shift workers (Zion and Shochat 2019), mainly in consideration of circadian rhythms (Caldwell et al. 2019).

Inter-shift is another risk factor since it is essential to recover the energy and rest the musculoskeletal structure (Jonge 2019). Proper rest after the workday must be obeyed because it is important to ensure physical and psychological detachment (Bullock et al. 2019). Suitable inter-shift safeguard a good sleep quality and duration (8-h a day) (Burke et al. 2009), which are important predictors for health.

Regarding these consequences, shift workers are more susceptible to overweight, especially due to alteration in food intake, increasing the ingestion of unhealthy food (Ulhôa et al. 2015). Obesity increases stress-related neuromuscular fatigue and, consequently, the risk of musculoskeletal injuries (Mehta 2015).

Healthy diet provide the substrates to enhance glycogen resynthesis, remodel skeletal muscle (Moore 2015) and increase functional capacity (Alghannam et al. 2018).

Concerning physical activity, there is a contradiction. Have been settled that leisure physical activity (PA) promotes health, reduces the risk of chronic diseases, and decreases in 20% the risk of long-term sickness absence. Contrary to leisure PA, a high occupational PA increases the risk of long-term sickness absence (Gupta et al. 2020). The reason is not clarified in the researches. Still, it may be related to overwork of the same muscle group for many hours.

Likewise, active recovery has also shown positive results, as physical activity improves the physical conditioning of individuals. It must be highlighted that individuals respond differently to the same stimuli. However, performing moderately vigorous short-term PA is effective in reducing the risk of absenteeism and increases individual health, reducing unnecessary costs (Gupta et al. 2020). The practice of physical activity must be careful since prolonged physical activity reduces muscle glycogen stores, which can be an initial factor of fatigue. Concerning the loss of energy, diet is crucial to recover vitality and maintain performance. Especially consumption of carbohydrates is crucial to recuperating loss of energy since it is the source that generates adenosine triphosphate (ATP) (Alghannam et al. 2018). Also, protein is an important macronutrient. It improves glycogen resynthesis and also repairs the skeletal muscle system (Moore 2015). Protein intake is essential because this nutrient can reduce muscle soreness (Kephart et al. 2016).

As already concluded, the causes of fatigue mentioned in this short review are related to each other. They can have harmful consequences if not treated combined. Restore energy with proper rest, combined with physical activities and a healthy diet, increases the life quality and, consequently, reduces the risk of muscular pain and excessive drowsiness.

4.2 Physical Fatigue

Physical fatigue is the loss of muscle strength during the performance of the activity due to energy depletion (Lock et al. 2018). As a consequence, it can be said that the first symptom is physical tiredness followed by musculoskeletal pain, which is a common health problem felt by the general and working population (Tang et al. 2020).

Pain characterises the main cause of work disability (Vieira et al. 2020), and its consequences are costly, especially due to medical and pharmaceutical expenses, presenteeism, and absenteeism (Nagata et al. 2018).

Fatigue is harmful to physical and psychological health, giving rise to many diseases. Exhaustion and pain are positively related to decreased work ability, turnover intentions, depression, sickness absence, and disability retirement (Pensola et al. 2016). Drowsiness is a complex and current phenomenon among individuals in general and has been usually felt by workers. The phenomenon has risen due to several causes.

According to Johnston et al. (2019) research, mood disorders and bad sleep quality were found to predict fatigue. The physical exhaustion caused by lack of sleep decreases work capacity and reduces risk awareness (Dawson et al. 2021).

A detrimental working environment propitiates physical problems, creating high economic costs (Baral et al. 2018). Useful methods for recovery from physical exhaustion, such as naps, good sleep, and healthy behaviour, such as regular exercise and a balanced diet (Lock et al. 2018), can reduce the incidence of more severe consequences.

Physical fatigue can be acute or chronic, with significant differences between these two types, especially regarding consequences. Acute fatigue is a temporary and reversible state that begins due to excessive physical and psychosocial overwork (Sagherian et al. 2017). It can be dealt with promptly. However, if not properly treated gives rise to chronic fatigue, which is the most severe stage of fatigue (Fang et al. 2012).

The chronic stage is often regarded as an illness related to the sleepiness that impeded full functioning at work and home (Wolf et al. 2017). The importance of caution is that it is directly related to job satisfaction, sleep quality (Li et al. 2019), work-related musculoskeletal disorder (WMSD) (Silva et al. 2018), turnover intentions, depression, and other damaging consequences (Frone and Blais 2019) that give rise to disease and monetary costs.

Musculoskeletal injuries can be caused by fatigue. Related to lost productivity attributable to musculoskeletal disorder among people of working age in the European Union is approximately 2% of gross domestic product (GDP) (Svendsen et al. 2020). In Portugal, it is also estimated a cost "corresponding to 2.71% of the Portuguese annual GDP" (Azevedo et al. 2016). It is a great cost especially considering that it can be minimised with non-expensive and effective measures.

Lack of sleep and daytime dysfunction increase the incidence of fatigue (Bullock et al. 2019), which can be detrimental to physical and psychological function. Drowsiness directly reflect in emotional exhaustion, increasing the occurrence of depression (Xu et al. 2020) and anxiety (Bullock et al. 2019).

Job stressors, that directly reflect on psychological health should have special attention, because manifest in productivity losses due to illnesses (Brunner et al. 2019). Job exhaustion and job strain, in addition to developing fatigue, are the main symptom of Burnout (Guan et al. 2017). Adequate relaxation is vital for workers, because it has positive effects for restoring energy and improving physical and psychological health (Burke et al. 2009).

A high economic burden of health problems, physical and psychological, in the workplace related to fatigue can be due to medical and pharmaceutical expenses, absenteeism, and presenteeism (Nagata et al. 2018). Regarding the high expenditure, there has been a growing interest in building sustainable organisations concerning fatigue management, focusing on increasing the employees' health, safety, and productivity (Caldwell et al. 2019).

Fatigue risk factors can be minimised with effective strategies (Lock et al. 2018). To ensure workers' well-being, companies have increasing carefulness in improving work conditions. The implementation of programs should be aimed at a better balance between job stressors and job resources. Studies have revealed that employees working under a supportive supervisor showed less presenteeism and absenteeism, reducing productivity losses (Brunner et al. 2019).

A dynamic workforce is a satisfied and productive team (Baral et al. 2018). To implement preventive strategies to support workers, the involved professionals must be aware of the necessary procedures to improve work conditions. Well-applied interventions have been shown to reduce absenteeism and guarantee health promotion at the workplace, which may prolong work careers (Nielsen and Midtsundstad 2020).

Limitations This study was not exhaustive, which makes it difficult to generalize the results to real conditions. Young and healthy health care professionals were evaluated. Future studies should focus on identifying health professionals with and without musculoskeletal disorders and at different schedules. A wider range of articles should be evaluated to conclude on the main causes of fatigue and paths to minimise risk factors.

5 Conclusions

The high workload is negatively related to physical and psychological conditions because it leads to physical fatigue. Demanding jobs require attention in the non-working period, mostly to ensure adequate sleep and energy restoration.

Fatigue arises predominantly from sleep disruption, which is related to daily stress and shift work schedules. These schedules reduce sleep quality and the rest, leading workers to become more susceptible to acute fatigue symptoms, physical fatigue, and lack of energy—consequently increasing work-related accidents and musculoskeletal disorders.

Long work periods also have consequences in risk factors such as lack of energy, physical activity, unhealthy food intake, and obesity. These factors raise muscular pain and excessive tiredness. Fortunately, the risk can be mitigated with effective and mostly non-costly strategies.

Guarantee proper rest and energy recovery are non-expensive and efficient measures that benefit the employees and minimise the incidence of fatigue.

Companies should recognise these factors as an important ally to workers' health. To mitigate the risk of fatigue, strategies must be implemented by the involved professionals to ensure an efficient and productive workplace, and reduce unnecessary costs to employees and companies.

References

Alghannam, A.F., Gonzalez, J.T., Betts, J.A.: Restoration of muscle glycogen and functional capacity: role of post-exercise carbohydrate and protein co-ingestion. Nutrients **10**(2), 253 (2018). https://doi.org/10.3390/nu10020253

Azevedo, L.F., Costa-Pereira, A., Mendonça, L., Dias, C.C., Castro-Lopes, J.M.: The economic impact of chronic pain: a nationwide population-based cost-of-illness study in Portugal. Eur. J. Health Econ. **17**, 87–98 (2016). https://doi.org/10.1007/s10198-014-0659-4

Baral, S., Subedi, H.N., Paudel, P., Chand, P.B., Shrestha, M.P., McCullough, A., Elsey, H.: Implementation research to assess a health workers performance-based management system in Nepal. Acta Paediatrica **107**(471), 24–34 (2018). https://doi.org/10.1111/apa.14406

Brum, M.C.B., Filho, F.F.D., Schnorr, C.C., Bottega, G.B., Rodrigues, T.C.: Shift work and its association with metabolic disorders. Diabetol. Metab. Syndr. **7**(45), 1–7 (2015). https://doi.org/10.1186/s13098-015-0041-4

Brunner, B., Igic, I., Keller, A.C., Wieser, S.: Who gains the most from improving working conditions? Health-related absenteeism and presenteeism due to stress at work. Eur. J. Health Econ. **20**(8), 1165–1180 (2019). https://doi.org/10.1007/s10198-019-01084-9

Bullock, B., Critchley, C., Davis, H., Tirlea, L., Fitzgerald, K., Farmer, J.: Sleep and psychological wellbeing of racehorse industry workers: a survey of Australian trainers. Aust. J. Pshychol. (September 2018), 146–153 (2019). https://doi.org/10.1111/ajpy.12230

Burke, R.J., Koyuncu, M., Fiksenbaum, L.: Benefits of recovery after work among Turkish manufacturing managers and professionals. Educ. Bus. Soc. Contemp. Middle East. Issues **2**(2), 109–122 (2009). https://doi.org/10.1108/17537980910960681

Caldwell, J.A., Caldwell, J.L., Thompson, L.A., Lieberman, H.R.: Fatigue and its management in the workplace. Neurosci. Biobehav. Rev. **96**(July 2018), 272–289 (2019). https://doi.org/10.1016/j.neubiorev.2018.10.024

Dawson, D., Sprajcer, M., Thomas, M.: How much sleep do you need? A comprehensive review of fatigue related impairment and the capacity to work or drive safely. Accid. Anal. Prev. **151** (2021). https://doi.org/10.1016/j.aap.2020.105955

Fang, J., Qiu, C., Xu, H., You, G.: A model for predicting acute and chronic fatigue in Chinese nurses. J. Adv. Nurs. **69**, 546–558 (2012). https://doi.org/10.1111/j.1365-2648.2012.06029.x

Frone, M.R., Blais, A.-R.: Work fatigue in a non-deployed military setting: assessment, prevalence, predictors, and outcomes. MDPI - Int. J. Environ. Res. Public Health **16**(16), 1–26 (2019). https://doi.org/10.3390/ijerph16162892

Guan, S., Xiaerfuding, X., Ning, L., Lian, Y., Jiang, Y., Liu, J., Ng, T.B.: Effect of job strain on job burnout, mental fatigue and chronic diseases among civil servants in the Xinjiang Uygur autonomous region of China. MDPI - Int. J. Environ. Res. Public Health **14**(8), 1–15 (2017). https://doi.org/10.3390/ijerph14080872

Gupta, N., Dencker-Larsen, S., Rasmussen, C.L., Mcgregor, D., Rasmussen, D.C.N., Thorsen, S.V., Holtermann, A.: The physical activity paradox revisited: a prospective study on compositional accelerometer data and long-term sickness absence. Int. J. Behav. Nutr. Phys. Act. **17**(1), 1–9 (2020). https://doi.org/10.1186/s12966-020-00988-7

Huang, Q., Ma, S., Tominaga, T., Suzuki, K., Liu, C.: An 8-week, low carbohydrate, high fat, ketogenic diet enhanced exhaustive exercise capacity in mice part 2: effect on fatigue recovery, post-exercise biomarkers and anti-oxidation capacity. MDPI **10**, 1–16 (2018). https://doi.org/10.3390/nu10101339

Johnston, D.W., Allan, J.L., Powell, D.J.H., Jones, M.C., Farquharson, B., Bell, C., Johnston, M.: Why does work cause fatigue? A real-time investigation of fatigue, and determinants of fatigue in nurses working 12-hour shifts. Ann. Behav. Med. **53**(6), 551–562 (2019). https://doi.org/10.1093/abm/kay065

Jonge, J. De.: What makes a good work break? Industrial Health, Off-job and on-job recovery as predictors of employee health (2019). https://doi.org/10.2486/indhealth.2019-0097

Kecklund, G., Axelsson, J.: Health consequences of shift work and insufficient sleep. BMJ (Online) **355**, 1–13 (2016). https://doi.org/10.1136/bmj.i5210

Kephart, W.C., Mumford, P.W., Mccloskey, A.E., Holland, A.M., Shake, J.J., Mobley, C.B., Roberts, M.D.: Post-exercise branched chain amino acid supplementation does not affect recovery markers following three consecutive high intensity resistance training bouts compared to carbohydrate supplementation. J. Int. Soc. Sports Nutr. **13**, 1–10 (2016). https://doi.org/10.1186/s12970-016-0142-y

Kulkarni, V.S., Devalkar, R.V.: Postural analysis of building construction workers using ergonomics. Int. J. Constr. Manag. 1–8 (2019). https://doi.org/10.1080/15623599.2018.1452096

Li, Y., Fang, J., Zhou, C.: Work-related predictors of sleep quality in Chinese nurses: testing a path analysis model. J. Nurs. Res. **27**(5), 1–10 (2019). https://doi.org/10.1097/jnr.0000000000000319

Litwiller, B., Taylor, W.D., Snyder, L.A., Steele, L.: The relationship between sleep and work: a meta-analysis. J. Appl. Psychol. **102**(4), 1–26 (2016). https://doi.org/10.1002/jcph.834.This

Lock, A.M., Bonetti, D.L., Campbell, A.D.K.: The psychological and physiological health effects of fatigue. Occup. Med. **68**(8), 502–511 (2018). https://doi.org/10.1093/occmed/kqy109

McDonald, A.C., Mulla, D.M., Keir, P.J.: Muscular and kinematic adaptations to fatiguing repetitive upper extremity work. Appl. Ergon. **75**, 250–256 (2019). Retrieved from https://doi.org/10.1016/j.apergo.2018.11.001

Mehta, R.K.: Impacts of obesity and stress on neuromuscular fatigue development and associated heart rate variability. Int. J. Obes. **39**, 208–213 (2015). https://doi.org/10.1038/ijo.2014.127

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.: PRISMA 2009 Flow Diagram. The PRISMA Statement (2009). https://doi.org/10.1371/journal.pmed1000097

Moore, D.R.: Nutrition to support recovery from endurance exercise: optimal carbohydrate and protein replacement. Curr. Sports Med. Rep. **14**(4), 294–300 (2015). https://doi.org/10.1249/JSR.0000000000000180

Nagata, T., Mori, K., Ohtani, M., Nagata, M., Kajiki, S., Fujino, Y., Loeppke, R.: Total health-related costs due to absenteeism, presenteeism, and medical and pharmaceutical expenses in Japanese employers. J. Occup. Environ. Med. **60**(5), 273–280 (2018). https://doi.org/10.1097/JOM.0000000000001291

Nielsen, R.A., Midtsundstad, T.I.: Do workplace health-promotion interventions targeting employees with poor health reduce sick-leave probability and disability rates? Scand. J. Public Health **1–9**, (2020). https://doi.org/10.1177/1403494820946543

Pensola, T., Haukka, E., Kaila-kangas, L., Neupane, S., Leino-Arjas, P.: Good work ability despite multisite musculoskeletal pain? A study among occupationally active Finns. Scand. J. Public Health **44**(3), 300–310 (2016). https://doi.org/10.1177/1403494815617087

Sagherian, K., Clinton, M.E., Huijer, H.A.-S., Geiger-Brown, J.: Fatigue, work schedules, and perceived performance in bedside care nurses. Workplace Health Saf. **65**(7) (2017). https://doi.org/10.1177/2165079916665398

Sanches, I., Teixeira, F., Santos, J.M.dos, Ferreira, A.J.: Effects of Acute Sleep Deprivation Resulting from Night Shift Work on Young Doctors. Acta Médica Portuguesa (2015). Retrieved from https://www.actamedicaportuguesa.com/revista/index.php/amp/article/view/5777/4417

Silva, T.P.D.da, Araújo, W.N.de, Stival, M.M., Toledo, A.M.de, Burke, T.N., Carregaro, R.L.: Musculoskeletal discomfort, work ability and fatigue in nursing professionals working in a hospital environment. J. Sch. Nurs. Univ. São Paulo **52**(e03332), 1–8 (2018). https://doi.org/doi.org/10.1590/S1980-220X2017022903332

Skovlund, S.V., Bláfoss, R., Sundstrup, E., Andersen, L.L.: Association between physical work demands and work ability in workers with musculoskeletal pain: cross-sectional study. BMC Musculoskelet. Disord. **21**(166), 1–8 (2020). https://doi.org/doi.org/10.1186/s12891-020-03191-8

Svendsen, M.J., Schmidt, K.G., Holtermann, A., Rasmussen, C.D.N.: Expert panel survey among occupational health and safety professionals in Denmark for prevention and handling of musculoskeletal disorders at workplaces. Saf. Sci. **131** (2020). https://doi.org/10.1016/j.ssci.2020.104932

Tang, S.K., Tse, M.M.Y., Leung, S.F., Fotis, T.: Acute and chronic musculoskeletal pain situations among the working population and their pain education needs: an exploratory study. Fam. Pract. **37**(4), 445–452 (2020). https://doi.org/10.1093/fampra/cmaa013

Ulhôa, M.A., Marqueze, E.C., Burgos, L.G.A., Moreno, C.R.C.: Shift work and endocrine disorders. Int. J. Endocrinol. (2015). Retrieved from https://doi.org/10.1155/2015/826249

Vanttola, P., Puttonen, S., Karhula, K., Oksanen, T., Härmä, M.: Prevalence of shift work disorder among hospital personnel: a cross-sectional study using objective working hour data. J. Sleep Res. (December 2018), 1–8 (2019). https://doi.org/10.1111/jsr.12906

Vieira, L.M.S.M.de.A., Sato, T.de.O.: Prevalence of multisite pain and association with work ability - Cross-sectional study. Musculoskelet. Sci. Pract. **50** (2020). https://doi.org/10.1016/j.msksp.2020.102279

Wickwire, E.M., Geiger-Brown, J., Scharf, S.M., Drake, C.L.: Shift work and shift work sleep disorder: clinical and organizational perspectives. Chest **151**(5), 1156–1172 (2017). https://doi.org/10.1016/j.chest.2016.12.007

Wolf, L.A., Perhats, C., Delao, A., Martinovich, Z.: The effect of reported sleep, perceived fatigue, and sleepiness on cognitive performance in a sample of emergency nurses. J. Nurs. Adm. **47**(1), 41–49 (2017). https://doi.org/10.1097/NNA.0000000000000435

Xu, S., Ouyang, X., Shi, X., Li, Y., Chen, D., Lai, Y., Fan, F.: Emotional exhaustion and sleep-related worry as serial mediators between sleep disturbance and depressive symptoms in student nurses: A longitudinal analysis. Journal of Psychosomatic Research, 129 (2020). Retrieved from https://doi.org/10.1016/j.jpsychores.2019.109870

Zion, N., Shochat, T.: Let them sleep: the effects of a scheduled nap during the night shift on sleepiness and cognition in hospital nurses. J. Adv. Nurs. **75**(11), 2603–2615 (2019). https://doi.org/10.1111/jan.14031

Sleep Quality and Quality of Working Life Among Brazilian University Professors in Telework

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Abstract Objective: The main objective of this study was to assess the quality of sleep and the quality of working life in teleworking professors from two Brazilian universities during a period of pandemic caused by COVID-19. Background: The fast pace of life that professors are subjected to affects their private life, and consequently their sleep. The teleworking conditions imposed by the pandemic could lead to some change in their sleep routine, influencing their quality of life at work. Method: Data collection, with a sample of 220 professors, was performed through an online questionnaire, integrating three instruments: Demographic, occupational and habits and lifestyle variables assessment questionnaire, Pittsburgh Sleep Quality Index, and Quality of Working Life Questionnaire. Results: Most of the studied teachers (82.7%) are teaching their classes through telework during the pandemic period and 55.8% have good sleep quality. Application: The Quality of Life at Work was considered satisfactory, as well as the Quality of Sleep. The correlation between them was statistically significant in all domains studied: physical and health, psychological, personal and professional, and good sleep quality positively influences the Quality of Life at Work.

Keywords Age · Ergonomics · Quality of life · COVID-19 pandemic · Work organization.

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1 Introduction

Given the social vulnerability that the pandemic has generated, a key point for fighting it is reducing the circulation of people on the streets and in collective public spaces. Data from the research by Bezerra et al. (2020) showed that most respondents are contributing to this purpose, as they believe that the isolation strategy will be effective to avoid the collapse in hospital care and the reduction in the number of victims of COVID-19. The lockdown has transformed people's routines, forcing them to quickly assess and redraw the balance in their lives, work, family and sleep. These exact circumstances raise an obvious question: How did people change their sleep during the lockdown (Kantermann 2020) and what was the influence of quality of sleep in quality of working life? Teachers are an extremely important professional class in a society's development. However, they are exposed to several adverse conditions, which directly influence the reduction of leisure and rest time (Mazon et al. 2008). Often, they sacrifice the time that would be devoted to sleep by doing extra tasks that are required by the profession, having the habit of depriving themselves of hours of sleep that would be essential. It is noteworthy that in a previous study one in three teachers were identified with excessive daytime sleepiness (Amaro and Dumith 2018).

With the COVID 19 pandemic, teachers had to adapt to a new remote work routine. Neither schools nor teaching networks were able, at first, to develop comprehensive plans and produce clear guidelines on how teachers should proceed. Teachers' accountability tends to strengthen the intensification and self-intensification of work, increasing teacher exhaustion, creating a difficult balance between continuing teaching activities and managing the current moment that has generated stress and anxiety (Saraiva et al. 2020).

A study that included people from all macro regions of Brazil confirmed that, among adults who had no sleep problems before the pandemic, 43.5% started to have problems and, among those who reported a previous history of sleep problems, 48% had the problem aggravated (Almeida et al. 2020).

Amaro and Dumith (2018), in a study carried out with teachers, show that the accelerated pace of life these professionals are subjected to may be related to daytime sleepiness; in this period they must prepare and teach classes, give extra attention to their students, prepare, apply and correct tests, produce academic articles, prepare research papers, guide students, among countless other activities. This often requires an extra workload, which ends up interfering in the private lives of teachers and especially in their sleep. So, often, they sacrifice time that would have been dedicated to sleep, doing the extra tasks that are required by the profession, having the habit of depriving themselves of hours of sleep that would be essential. These may have been aggravated by greater demands due to virtual work, and all the learning that was required from these professionals in a short adaptation time.

Thus, this study aimed to assess the quality of sleep in teleworking professors at two Brazilian universities during a COVID-19 pandemic period, in an attempt to further assist in the development of strategies to improve sleep in this class of professionals. Also, it aimed at analyzing the relations between quality of sleep and quality of working life.

2 Materials and Methods

This was an observational, descriptive and analytical study, as the characteristics of the studied population were analyzed, establishing correlations between variables. The research project was approved both by the Ethics and Research Committee of the University of Rio Verde (CEP—UniRV), Brazil, on December, 2019 (CAAE number: 25835719.3.0000.5077) and by the Ethics Council for Research of the Faculty of Human Kinetics, Portugal, on July, 2020 (CEIFMH No.: 22/2020).

The target population consisted of 508 professors, involved only with teaching functions, from two Higher Education Institutions in the city of Rio Verde, Goiás, Brazil: Universidade de Rio Verde (UniRV) and Instituto Federal Goiano (IF Goiano). The calculation of the sample size was performed in GPower 3.1, with a significance level of 5%, effect size of 0.35 and test power of 0.80, totaling a minimum number of 101 (one hundred and one) participants (Faul et al. 2009).

The questionnaire included the following three instruments: Questionnaire to assess demographic, occupational and habits and lifestyle variables, and the Brazilian Portuguese versions of the Pittsburgh Sleep Quality Index—PSQI (Bertolazi et al. 2011) and Quality of Working Life Questionnaire (QWLQ-bref) (Reis Junior et al. 2008), as well as an Informed Consent Form.

The PSQI assesses sleep quality over a one-month period. The questionnaire consists of 19 self-rated questions and 5 questions that should be answered by bedmates or roommates. The latter questions are used only for clinical information. The 19 questions are categorized into 7 components, graded on a score that ranges from 0 to 3. The PSQI components are as follows: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication and daytime dysfunction. The sum of scores for these 7 components yields one global score, which ranges from 0 to 21, where the highest score indicates worst sleep quality. A global PSQI score greater than 5 indicates poor sleep quality with major difficulties in at least 2 components or moderate difficulties in more than 3 components (Bertolazzi et al. 2011).

The QWLQ-bref is an abbreviated version of QWLQ-78, a WHOQOL-based questionnaire that was developed to assess quality of life at work. It is a self-administered questionnaire, composed of 20 questions that are also divided into four domains: physical, psychological, personal and professional. The higher the score (from 0 to 100) the better the quality of life at work. Indices below 45 are considered unsatisfactory, while indices between 45 and 55 are considered intermediate and indices above 55 are considered satisfactory or very satisfactory (from 77.5 to 100) (Cheremeta et al. 2011).

The questionnaires were transported to the SurveyMonkey online platform. A link was sent via e-mail to all professors on all UniRV Campus and to IF Goiano, from October, 2020 to March, 2021. A recall was performed each two weeks. Individuals were able to answer the questionnaires calmly and voluntarily, according to the best convenience in terms of time and place for each one. Only one questionnaire per email was allowed to be filled in.

Questionnaires that were not completely filled out were eliminated. Of the 508 professors, we obtained 220 complete responses, 163 from UniRV and 57 from IF Goiano, corresponding to a response rate of 43.3%. Three participants were excluded because they did not answer all the items of PSQI, so the final sample was 217 subjects.

Data analysis was performed using the SPSS Statistics 25 software. Initially, descriptive analysis was made with the characterization of nominal and ordinal variables through absolute and relative frequencies, and the description of quantitative variables performed through central tendency parameters (mean and median) and dispersion (standard deviation, minimum and maximum). Using Spearman's correlation coefficient, the relationship between quantitative variables was analyzed. Values of p less than or equal to 0.05 were considered significant.

3 Results

The 220 individuals had an average age of 40.5 years [±8.2], ranging from 25 to 64 years old (77.2% in the range of 31 to 50 years old). Most were married (57.7%), 53.2% (117) were male; 67.6% had dependents at home (minors, elderly or disabled), and most of them had 2 dependents (28.2%), or 1 dependent (23.5%). The highest percentage of respondents were overweight according to the Body Mass Index (62.6% of individuals fall into the overweight, moderate or severe obesity categories). The teaching time ranged from 1 to 40 years, with an average of 12.5 years, and most have been teaching for more than 5 years (86.3%). Most professors have a weekly workload of 40 h per week (66.8%), working an average of 36.6 [±10.1] hours in the studied institutions (UniRV or IF Goiano) and 43.2% work in the morning and afternoon periods, while 90.5% do not work as professors in other institutions.

The vast majority of university professors studied (82.7%) were teleworking, either exclusively or partially. Most work in the health area (44.5%), on campuses located in the city of Rio Verde (92%); 83.1% have a civil service employment contract; and 88.6% had undergone professional improvement in the last 12 months.

Of the respondents, 75% reported the habit of drinking coffee, ranging from 1 to 15 cups a day, and the average consumption was 2.7 cups a day. Regarding smoking, 87.3% do not smoke, 10% are former smokers and only 2.7% declare themselves smokers. Regarding alcohol consumption, 41.8% do not consume alcohol and 34.1% consume less than 15 glasses a week. However 14.5% consume 15–21 glasses a week and 9.5% consume 22 or more glasses. Most (60.1%) do not practice physical activity, 34.4% declare themselves anxious and 11.6% report depression.

Most of the professors studied showed great satisfaction with the relationships between co-workers (78.1%), with students (75.9%) and with immediate superiors (74.6%). The frequency of problems or difficulties occurring in telework was not very high, with the most reported difficulties being with physical and material resources (32.7%), in adapting to distance classes (21.8%) and lack of skill and/or knowledge with the required technologies (29.1%). The number of hours slept ranged from 4 to

Table 1 Pittsburgh sleep quality index, total and by gender: frequency and percentage

Sleep quality level	Total (%)	Men (%)	Women (%)
Good	121 (55.8)	72 (63.2)	49 (47.6)
Bad	74 (34.1)	34 (29.8)	40 (38.8)
Sleep disorders	22 (10.1)	8 (7.0)	14 (13.6)
Total	217 (100)	114 (100)	103 (100)

Table 2 Pittsburgh sleep quality index, total and by age group: frequency and percentage

Sleep quality level	Total (%)	Until 40 years (%)	Over 40 years (%)
Good	121 (55.8)	71 (65.14)	50 (46.30)
Bad	74 (34.1)	31 (28.44)	43 (39.81)
Sleep disorders	22 (10.1)	7 (6.42)	15 (13.89)
Total	217 (100)	109 (100)	108 (100)

10 h per night with an average of 7.07 h. Through the Pittsburg instrument, most of the studied teachers had good sleep quality (55.8%). However, about a third (34.1%) has poor sleep quality and 10.1% were classified as having a sleep disorder (Table 1).

Women have worst sleep quality than men with more cases of bad sleep and sleep disorders. However, differences were not significant with Pearson's chi-squared test: χ^2 (2, N = 217) = 5.952; p = 0,051. It was also observed that age influences sleep quality, with a reduction in sleep quality being more common among older individuals (over 40 years old), with significant differences using Pearson's chi-squared test: χ^2 (2, N = 217) = 8.495; p = 0.014 (Table 2). The median value (40 years) was used to define the two age groups.

The Quality of Working Life (QWL) of the professors participating in this study (Fig. 1) was considered satisfactory with an index of 72.66%, since according to Cheremeta et al. (2011) indexes ranging from 55 to 75% are considered satisfactory. It is also important to highlight the Physical/Health (68.81%), Psychological (73.60%), Personal (78.55%) and Professional (69.68%) domains.

Using Spearman's coefficient, correlations between Quality of Working Life and the Pittsburgh Sleep Quality Index were analyzed. Correlations were significant for all 4 domains of QWL ($p < .001$): physical and health, psychological, personal and professional (Table 3). All correlations were negative meaning that as sleep quality gets better the QWL also improves.

All correlations between the 7 components of the PSQI and QWL were also significant and negative (Table 4), meaning that the improvement of this components contributes to a better QWL.

There was a statistically significant correlation between Quality of Working Life and Sleep Quality, with QWL being better in those with better subjective sleep quality ($p < .001$); in those with lower sleep latency ($p < .001$); in those with longer sleep duration ($p < .001$); in those with better sleep efficiency ($p < .001$); in those who use

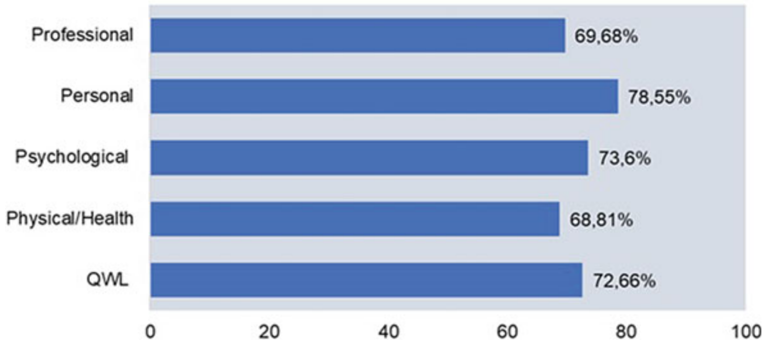

Fig. 1 QWL and its domains among university professors at UniRV and IF Goiano

Table 3 Spearman's ρ correlation of the PSQI with QWL and its 4 domains (N = 217)

QWL domains	Correlation coefficient	Sig.
Quality of work life	–0.551**	<.001
Physical and health domain	–0.608**	<.001
Psychological domain	–0.417**	<.001
Personal domain	–0.408**	<.001
Professional domain	–0.479**	<.001

**The correlation is significant at the 0.01 level (2-tailed)

Table 4 Spearman's ρ correlations of the 7 PSQI components with QWL (N = 220)

PSQI components	Correlation coefficient	Sig.
Subjective sleep quality	–0.528**	<.001
Sleep latency	–0.358**	<.001
Sleep duration	–0.317** (N=217)	<.001
Sleep efficiency	–0.276** (N=217)	<.001
Sleep disorders	–0.408**	<.001
Use of sleeping medication	–0.348**	<.001
Daytime dysfunction	–0.431**	<.001

**The correlation is significant at the 0.01 level (2-tailed)

medication to sleep ($p < .001$); and worse in those with sleep disorders ($p < .001$) and in those who show daytime dysfunction ($p < .001$).

4 Discussion

A study by Silva and Oliveira (2019), with 179 university professors from private institutions, showed a sample with a slight majority of females (50.3%), not very different from our sample (46.8%), with a similar age average of 39.9 years old

(40.5 years in our data), with an also similar average teaching time of 11.4 years (12.5 years in our study). They differ in the number of weekly hours worked, almost half of our sample, dedicating an average of 20.48 h weekly.

The average sleep time considered optimal is 7 to 8 h per night, but the period, duration and structure of sleep vary between individuals and their age. In our study, the number of hours slept per night (7.07 h) is within the recommended average by the authors (Santos et al. 2014). A study among general consumers in Brazil (Arruda et al. 2009) reveals that 83.3% of respondents consume an average of 3.75 cups of coffee a day, a result higher than that of the present study (2.72 cups).

Regarding smoking, 87.3% of our sample does not smoke, a result similar to that of Oliveira Filho et al. (2012) with 90.8% of non-smoking teachers. Santos et al. (2020) demonstrate that smokers and former smokers had an 11% increase in poor sleep quality when compared to non-smokers.

Barros et al. (2020), during the COVID-19 pandemic period, found that among those who did not have sleep problems, 43.5% started having them, while 48% of those who had the problem, it was aggravated. According to Ferreira et al. (2015), only 9.5% of the professors studied by the authors report having depression and 31.4% report having anxiety, similar data to this study (11.6% and 34.4% respectively). Anxiolytics, antidepressants and sleep inducers, in the last 12 months, were used by less than 16.1% of our sample and, in the last 7 days, less than 14.2% used these types of medications.

Studies by Ehlers et al. (2010) suggest that alcohol use disorders are significantly associated with poorer sleep quality in a population of young adults. Not confirmed in a study by Antunes and Costa (2019), where it was not possible to establish a statistically significant correlation between alcohol consumption and sleep quality levels.

Unlike what was found in this study (55.8% with good sleep quality, 34.1% with poor sleep quality and 10.1% having a sleep disorder), Santos et al. (2019), in a survey carried out with professors of a higher education school in the health area, showed that most of them (56%) had poor sleep quality, one of them with a score indicating sleep disturbance and only 44% had good sleep quality, factors attributed to long working hours, lack of time for oneself, multiplicity of educator tasks, bureaucracy of activities, lack of satisfactory remuneration, excessive dedication time required and lack of administrative recognition of the professional. In our study, age and gender were also important factors with worse quality of sleep for women and people over 40 years old.

Sanchez et al. (2019) demonstrated, with respect to sleep assessment, that it was considered good or fair by most of the teachers assessed and that sleep quality was also reflected in Quality of Life (QL) and QWL. In this same study, it was found that teachers who reported having very good sleep had a significantly better perception of QL and QWL, compared to those who reported having regular or poor sleep quality, as well as those who reported having good sleep quality had significantly better QL compared to those with regular sleep and poor sleep. Therefore, they conclude that poor sleep quality contributes to a worse QL and QWL. These results corroborate those found in this study.

5 Conclusions

In this study, where most teachers (82.7%) were teleworking, the Quality of Life at Work was considered mostly satisfactory, as well as the Quality of Sleep. The correlation between them was statistically significant in all domains studied: physical and health, psychological, personal and professional, since good sleep quality positively influences the Quality of Life at Work. Despite this, an important group of professors have poor sleep quality (34.1%) or even sleep disorders (10.1%). Thus, it is necessary to investigate the causes of poor sleep or even sleep disorders and to develop strategies to improve sleep in this class of professionals. It is also important to pay attention to risks and prevention strategies related with teleworking during the COVID-19 pandemic and considering the post-pandemic future where is likely to see a permanent increase in the prevalence of teleworking (Broughton and Battaglini 2021).

The presented results are still preliminary and the analysis will proceed with the integration of occupational variables. Also, this study is part of a longitudinal project that will continue with a new data collection, scheduled for the end of this year.

References

Almeida, W.S., Szwarcwald, C.M., Malta, D.C., Barros, M.B.A., Souza Júnior, P.R.B., Azevedo, L.O., Romero, D., Lima, M.G., Damacena, G.N., Machado, I.E., Gomes, C.S., Pina, M.F., Gracie, R., Werneck, A.O., Silva, D.R.P.: Mudanças nas condições socioeconômicas e de saúde dos brasileiros durante a pandemia de COVID-19. Rev. Bras. de Epidemiol. **23**(e200105), 1–14 (2020). https://doi.org/10.1590/1980-549720200105

Amaro, J.M.R.S., Dumith, S.C.: Excessive daytime sleepiness and quality of life related to the health of university professors. J. Bras. de Psiquiatr. **67**(2), 94–100 (2018). https://doi.org/10.1590/0047-2085000000191

Antunes, A., Costa, E.C.V.: Sono, agressividade e comportamentos de risco em indivíduos dependentes de drogas e álcool. Análise Psicológica **37**(1), 1–14 (2019). https://doi.org/10.14417/ap.1390

Arruda, A.C., Minim, V.P.R., Ferreira, M.A.M., Minim, L.A., Silva, N.M., Soares, C.F.: Justificativas e motivações do consumo e não consumo de café. Food Sci. Technol. **29**(4), 754–763 (2009). https://doi.org/10.1590/S0101-20612009000400009

Barros, M.B.A., Lima, M.G., Malta, D.C., Szwarcwald, C.L., Azevedo, R.C.S., Romero, D., Souza Júnior, P.R.B., Azevedo, L.O., Machado, I.E., Damacena, G.N., Gomes, C.S., Werneck, A.O., Silva, D.R.P., Pina, M.F., Gracie, R.: Relato de tristeza/depressão, nervosismo/ansiedade e problemas de sono na população adulta brasileira durante a pandemia de COVID-19. Epidemiol. e Serviços de Saúde **29**(4), 1–12 (2020). https://doi.org/10.1590/S1679-49742020000400018

Bertolazi, A.N., Fagondes, S.C., Hoff, L.S., Dartora, E.G., Miozzo, I.C.S., de Barba, M.E.F., Barreto, S.S.M.: Validation of the Brazilian Portuguese version of the pittsburgh sleep quality index. Sleep Med. **12**(1), 70–5 (2011). https://doi.org/10.1016/j.sleep.2010.04.020

Bezerra, A.C.V., Silva, C.E.M., Soares, F.R.G., Silva, J.A.M.: Factors associated with people's behavior in social isolation during the COVID-19 pandemic. Ciência Saúde Coletiva **25**(1), 2411–2421 (2020). https://doi.org/10.1590/1413-81232020256.1.10792020

Broughton, A., Battaglini, M.: Teleworking during the COVID-19 pandemic: risks and prevention strategies—literature review. Eur. Agency Saf. Health Work., EU-OSHA (2021). https://doi.org/10.2802/843915

Cheremeta, M., Pedroso, B., Pilatti, L.A., Kovaleski, J.L.: Construção da versão abreviada do QWLQ-78: um instrumento de avaliação da qualidade de vida no trabalho. Revista Brasileira de Qualidade de Vida **3**(1), 1–15 (2011). https://doi.org/10.3895/S2175-08582011000100001

Ehlers, C.L., Gilder, D.A, Criado, J.R., Caetano, R.: Sleep quality and alcohol-use disorders in a select population of young-adult Mexican Americans. J. Stud. Alcohol Drugs **71**(6), 879–884 (2010). https://doi.org/10.15288/jsad.2010.71.879

Faul, F., Erdfelder, E., Buchner, A., Lang, A.: Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav. Res. Methods **41**(4), 1149–1160 (2009). https://doi.org/10.3758/BRM.41.4.1149

Ferreira, R.C.S., Silveira, A.P., Sá, M.A.B., Feres, S.B.L., Souza, J.G.S., Martins, A.M.E.B.L.: Transtorno mental e estressores no trabalho entre professores universitários da área da saúde. Trabalho, Educação e Saúde **13**(Suppl. 1), 135–155 (2015). https://doi.org/10.1590/1981-7746-sip00042

Kantermann, T.: Behavior: how a global social lockdown unlocks time for sleep. Curr. Biol.: CB **30**(14), R802–R830 (2020). https://doi.org/10.1016/j.cub.2020.06.037

Mazon, V., Carlotto, M.S., Câmara, S.: Síndrome de Burnout e estratégias de enfrentamento em professores. Arq. Bras. de Psicol. **60**(1), 55–66 (2008)

Oliveira Filho, A., Netto-Oliveira, E.R.O., Oliveira, A.A.B.: Qualidade de vida e fatores de risco de professores universitários. Revista da Educação Física/UEM] **23**(1), 57–67 (2012). https://doi.org/10.4025/reveducfis.v23i1.10468

Reis Junior, D.R., Pilatti, L.A., Pedroso, B.: Qualidade de vida no trabalho: construção e validação do questionário QWLQ-78. Rev. Bras. Qual. de Vida **3**(2), 1–12 (2008). https://doi.org/10.3895/S2175-08582011000200001

Sanchez, H.M., Sanchez, E.G.M., Barbosa, M.A., Guimarães, E.C., Porto, C.C.: Impact of health on quality of life and quality of working life of university teachers from different areas of knowledge. Ciência e Saúde Coletiva **24**(11), 4111–4123 (2019). https://doi.org/10.1590/1413-812320182411.28712017

Santos, A.F., Mussi, F. C., Pires, C.G.S., Santos, C.A.S.T., Paim, M.A.S.: Qualidade do sono e fatores associados em universitários de enfermagem. Acta Paul. de Enferm. **33**, 1–8 (2020). https://doi.org/10.37689/acta-ape/2020AO0144

Santos, L.C., Castro, N.J., Ruback, O.R., Trigo, T.J.B., Rocha, P.M.B.: Transtornos do ciclo sono-vigília/circadiano - uma revisão de literatura. Braz. J. Surg. Clin. Res. **7**(2), 38–43 (2014)

Santos, F.C., Viana, C. S.O., Melo, L.S., Costa, P.B.M., Ykeda, D.S.: Sono e fatores de estresse de professores do ensino superior da área da saúde. Assobrafir Ciência **10**(1), 21–30 (2019). https://doi.org/10.47066/2177-9333.AC.2019.0003

Saraiva, K., Traversini, C., Lockmann, K.: A educação em tempos de COVID-19: ensino remoto e exaustão docente. Práxis Educativa **15**, 1–24 (2020). https://doi.org/10.5212/PraxEduc.v.15.16289.094

Silva, S.M.F., Oliveira, A.F.: Burnout em professores universitários do ensino particular. Psicol. Esc. Educ. **23**(e187785), 1–10 (2019). https://doi.org/10.1590/2175-35392019017785

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In the original version of the book, the following corrections have been incorporated:

In Chapter 5 "Analysis of Safety Culture Maturity in Two Finnish Companies", the first author name was corrected from Julius Pirhonena to Julius Pirhonen. The corresponding chapter author has been changed to 'Sari Tappura' and the email address was corrected from saritappura@tuni.fi to sari.tappura@tuni.fi

In Chapter 16 "Long-Term Driving Causes Gait Plantar Pressure Alterations in Subjects Groups", section "3.2 Plantar Pressure Distribution" was included.

In Chapter 22 "Cortisol as a Biomarker of Work-Related Stress in Firefighters: A Systematic Review", the author list was updated with the correct information (name, affiliations and email address) of the second author, Joana Santos.

In Chapter 42 "Ergonomics and Safety in the Design of Industrial Collaborative Robotics", the affiliations of all authors were revised and updated with the correct information. Moreover, the corresponding author was changed to Joana Santos.

The chapters and the book have been updated with the above-mentioned changes.

The updated versions of these chapters can be found at
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