Studies in Systems, Decision and Control 449

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

Occupational and Environmental Safety and Health IV

Springer

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Volume 449

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Preface

Occupational and Environmental Safety and Health IV is a compilation of the most recent work of some selected authors from 17 countries (four more than last year) within the occupational safety, health and ergonomics domain.

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. This book also features a section dedicated to reviewing papers for the first time in this series. The chapters that compose it were prepared by recognised experts and allow the reader to quickly have a comprehensive and in-depth view of various subjects.

Due to the broad scope, relevance and originality of the contributions, it is expected that this book contains valuable and up-to-date information, and it presents fundamental scientific research that is being carried out on the subject, as well as 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 occupational safety, health and ergonomics.

This book is based on selected contributions presented at the 18th edition of the International Symposium on Occupational Safety and Hygiene (SHO 2022), held on 8–9 September 2022, in Porto, Portugal.

All the contributions included in this book were previously peer-reviewed by at least two of the 84 members from 12 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 also wish to thank all the reviewers, who gave a

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Occupational and Environmental Safety

Theoretical Analysis of the Worker's Movement Prediction in Construction Sites and Their Stress Level for the Dangerous Situation Prevention

Antonio José Carpio, María de las Nieves González, João Santos Baptista, and Fernanda Rodrigues

Abstract The occupational risk assessment methodology called Level of Preventive Action (Lpac) evaluates the amount of preventive action to obtain an optimal prevention level, measuring the degree of danger concerning the building geometry, the worker position concerning the slab edge and the worker's emotional states. The mathematical basis of Lpac can be extended to include the perspective of collective behaviour models, which can describe the predictable human behaviour based on the probability of acts. Research in the mathematical field satisfactorily models the movement that individuals follow or will follow in different scenarios (e.g., street crossing, emergency evacuation), including social parameters such as mood and emotions. This paper presents a theoretical case applied to the predictive analysis of behaviours and interactions between individuals working on constructing a slab. It is essential to include the worker's movement prediction regarding unsafe acts and movements in the risk assessment and add the emotional states. From a case study at the microscopic level, stress can trigger dangerous situations, and its evaluation can prevent them.

Keywords Risk assessment · Workplaces · Risk perception · Heuristic · Stress level

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1 Introduction

It is essential to decrease the occupational accident rate in construction works to reasonable values, applying accident prevention systems and managing risk (Ahn et al. 2020). However, risk assessments in construction sites require a detailed study of the different risks to which workers are exposed (Albrechtsen et al. 2019). As a base criterion, three phases are often required in evaluation methodologies to establish a risk assessment (Gul et al. 2018): identification of potential hazards; risk assessment and quantification; and risk categorisation. In addition to these criteria, a parametric selection of subjective (qualitative) analysis and objective (quantitative) analysis for risk assessment should be added (Okudan et al. 2021). Although, the evaluation criteria are usually oriented individually in each risk-fighting technique (Forteza et al. 2022). However, the processes in the construction industry offer a complexity of management, organisation (interdependence between work units, different phases of work execution…), planning of the environment (climate, auxiliary means…), human resources (trades, tasks, qualification, temporality…), material, among others. (Pinto 2014). Occupational accidents in the construction industry demand risk analysis from a comprehensive environment point of view (Claudino Véras 2012). Methodologies evaluation, both those designed for the industry sector and those designed, lately, for the construction sector, establish observation and analysis criteria according to the characteristics of the jobs and the approaches of the methodologies themselves. They seek the identification of hazards, the evaluation and quantification of risk, and its classification. Each of the methodologies applies the parameters and protocolisation systems that best adapt to the objective sought.

Furthermore, to a greater or lesser extent, they cover four techniques for combating risk: Occupational Safety, Industrial Hygiene, Ergonomics and Psychosociology. There is a need to establish the parameters that better reflect the reality of a work environment, covering these four techniques to combat the risk. These parameters are, based on risk tolerance (Carpio 2017): the constructive reality, observing and evaluating the risks associated with the complexity of the work units, their location and interdependence (Farid 2020); the economic investment of the contractor with the implementation of construction systems and prevention systems (Newaz et al. 2018); and social aspect with the participative interest and the state of mind of the workers (Ahn et al. 2020). These parameters cover the environments: initial, documentary (Rudolf 2018), constructive (Van der Molen et al. 2018) and social, as fundamental elements associated with the execution of a work (Garcia and Segovia 2020). The difficulty and characteristics of the construction work environment establish a directly proportional value of complexity that affects the initial guidelines established in the documentary environment. However, the development of prevention systems, social activity, roles, hierarchies, and work stress add parameters that can be evaluated in the construction environment (Casey et al. 2017).

The Risk assessment method, Lpac (Carpio 2017), developed from the mathematical model of William T. Fine (1971), relates the four evaluation and observation environments of the construction work processes: the initial environment that corresponds to the process of conception, design and project of the building; the documentary environment, which corresponds to the physical and geometric characteristics of the building; the construction environment, concerning the worker's degree of exposure to risk and the company's safety systems and means; and the social environment regarding the level of participation in prevention and the level of satisfaction of the workers.

There are risk assessment methodologies that have broadened the observation parameters in the search for their suitability for implementation for construction works. Forteza et al. (2022), in their methodology of the Global Tool for the Evaluation of Construction Works, collect information on the structure of the work, its environment, the situation, the physical development, the agents, and the type of work; to identify and assess risks, barriers and means. Pinto (2014) bases his Qualitative Occupational Safety Risk Assessment Model (QRAM) on the Event Tree on which certain characteristic risks of construction works are analysed from four observation dimensions: safety climate, severity factors (consequences), factors of possibility (probability) and safety barriers (means of safety). Reyes et al. (2014) unifies criteria in the decision-making hierarchy and evaluates the consequences of variations in the building's life cycle, from the design phase to reintegration. Meng et al. (2020) present their study on risk by analysing accidents at workplaces in the construction industry and determine that a correct definition of the project with adequate measures in planning and organisation of the work can minimise accidents by more than 60%. They highlight the need to manage health and safety during the building's life cycle: design, execution, and use. Finally, Gil-Beltrán et al. (2020) establish the importance of studying psychosocial and ergonomic factors since risk assessments in construction consider physical, technical, and managerial aspects, being overconfidence and forced postures the leading causes of accidents in construction.

This research proposes expanding the four environments of observation and preventive evaluation of the construction work processes with a fifth environment that offers relevant perspectives for risk assessment. It is about predictable human behaviour, which encompasses aspects of social relationships and numerical environments based on the probability of actions. It considers research in the mathematical field that satisfactorily determines the movement that individuals and groups follow or follow in different scenarios (e.g., street crossing, emergency evacuation), including variable parameters such as mood (Rosado 2010). The state of mind conditions worker's movement, causing erratic movements due to stress. A theoretical mathematical based analysis of the predictable movements of the workers during the construction phase of a slab is conducted, analysing their behaviour at the edges of the slab regarding unsafe acts and movements. Moreover, it is incorporated, in the mathematical model of the (Lpac) methodology, a parameter for predicting the movement of workers that measures their level of stress or state of mind. It is intended to minimise dangerous situations.

1.1 Prediction of the Worker's Movement

An extensive bibliography includes the study of people agglomerations in mass events, the movements of the masses and the study of the prediction of these behaviours. From a study with microscopic interactions, a macroscopic model can be derived, in which the pedestrian variables are the obstacles, the speed of the obstacle and the analysis of the trajectories to avoid a future collision. The pedestrian observes how the obstacles (other pedestrians) vary their position and speed from their field of vision. To avoid collisions, the pedestrian varies his speed and his direction. The mathematical model determines the interaction of two pedestrians in motion and who avoid their collision (Appert-Rolland et al. 2014).

Other study models interpret the movement or dynamic flows of people and the contagion that is generated when there is contact between two individuals: the behaviour of one is transferred to the behaviour of the other, like swarm behaviours (Bertozzi et al. 2015). With the increase in the size and frequency of mass events, the study of mass disasters and the simulation of pedestrian flows have become important research areas. Understanding crowd dynamics through cognitive heuristics is crucial for better preparation for safe mass events. It also paves the way for a more realistic model of collective social behaviours, particularly human crowds and biological swarms. Behavioural heuristics are quick and simple cognitive procedures often used when decisions must be made under time pressure or overwhelming information. It successfully explains decision-making in various situations, such as investment behaviour in the stock markets or medical diagnosis in emergencies (Moussaïd et al. 2011). It is essential to propose heuristics on new models of collective human behaviour, on how group decision-making is going to proceed (Lazer et al. 2020), on the patterns of specific group activities (Zhou 2019) or the different simultaneous interactions between multiple individuals (Lorenz-Spreen et al. 2019).

1.2 Measurement of Worker's Stress Level

Regarding worker's stress level data collection, Bustos et al. (2022) focused on reviewing different research works on physiological monitoring systems for firefighters. Determined the usefulness of real-time monitoring of the physiological demands of firefighters from the measurement of heart rate (HR), heart rate variability (HRV), electrocardiogram (ECG) signal, core temperature (Tco), respiratory rate (RR), skin temperature (Tsk), and rates of perceived exertion (RPE). Measuring cardiac and thermal load. Likewise, it establishes the need to categorize physiological registers together with stress perceptions, to optimize work and rest cycles and, therefore, prevent further health problems.

The research of Kyriakou et al. (2019) proposes detecting moments of stress from measurements of wearable physiological sensors. The algorithm used detected moments of stress with 84% accuracy, showing high correlations between stress events measured by wearable sensors, reported by questionnaires, and recorded by video. Everyday real-world stressors originate from traffic congestion, dangerous driving situations, and crowded areas, e.g., tourist attractions. The research posited that detection of real-life stress could be improved and thus foster a better understanding of the circumstances that cause physiological stress in people.

There are devices on the market that allow monitoring and detecting moments of stress in real-world actions. In the case of the research by Khalili-Mahani et al. (2020), it is proposed to detect the interaction between the difficulty of a game concerning cognitive ability and the physiological responses of the stress level. The results indicated that the participants did not show marked stress levels for a certain type of game. It is proposed to develop predictive models for health outcomes in its conclusions.

2 Methodology

2.1 Level of Preventive Action Parameters

The Lpac method is an occupational risk assessment methodology adapted to construction works (Carpio 2017). The Lpac parameters quantitatively observe the risk levels that correspond to the complexity of the work units, their location on the work and their interdependence (Carpio et al. 2020) (in the documentary environment) (Van der Molen et al. 2018); risk levels depending on the characteristics of construction systems and preventive systems (Newaz et al. 2018) (in the construction environment) (García and Segovia 2020); and, the levels of risk based on the perception of the environment and the state of mind of the workers (Ahn et al. 2020) (in the social environment) (Casey et al. 2017). The Lpac is developed in five phases based on technical analysis, observation, and an on-site psychosocial survey (Carpio and González 2020). The first phase defines a characteristic value inherent to the real situation of the work observed in the documentary, constructive and social environments, and is applied to each of the parameters of the Lpac formula (Carpio et al. 2021a). The second phase determines the incidence of the characteristic value to each of the evaluated risks. The third phase indicates the bases for the control of the preventive action with the value obtained from the Lpac concerning the absolute risk as a deviation from the initial preventive action (Carpio et al. 2021b). The fourth phase indicates the recommendation actions. And in the fifth phase, the improvement of preventive action during the construction process is checked. The Lpac is expressed by the mathematical formula (1):

$$\text{Lpac} = (P \cdot C) \cdot \left(\frac{R_r \cdot B_r \cdot E}{E_C \cdot P_i \cdot L_S} \right) \tag{1}$$

Its parameters are the following:

- Initial or absolute environment (basic risk parameters):
  - Probability (P): probability of damage occurring.
  - Consequences (C): expected consequences of the damage that may occur.
- Documentary environment (physical and geometric risk parameters):
  - Relative Risk (Rr): evaluates the constructive complexity of the work unit.
  - Border Risk (Br): evaluates the location of the work unit.
- Construction environment (parameters of construction and human resources):
  - Degree of Exposure (E): evaluates the time that the worker is exposed to risk during the development of the work unit.
  - Economic Capacity (Ec): evaluates the amount of economic means for construction prevention systems.
- Social environment (parameters of the level of satisfaction and participation):
  - Relative Importance (Pi): evaluates the participatory interest of workers and their perception of health and safety.
  - Satisfaction Level (Ls): evaluates general aspects of behaviour, mood, and human attitude.

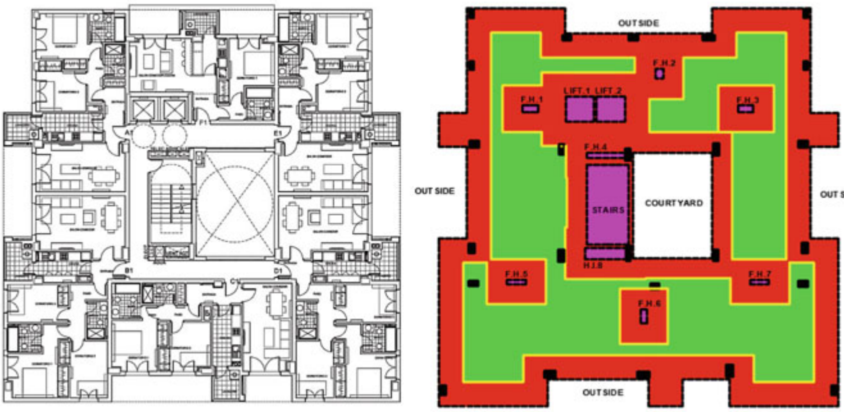
2.2 *Theoretical-Mathematical Case Study*

This document presents a theoretical case applied to the predictive analysis of behaviours and interactions between individuals working on constructing a slab. The plan in Fig. 1a indicates the study floor distribution, and in Fig. 1b, the danger zones in the study slab. In red, the danger zones of the slab edge are shown. The magenta zones correspond to the risks of falling material on the operator and are in the shafts of lifts, installations, and stairs. Green areas indicate that the risks of people falling are minimal, and the Lpac is optimal.

2.3 *Design of the Mathematical Model*

In the Lpac risk assessment methodology (Carpio 2017), it is described that the state of mind affects the perception of risk and, therefore, the worker's attitude towards it. It will try to study this phenomenon in more detail, considering the influence of the other workers in the plant (Rosado 2010). This provides an Eq. (2) for the emotional state interaction:

$$\frac{dl_{qi}}{dt} = \mathrm{A}\frac{1}{4}\sum_{j\neq i}\left(l_j - l_{qi}\right) + \mathrm{B}\frac{1}{3}\sum_{k\neq q}\left(l_k - l_{qi}\right)$$



(a) (b)

Fig. 1 **a** Layout of the building floor plan; **b** Risk areas in the slab plant

$$+\mathrm{C}\left(\frac{l_E + l_J + l_{DF} + l_S}{2} - l_{qi}\right) + \mathrm{f}\left(R, r_{qi}, t\right) \tag{2}$$

To simplify the model, it is assumed that the state of mind of the site manager, the site foreman, the project manager, and the health and safety coordinator does not change. Changes in the mood of a worker in a crew are allowed. These changes will be affected to a greater extent by the state of mind that the manager perceives in his teammates and, to a lesser extent, by the general state of mind perceived in the plant, both in the other crews and in the site foreman and the site manager. In addition, the stress due to working in a risk area can also continuously affect his state of mind. The objective is to give a more adjusted estimate of the risk assumed by the worker, considering the influence of his colleagues. This occurs partly indirectly, through the effect on his mood, but also directly by mimicking the risk taken by other individuals. This provides an Eq. (3) for the variation in risk assumed:

$$\begin{aligned}\frac{dr_{qi}}{dt} &= -\mathrm{K}\frac{R \cdot h'\left(l_{qi}\right)\frac{dl_{qi}}{dt}}{\mathrm{h}\left(l_{qi}\right)^2} + \mathrm{A}\frac{1}{4}\sum_{j \neq i}\left(r_{qj} - r_{qi}\right) \\ &\quad + \mathrm{B}\frac{1}{3}\sum_{k \neq q}\left(r_k - r_{qi}\right) + \mathrm{C}\left(\frac{r_E + r_J + r_{DF} + r_S}{2} - r_{qi}\right)\end{aligned} \tag{3}$$

l_{qi}, emotional state;
r_{qi}, risk assumed; of the worker i of the crew q.
l_J, emotional state; r_J, risk assumed; of the construction Site Manager.
l_E, emotional state; r_E, risk assumed; of the construction Site Foreman.
l_{DF}, emotional state; r_{DF}, risk assumed; of the Project Management Faculty.

l_S,emotional state; r_S, risk assumed; of the Health and Safety Coordinator.
J; k; are variable and determine the interaction of the alternate emotional state.
$f(R, r_{iq}, t) = 0$, in a first approximation, it can be considered zero.
R, is the level of characteristic risk associated with a work zone.
t,indicates the time variable.
h,indicates to what extent the state of mind corrects the characteristic risk.
$A + B + C = 1$ with $A > B > C$.
K, it is constant and determines the work environment for the emotional state.

Concentrating on the description of the risk assumed, of the Lpac, in a specific work and a certain state, most of the factors that intervene in Eq. (1) can be considered constant. The general expression for the movement is defined in Eq. 2, which models the variation of the mood of each worker in response to the rest of the individuals in the plant. This allows us to use a simplified expression of it, which depends only on the mood through the level of satisfaction (4):

$$r_{qi} = L_{pac}\left(l_{qi}\right) = \frac{K}{L_s\left(l_{qi}\right)} \tag{4}$$

The indications of the Health and Safety Coordinator can be included in this second type of influence, interpreting these as the optimal Lpac coordinator perception. This would provide an equation for the variation in assumed risk similar to Eq. 2 for the variation in mood. However, the lack of regularity of Ls concerning mood discourages this approach. Instead, the variation of the Lpac for a worker can be described using a discrete formulation concerning time through differential equations. Rewriting (Eqs. 2 and 3) and using this formulation, the system that will serve as the basis for this heuristic (Eq. 5) is obtained:

$$\frac{dx_i}{dt} = \Gamma_i'(t) + \alpha(r_i)\sum_{i \neq j} \nabla U\left(x_i - x_j\right) + \sigma(r_i) \tag{5}$$

where $\Gamma(t)$ is the trajectory that the worker i must follow, $U(x_i – x_j)$ is an attraction–repulsion potential that describes the variation in the trajectory due to the interaction with other workers, adjusted by a coefficient $\alpha(r_i)$ that allows the worker's risk perception to be taken into account. Finally, $\sigma(r_i)$ is a random disturbance whose intensity depends on the Lpac.

3 Results

A case study is taken on the theoretical construction of an eight-story building with 41 dwellings above ground: 62 parking spaces and 47 storage rooms below ground. The building is of isolated typology. The proposed procedure is to design the mathematical model to analyse the movement that workers and building agents may have on the construction site under the conditions due to the risk of people falling and the risk of falling material. In turn, the mood parameter is incorporated in each person; since, depending on the intensity of the emotional state, it can spread to those who are close. When they are of a positive type, it motivates movements within the enclosure to be more effective in the face of risks, improving the perception of risk. When they are of a negative type, it makes the movements and the less risk perception, which tends to insecure behaviours (Rosado 2010). The mathematical basis that arises will give rise to a series of critical questions in the case study; to be able to expand the research in future actions on real constructions and with data collection and its effective monitoring through body sensors to measure the level of stress.

The predictive motion formula has been modelled with the MATLAB programming and numerical calculation platform. A warforged has been raised in which four workers have been given a mission (blue circle). They always start moving from the same place. There are three mood assumptions: apathetic as a non-interaction mood type, focused as a positive mood type, and excited as a negative mood type (Rosado 2010). The red circle indicates the degree of contagion or mood interaction. In the following illustration (Fig. 2), the different assumptions are shown in the same time intervals (5, 15 and 30 s), being able to observe how the workers behave in different ways. In the case of the excited state of mind assumption and at the end of the trajectory, it is observed that one of the workers exceeds the edge of the slab (red circle).

4 Discussion

The term "heuristics" is a broad concept that addresses different techniques or methods to solve a given difficulty. Moussaïd et al. (2011) indicate the importance of heuristic approaches to predict the movements of individuals individually more easily and in groups. Although it is the result of individual behaviours, the behaviour of crowds can lead to pattern formation at a larger-scale level. These patterns have a strong influence on flow efficiency. Therefore, it is interesting to understand how they spontaneously emerge in a crowd. Even in a more homogeneous flow, the global behaviour of the crowd can be predicted from the local interactions of the individuals. In different movement flows, the movement of people can be analysed to check how the interaction of the lines or trajectories of each one of the pedestrians behaves in different scenarios.

The approach of this document proposes introducing to the Lpac risk assessment method the experience of its authors both in the field of safety and health in construction, as well as in the field of predictive mathematics and data monitoring. by body sensors.

Within the heuristic principles, several suggestions of real situations that happen and are repeated in construction works have been established. Based on the heuristic rules, the ways to solve these suggestions are based on a fundamental parameter: participation in prevention based on communication. As heuristic strategies, the

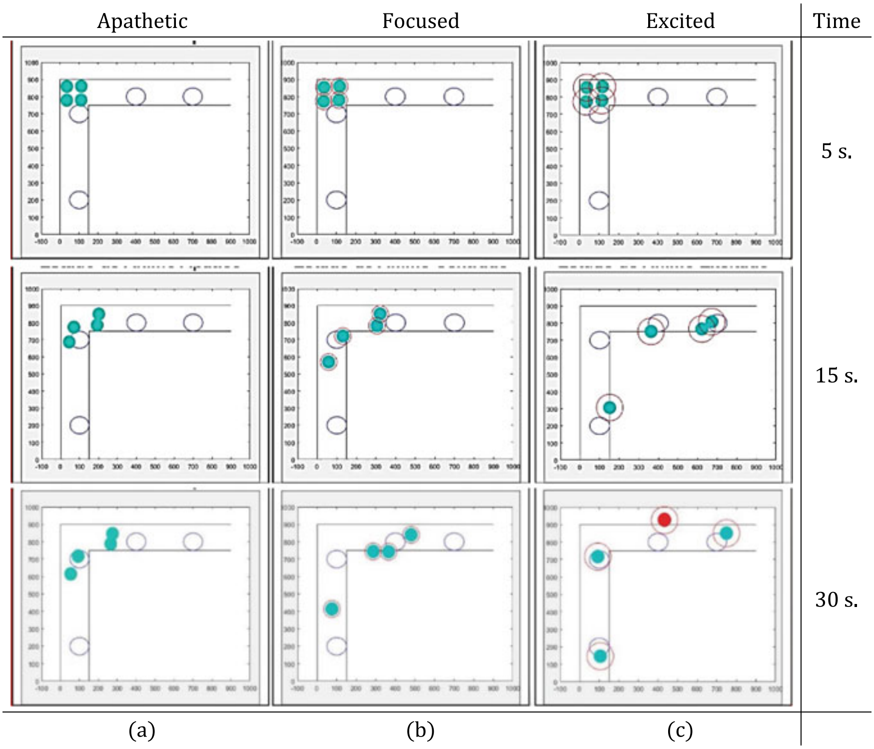


Fig. 2 Modelling the theoretical-mathematical assumption with the animation time intervals at 5, 15 and 30 s. **a** Apathetic mood, **b** Focused mood, and **c** Excited mood

means available to focus on solutions to risk situations in construction sites entail a broader training of building workers and agents in prevention matters, collaborating and sharing the knowledge between the different individuals who coincide on a worksite. It is proposed to add the real-time measurement of the worker's physiological condition (stress level) in this context. This will imply the necessary participation of the workers to improve the dangerous situation when a computer system detects a dangerous situation based on the inherent risk of the construction, the movement prediction, and the stress level.

5 Conclusions

In the case study, the flows of individuals on the work platform and their interaction are analysed, both by their movement and by the contagion of their mood. It was found that moods influence both the worker's movement and perception of risk. The limits introduced as fixed variables (e.g., slab edge, stairwells, structure pillars) condition the individual´s decision-making and make him repeat safe or unsafe scenarios based on the number of infections due to the behaviour of others. The study with more real situations with different emotional states among workers, different risks assumed and changing work environments of the different phases of the work execution process in which the values obtained in application of the defined mathematical design will be shown is the reason for later work.

The Lpac risk assessment methodology evaluates the documentary environment (construction project), the construction environment (construction management) and the social environment (safety climate) of the building process based on parameterisation concepts of the characteristic value of the complexity of the work itself and the perception of the environment by the workers, through technical-social criteria. With this study, a conceptual environment based on predictive mathematics is incorporated to determine with predictive models the movement and behaviour of workers on construction sites, considering the monitoring of the measured stress levels with physiological sensors.

It is essential to learn to observe people, paying attention to their behaviour and movements around the construction site, from the different environments of the construction process, in their jobs to identify unsafe or deficient acts since the prevention of accidents and management of risk is a social priority in the construction industry. It is necessary to incorporate into the knowledge of preventive observation real-time measurements of the geolocation of individuals and physiological data to prevent possible unsafe acts in areas predefined as dangerous and that the conditions of the worker's stress level could imply unsafe acts. Assessing possible unsafe situations in real time should be treated as a fundamental basis for future research on real cases. This treatment involves adding preventive environments associated with movement prediction, stress level monitoring and BIM (Building information modelling) technology.

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Development of Guidelines for an Occupational Health and Safety Management Systems Towards Industry 4.0

Cátia Pinto, Ana Colim, Pedro Domingues, Paulo Sampaio, and Pedro Arezes

Abstract Despite being a topic addressed by several researchers, it continues to be the subject of investigation because nothing relevant has been concluded yet. The main goal of the current study is to develop guidelines in order to define the requirements and externalities of Industry 4.0 (I4.0) from the Occupational Health and Safety Management System (OHSMS) perspective. A literature review was carried out to understand the main concepts applied and semi-structured interviews were applied to five active Occupational Health and Safety (OHS) technicians. It was concluded that companies aren't prepared to face the challenges posed by I4.0 through an OHSMS and ISO 45001:2018 doesn't contemplate the new industrial revolution yet. The main difficulties highlighted by the companies were the extensive legislation that doesn't follow the industrial developments, the high capital required for the initial investment, the difficult access to know-how and the impact that this will have on production.

Keywords Industry 4.0 · ISO 45001 · Occupational health and safety · Management systems

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1 Introduction

It is currently unclear how the I4.0 concept will impact the organizational component of companies, namely the organizational component associated with OHS. Thus, with this work we intend to identify the dimensions of an OHSMS that should evolve to a level that allows them to successfully face the challenges posed by I4.0, answering three research questions:

1. What are the dimensions of an SGSSO that will evolve in an I4.0 context?
2. How is this evolution envisaged?
3. What is the state of readiness of companies with SGSSO to face the challenges posed by the I4.0 concept?

1.1 Industry 4.0

The fourth industrial revolution is the combination of production methods with the latest developments in information and communication technology. This development is caused by the trend toward digitization of the economy and society. The technological basis of this development is possible due to intelligent and interconnected cyber-physical systems that will allow people, machines, equipment, logistical systems, and products to communicate and collaborate directly with each other (COTEC Portugal 2020). With the implementation of I4.0, it is expected to present benefits such as the sharing of information in real-time, the reduction of defects, and the increase in the speed of the delivery of a certain product and/or service. The implementation of state-of-the-art technologies encourages organizations to use less scarce resources (Khanzode et al. 2021). In short, the main words associated with I4.0 are represented in Fig. 1 (Silva et al. 2020a, b).

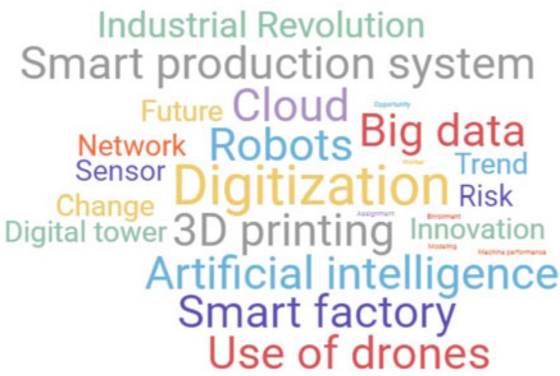

Fig. 1 Cloud of words associated with I4.0

1.1.1 Key Changes Driven by I4.0

Humans and machines will be able to work together, and smart tools will also be able to monitor the work activity, to ensure quality control and eliminate manual control (Davies 2015). Human–machine interaction isn´t something new, as it already happens daily through various actions, but this interaction will be deepened and expanded, specially at the work context. Romero et al. (2016) argue that the new worker will be intelligent and competent to know how to deal with all the features of this interaction and automation will complement their capabilities (Romero et al. 2016). The categories of interactions raised by Lorenz et al. (2015) give us an idea of the potential of this scenario. Robot-assisted production will minimize the exhausting effects of repetitive work on workers so that they with impaired physical capacity can continue to work, as well as older people. This will also prevent accidents in hazardous environments for humans, as there will be the possibility to remotely control the robot. Operational control will be simplified by the tutorial incorporated in the equipment itself, increasing the technological capacity of the worker and reducing the training time for a specific machine. This interaction will allow the worker to be responsible for more machines. Therefore, human–machine collaboration is considered essential for the success of companies with high productivity demanded by competition, through the use of the principles of I4.0 (Lorenz et al. 2015).

1.2 Occupational Health and Safety Management System

The OHSMS enables the systematic management of risks related to OHS, identifies, and organizes processes and procedures, and ensures the implementation, review, and continuity of what has been established. With an OHSMS, organizations improve their performance and for that, it is necessary: to define, develop and implement objectives and an OHS policy; create systematic processes that consider their context and that address risks and opportunities, legal requirements and other requirements to which the organization is committed; determine the hazards and risks of OHS related to its activities and try to eliminate them or establish control mechanisms to reduce their effects; establish operational control mechanisms to manage OHS risks, legal requirements and other requirements for which the organization is responsible; raise awareness of OHS risks; assess OHS performance and seek to improve it through appropriate actions; ensure that workers take an active role in OHS through their involvement (Cąliş and Buÿükakinci 2019; Occupational Health and Safety 2015). With these measures, the organizations will be seen as a safe workplace can bring benefits such as improving responsiveness concerning legal compliance issues, reducing overall incident costs, reducing work accidents, ensuring the safety of workers, reducing downtime and costs of interruption of operations, reduce the cost of insurance premiums, reduce absenteeism and turnover of the organization's workers and achieve an international reference point, which in turn can influence a portfolio of clients who are concerned about social responsibilities (Çaliş and Buÿükakinci 2019; Occupational Health and Safety 2015).

1.2.1 ISO 45001 Standard

ISO 45001 is an international standard that specifies the requirements for an OHSMS and provides guidance for its proper use, in order to enable an organization to provide safe and healthy workplaces, prevent work-related disorders and health problems, as well as how to proactively improve their OHS performance (ABNT 2018). This was developed by a group of OHS experts and it took into account other international standards in this area, such as OHSAS 18,001 (standard with wide use worldwide), various national standards and the ILO conventions and guidelines in terms of safety and health (Occupational Health and Safety 2015). The first and so far only version of the ISO 45001 standard was published in March 2018 and follows the high-level structure outlined in Annex SL.

ISO 45001 isn't intended to be a legally binding document, it's a management tool for voluntary use by all organizations, and it provides to eliminate or minimize the risk of accidents and occupational diseases (Occupational Health and Safety 2015). It was possible to verify that companies aren't prepared to face the challenges posed by I4.0 through an OHSMS, since ISO 45001:2018 still doesn't contemplate this new industrial revolution. It is essential to adapt this standard to the new work context.

2 Material and Methods

The methodology was developed according to the "onion" scheme of Saunders, where the research philosophy was classified as positivism, following a deductive approach, its nature of the investigation being classified as an exploratory study, which was supported by the case study through the interviews, being a unique method (qualitative), a cross-sectional study, and finally the collection and analysis of data. A key element in this investigation was the interviews, with the semi-structured approach being the chosen typology. By carrying out the interviews, it's intended to identify which are the variables and dimensions (organizational issues) and what is their relationship with the concepts raised by I4.0. The interviewees were informed in advance about the date and time of the interview, and the topic and confidentiality protocol were explained. The interviews took place during the months of July and September 2021, and they had an average duration of 45 min. After the transcription of each interview, it was sent to the participants so that they could read and reconfirm the information collected. Due to the Covid-19 pandemic, the interviews were carried out through the Zoom and Microsoft Teams platforms. It should be noted that for both parties there was no noise, the thermal environment was pleasant, the lighting was adequate and there were no reflections on the screen. The interviews carried out were of the semi-structured type that are guided based on specific points, from which the questions were created. To this end, a guide was drawn up to ensure that the required information was obtained:

1. In part 1, characterization of the interviewee and the company, the interviewee was asked to indicate their position and responsibility, departments involved in I4.0, size of the company, activity, type of OHS services and the number of workers in the company.
2. In part 2, the perception and contribution of I4.0, was intended to survey the perception of this new digital age for the companies under study, which technologies are being developed and implemented, and the expected impacts and difficulties they have faced.
3. In part 3, perception of the impact of I4.0 on OHS, the aim was to assess the future of this area in the new industrial era, such as the new associated risks, the future of employability, non-compliances and the most unsafe behaviors and the central theme of this investigation, the impact it will have on the revision of the ISO 45001 standard. In addition, two questions were introduced about the main risks found and the personal protective equipment made available by the company.

The disclosure of the interview was made in two ways: an email message was sent to all the companies targeted by the study and telephone contact, in order to reinforce and encourage adherence to participation. Both modes of dissemination and the call for participation in the interview included the presentation of the interviewer, the description of the study and the mention of the main objectives.

For this investigation, two criteria were considered for the selection of interviewees: one is to be OHS technicians or senior technicians with a professional aptitude certificate, with the intention that the interviewees have training in the area of OHS, in order to understand the concepts and the purposes of the interview; another is to have knowledge and applicability of ISO 45001 in the real context, aiming to standardize the sample used.

3 Results

To carry out this investigation, 30 nationally and internationally renowned companies were contacted, but only 36.67% answered to the email sent and only 16.67% showed interest and continued to participate, representing the sample under study. The interview was carried out with 5 people who specialized in the subject under study and the appropriate approvals/consent was obtained by them.

In Table 1, the interviewers are identified individually according to the order in which the interview was carried out, where it is possible to observe the role they perform, the sector of activity where they work, the total number of workers, the date and the platform where the interview took place.

Table 2 presents a summary of the responses collected in the interviews compared with the evidence resulting from the literature review carried out.

Table 1 Information about the interviewees and interviews carried out

Company coding	Respondent's role	Activity sector	Number of workers	Date of the Interview	Platform used
A	Responsible for the OHS team	Automobile industry	3550	29/06/2021	Microsoft teams
B	Environment and OHS coordinator	Furniture industry	1792	30/06/2021	Microsoft teams
C	Superior OHS technique	Metalworking industry	120	12/07/2021	Zoom
D	Responsible for OHS services	Textile industry	100	12/09/2021	Zoom
E	Superior OHS technique	Textile industry	75	19/09/2021	Zoom

3.1 Analysis of I4.0 Dimensions in Relation to OHS

Occupational safety isn't a new topic and is among the biggest concerns of companies, which have full-time people to take care of this area. Most of the knowledge accumulated over decades on this topic addresses human behavior, which becomes a problem because with the automation of industry and intelligent machines, the trend of safety at work changes. The concern is no longer centralized in manuals of conduct and starts to focus on the robustness of information systems and the prevention of communication problems between machines. In a management system, all information must be documented and with I4.0 it becomes available in digital form instead of in paper form, as it was done before. Audits, which aim to measure the effectiveness of the system and its improvement over time, must be periodic to determine if the OHSMS and its elements are well implemented if they are adequate and effective in protecting the safety and health of workers and in the prevention of work accidents. In the context of I4.0, these can be carried out online or by b-learning, and the presence of the auditor in loco is no longer necessary. The communication starts to be elaborated with another type of technology, much more appealing, in order to capture the attention of those involved, in this case, the workers. Consultation with workers is carried out through questionnaires developed by OHS technicians. Previously, they were carried out in paper format, but now they can be carried out in online format, where data is processed automatically and in real-time. The awareness of workers will be carried out through augmented reality, which allows the integration of elements or virtual information into real-world views through a camera and with the use of motion sensors such as a gyroscope and accelerometer. In other words, it is no longer held in a room with a painting, evolving to the exhibition by images transmitted by computers and will be carried out more appealingly through augmented reality. The control of suppliers and subcontractors is carried out electronically, where it is possible to automatically generate notifications about the needs

Table 2 Detailed analysis of the responses collected in the interviews compared to the evidence resulting from the literature review carried out

Perception	Interview	Literature
I4.0	Production lines are increasingly automated through the introduction of collaborative robots, systems to help transport loads, use of technology in terms of the rehabilitation of musculoskeletal injuries, optimization of administrative processes, artificial vision, cloud data, additive manufacturing and computerization of the whole business	Schwab (2016), Silva et al. (2020a, b), Stacey et al. (2017)
	Union of technology and human reasoning, aiming at increasing productivity and improving processes, since technological tools will contribute to increased productivity and personalized customer service	Chiarini et al. (2020), Santos and Martins (2020)
	Future of employability and work content: change in workers' skills, discontinuation of heavy tasks, more intense work rhythms and greater exposure to stress	DJP Automação Xavier (2019)
	ISO 45001 compared to OSHAS 18,001: more comprehensive, greater difficulty/challenge in its implementation and improvement of the structure	Constantine (2018), Oliveira (2020), Severo (2018)
	Positive aspects: prevention and reduction of potential risks for workers, faster response (increased productivity), reduced non-quality and increased reality in terms of training Negative aspects: perception of the origin of the injuries that the new generations create over time, lack of alternatives in case of computer problems and fear of keeping up with the evolution of technology by the older population	Barreto et al. (2017), Dalkir (2017), Lee et al. (2014), Rüßmann et al. (2015), Schuh et al. (2014), Sousa (2019)
	Main difficulties: economic availability necessary for the implementation of new technologies and lack of knowledge in the area	Ribeiro (2017), Romero et al. (2016)

(continued)

Table 2 (continued)

Perception	Interview	Literature
OHS	Main non-compliance within the scope of OSH: lack of verification of equipment safety, which is quite serious since many of the work accidents result from pinching of the upper limbs	Badri et al. (2018), Bonekamp and Sure (2015), Leso et al. (2018)
	Activities in the field of OHS: proactive attitude towards safety and training people, in order to instill safety thinking and practice. On this basis, they will be able to act, accept safety processes and procedures, as well as apply the practices and methods of effective implementation of Safety and Health Management, especially among the resistant, the undecided and outside the Organization	Badri et al. (2018), Leso et al. (2018), Oliveira (2020), Ramos (2019), Santos et al. (2018), Severo (2018), Xavier (2019)
	Main risks: musculoskeletal injuries, moving parts, cuts/traps in the hands/upper limbs between moving elements, and chemical and physical risks	Agência Europeia para a Segurança e Saúde no Trabalho (2021), Costa (2017), Sigga Technologies (2019)
	Unsafe acts: overconfidence and non-compliance with established rules	Çaliş and Buÿükakinci (2019), Costa (2019), Occupational Health and Safety (2015), Ramos et al. (2020), Santos et al. (2018)
	With the introduction of I4.0 technologies nothing will be changed as this is due to cultural issues, but many of the situations in which there is disrespect/non-compliance will be overcome by vision systems	Barreto et al. (2017), Dalkir (2017), Javaid et al. (2022)
	In addition to psychosocial risks, no new risks are associated with I4.0, since its implementation is already carried out with people's prevention in mind	Badri et al. (2018); Bonekamp and Sure (2015), Leso et al. (2018), Xavier (2019)
	OHS technicians should follow this evolution, in order to dedicate themselves more to people's behavior and to obtain more know-how through research. As for the involvement of workers, ISO 45001 requires information and training of workers to identify risks and enable the success of a health program	Oliveira (2020), Severo (2018)

(continued)

Table 2 (continued)

Perception	Interview	Literature
	Advantages: reduction of certain risks, training necessary to perform certain tasks, reduction of accidents due to more automated processes, more interactive (but more isolated) work, smart PPE and reduction of musculoskeletal injuries Disadvantages: risk of making jobs more static/sedentary, which could lead to other ergonomic risks, increased psychosocial risks, invasion of privacy, reduced human contact and unemployment	Barreto et al. (2017), Dalkir (2017), Ramos (2019), Ribeiro (2017)

of each moment. The definition of OHS objectives must be adequate with the evolution of technologies because the risk that existed before isn't the same, and new risks arise with I4.0.

3.2 Answering Research Questions

The three research questions initially posed can now be answered:

1. What are the dimensions of an OHSMS that will evolve in an I4.0 context?

The dimensions of an OHSMS that will evolve in the context of I4.0 will be document management, corrective and preventive actions, awareness, communication, policy, worker participation, identification of hazards, the definition of OHS objectives and audits. Workplaces will be safer and healthier organizations in order to prevent occupational injuries and illnesses and improve performance. There will be a need to reinforce worker participation and involvement, as well as meet worker and stakeholder needs and expectations. Top management will have active participation, being responsible for the effectiveness of the management system, highlighting the importance of the need to take measures, both for risks and opportunities for improvement, in order to optimize the capacity of the management system.

2. How is this evolution envisaged?

Key concepts focus on augmented reality, autonomous robots, industrial automation, and artificial intelligence. This evolution will focus on six pillars that are seen as essential for a company: human resources, strategy and organization, the smart factory concept, smart operations, smart products, and data-driven services. Companies will have to assess whether the skills of the human resources available within the company will be sufficient for the transition and implementation of the I4.0 concepts or if it will be necessary to recruit specialized people and/or even train the human resources that already exist in the company, to adapt them to this new industrial reality. It will be necessary to know to what extent I4.0 is anchored and implemented in the company's strategy, as it will require a large investment, highlighting innovation, which will be the key to highlighting the market. Companies will have to find out to what extent they have a digitally networked and automated production through cyber-physical systems. Intelligent operations will have to be defined and, for this, it will have to be verified to what extent the company's processes and products are digitally mapped and can be controlled through information and communication technology systems and algorithms in an increasingly virtual world. In the development of intelligent products, it will be necessary to verify the extent to which they can be controlled by information technologies and communicate and interact with higher-level systems along the value chain, in order to be able to analyze the data during use (product traceability). Data-based services should offer services that can only arise through the network of products, production, and customers.

3. What is the state of readiness of companies with OHSMS to face the challenges posed by the I4.0 concept?

Most companies aren't prepared to face the challenges posed by the I4.0 concept as the standard doesn't contemplate this new industrial revolution. There will have to be an adaptation of the standard to the new work context.

4 Conclusions

The implementation of the I4.0 will be a long way, an evolutionary and adaptive process, and the production will be very technological, where the first step, digitization, has already been verified. I4.0 updates are still far from being practiced or accessible to most companies, although there is some progress and development in this direction. With this industrial revolution comes the need to renew the structures that manage organizational processes, namely integrated management systems, and make them able to face all changes. The young generation will be an asset in this new industrial era, as it is a generation that was already "born" with technology incorporated.

In this transition, the main obstacle is centered on legislation, since it is extensive and isn't keeping up with industrial developments, highlighting the directives (Work Equipment Directive through Decree-Law 50/2005 and Machinery Directive through the Decree-Law 103/2008). Other difficulties faced by the companies were the high capital needed for the initial investment, the difficult access to know-how (lack of workers with knowledge or ability to work with the technologies) and the impact that this will have on current production (stops and time non-production).

As for the future of employability and the content of work, companies will start to give people more time (workers will have more time, will be freer, believing that daily working hours will be reduced), resources will be optimized in detail and people will be able to give more detail to something they couldn't before (they will be able to stop, study and suggest to improve), jobs will no longer have too heavy tasks and will be safer, and there will be a change in worker's skills (preparing people for the new reality, not expecting a decrease in effective workers). The main risks identified continue to be musculoskeletal injuries, mainly caused by repetitive movements, which tend to decrease due to the investment of companies in I4.0 and people on the move where augmented reality, still in the development phase, will have a significant impact positive in claims.

Most work-related accidents continue to result from unsafe acts and the most common unsafe act is overconfidence that leads to non-compliance with established rules, something that is part of being human, being what most contributes to serious accidents. In order to comply with a set of rules and principles, it is essential to make people aware of the need to change some behaviors to prevent occupational risks.

In this new industrial context, it is estimated that the psychological burden will be greater than the physical burden, as workers are expected to act on their initiative, have excellent organizational skills and have more responsibilities. There will be a greater demand for new and trained workers due to the need to deal with the digital world, which is generally simpler for younger generations, leading to a demographic change in companies.

Regarding safety management, OHS technicians must follow this evolution, to dedicate themselves more to people's behavior and to obtain more know-how through research. In a management system, all information must be documented and with I4.0 it becomes available in digital form. Audits, which aim to measure the effectiveness of the system and its improvement over time, are now carried out online since all information can be accessed digitally in real-time.

Communication can also be elaborated with another type of technology, much more appealing, in order to capture the attention of those involved. The awareness of workers will be carried out through augmented reality, which allows the integration of virtual elements or information to real-world views through a camera and with the use of motion sensors.

It will be necessary study the impact that this new technological revolution will have on OHSMS, being necessary to identify new risks and develop new evaluation methods.

Continuing the investigation of this study, the levels will be validated by a focus group specialized in the area, weighting algorithms will be developed, each dimension will be validated/weighed through the application of a questionnaire and the sample of interviewees under study will be increased.

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Characterisation of Accidents at Work in the Manufacturing Industry: In the Pursuit of Their Prevention

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Abstract 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. Accident research aims to understand accidents, characterise them, and search for their causes to implement preventive actions. Thus, this study will search for relevant information about the characterisation of accidents at work in the manufacturing industry pursuing their prevention. Following the guidelines of PRISMA Statement, this review aims to obtain relevant information about the portrayal of accidents at work in the manufacturing industry. Three databases, namely: Scopus, Web of Science, and IEEE Xplore, are used to develop a data search based on the defined keywords. A total of 6 publications are included in the scoping review. Topics such as sample characteristics, context assessment, research methods and major study conclusions are analysed. Accidents at work were studied in different manufacturing companies. The main types of accidents found were: "falls", "caught in, on and between", and "got cut". The top causes for accidents were: "human element"; "nature of work"; "poor management" and "equipment". Proactive actions such as training, effective leadership, equipment management and work reorganisation are recommended to identify risk situations upstream.

Keywords Manufacturing industry · Work accident · Occupational accident · Prevention

1 Introduction

Industrial companies and manufacturers must be competitive as the world is changing and companies are facing new challenges (Katsakiori et al. 2010; Zare et al. 2016).

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The prevention of accidents at work is the key to the effective safety management of any industry, reducing costs and consequently increasing competitiveness.

An accident at work is defined in ESAW (European Statistics on Accidents at Work) as a discrete occurrence during labour which leads to physical or mental harm. The data shall be collected, for the entire workforce, for fatal accidents at work and accidents at work resulting in more than three days of absence from work. This reporting uses administrative sources complemented with relevant additional sources whenever necessary and feasible for specific workers or national situations. A limited subset of primary data on accidents with less than four days of absence may be collected, when available (it is optional), in collaboration with the International Labor Organization (ILO). Accordingly, to the above referred ESAW methodology, a fatal work accident is an accident resulting in the victim's death within one year (after the day) of its occurrence (Eurostat 2022).

The Workplace Safety and Health Institute (WSH)'s report estimates that 2.78 million deaths occur annually across countries attributed to work. According to ILO, 317 million work accidents are reported annually (Gómez-Ceballos 2016), and the economic burden of poor occupational safety and health practices is estimated at 4% of global Gross Domestic Product each year, and the human cost is vast (Hämäläinen et al. 2009; ILO, n.d.; Mekkodathil et al. 2016; Takala et al. 2014).

The manufacturing industry is one of the most dangerous sectors due to occupational accident frequency (Nenonen, 2011). In 2017, this sector had 15.0% of fatal work accidents in the EU-28 (Ivascu and Cioca 2019). Nevertheless, few studies record the number of occupational accidents in this industry (Mutlu and Altuntas 2019). Occupational accidents are undesirable events that cause damage to individuals, institutions and society as a whole (Mutlu and Altuntas 2019). Therefore, preventing and reducing accidents and injuries save workers from suffering and help reduce many direct and indirect financial costs to organisations and society (Khahro et al. 2020). The country's occupational health and safety policies and other laws and regulations lead to proactive practices to prevent occupational accidents, occupational diseases, and possible undesirable situations (Mutlu and Altuntas 2019). Employers must implement education and training in worker safety to prevent accidents, and safety rules should be in place. Self-inspection work must be a reality, and occupational health and safety personnel must be appointed. Inspection, maintenance and protective tasks must be performed concerning potential hazards (Cheng et al. 2010).

Accident participation is crucial, and communication between supervisors and workers may benefit safety performance (Liu et al. 2015; Sampson et al. 2014). Accidents cannot be forgotten with time. They must be identified and passed to all interested parties since organisations have no memory; only people (employees) have, and they move on taking that information with them (Kletz 2003). 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). Behaviour-based safety (BBS) is the main strategy for reducing unsafe behaviour and thus lowering the accident rate (Askaripoor and Jafari 2015; Nunu et al. 2018). Workers need to feel involved in the whole process of accidents' prevention: they are an important source of information. Participation generates a feeling of ownership of the new ideas and motivates workers into the process, rather than having someone above dictating it (Getty and Getty 1999).

Accident research aims to understand accidents, characterise them, and search for their causes. Thus, preventive actions can be implemented (Jacinto et al. 2009); this is generally done by searching for their causes. Therefore, adequate prevention measures can be designed.

Therefore, this scoping review's main objective is to search for relevant evidence on fieldwork on the characterisation of accidents at work in the manufacturing industry to pursue their prevention.

2 Materials and Methods

This scoping review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Statement.

This scoping review focuses on literature that addresses the most relevant information about the characterisation of accidents at work in the manufacturing industry to pursue their prevention. First, a search was specified with selected keywords categorized in the following combination: "manufacturing industry"; "manufacturing sector"; "accident at work"; "work accident"; "occupational accident"; "prevention". This combination was formed to find results that relate the number and type of accidents at work in manufacturing companies with the prevention of future work accidents.

One combination was formed, and 109 first items were found from the three databases (91 from Scopus, seven from Web of Science and 11 from IEEE Xplore.

The search was initially conducted by inserting the combination and selecting, when possible, "Article title, Abstract, Keywords". Three phases of exclusion were applied in this process.

A first phase was applied through the search filters of the databases to obtain relevant results. The first criterion was the "Date": selected years were from 2010 to July 2020 (but if an article from a recognised author would not follow this criterion but were found interesting, it would still be selected). The second general criterion was "Document type": only Articles and Reviews were filtered. However, reviews were not considered later in the final selection but as a source of complementary information. When applying the "Source Type" filter, only Journals were chosen. All articles but those written in English were excluded. Another criterion was that if the article could not be retrieved, it was also excluded (4 articles found by Scopus were excluded due to this criterion). The same criteria (excluding the date, as older articles from reference authors were also included) were applied to 4 additional records identified through other sources. As a result of this, 53 items were gathered.

Since some of the above items were duplicates, all these repeated articles were removed in a second phase, leading to 49 publications.

Lastly, the third phase in the screening process ("on topic") followed these guidelines: Title and abstract were analysed. Studies were automatically excluded if one of these conditions was met: (1) Studies that do not apply to the manufacturing industry; (2) Studies that only consider qualitative data (not field studies).

From this phase, a total of 20 articles were selected.

Full-text analysis of the selected studies was retrieved and considered whenever the title and abstract did not provide enough information to determine if the selection criteria were met.

If one or both of the following conditions are not met, articles would be deleted: Studies should explicitly refer to the number and/or type of accidents at work; studies should be in the manufacturing industry.

After a full-text assessment, 14 articles were excluded due to: 10 of them not being a quantitative study (not a field study), and four did not evidence any accidents' at work characteristics and/or number. This process led to a total of 6 articles.

3 Results

Some general characteristics of the six selected are presented in Table 1.

All the six field studies ("on-situ", quantitative studies) have the objective explicitly or implicitly to identify the number and/or type of accidents. Some also aim to reach the leading direct or indirect causes of accidents (Jacinto et al. 2009; Katsakiori et al. 2010; Khahro et al. 2020), and another suggests corrective actions (Khahro et al. 2020). The questionnaire was the main source of research, as only Katsakiori et al. (2010) have chosen to obtain freshly made reports of previous accidents. The different results found will be discussed later.

4 Discussion

The expected outcome of this research is the following:

- The search for relevant information about the evidence on fieldwork on the characterisation of accidents in the manufacturing industry to pursue their prevention.

In Hussain Khahro et al.(2020), the main accidents identified are: "fall from elevation", "electrocution from faulty tool", "snakebite", "caught between", and "fall at ground level". Apart from the "snakebite", which is very specific to the country where the study took place (Pakistan), other studies (Holcroft and Punnett 2009; Yamauchi et al. 2019) also refer to "falls" as one of the main types of accidents. Suppose a "fall" is intended as intimately linked to "movement". In that case, these figures are also corroborated by Eurostat (2020). It refers to "movement" as one of the main activities executed immediately before or during the occurrence of an accident.

Table 1 Some general and specific characteristics of the six studies

Author	Year	Country	Type of manufacturing industry	Some specific characteristics mentioned
Khahro et al.	2020	Pakistan	Cement industry and steel industry	Some references to the professional experience of participants
Yamauchi et al.	2019	Japan	Indiscriminate manufacturing companies	Three thousand eight hundred eighty-eight workers in the manufacturing industry. References to the gender and the mean age, number of years of education
Nunu et al.	2018	Zimbabwe	Cement industry	Forty respondents, with 20 employees, followed/observed closely. References to work shifts, existing safety procedures
Katsakiori et al.	2010	Greece	Food and Beverages Industry	
Jacinto et al.	2009	Portugal	Food and Beverages Industry	References to the gender, the mean age, work categories
Holcroft and Prunnett	2009	USA	Wood product manufacturing	408 participants. References to the gender, the mean age, work shifts, workers 'origin, work categories, professional experience of participants

Holcroft and Punnett (2009) also mentions "struck against or by", "overexertion", and "caught in or abraded". This last type is also corroborated with: the "caught on, and between" in Khahro et al. (2020), the "got caught in/between " in Yamauchi et al. (2019) and with the "impacts with/against a stationary object or structure" of Jacinto et al. (2009). The "Struck against or by" of Holcroft and Punnett (2009) may be related to the "contacts with sharp, pointed, rough material agents" of Jacinto et al. (2009), with the "got cut" of Yamauchi et al. (2019) and with the "Struck against", of Hussain Khahro et al. (2020). These results follow the findings from Eurostat (2020).

In Khahro et al. (2020), direct and indirect causes are related mainly to the human element and the nature of work. Afterwards comes poor management and finally causes related to equipment. Those results are also found in Jacinto et al. (2009), with 65% of human failures and 25% due to faulty equipment and buildings. Human failures are also seen as one of the leading causes of accidents at work in Carrillo-Castrillo et al. (2013) designated by "personal factors". Accordingly to Lal (2014), unsafe or at-risk behaviours of employees are the root cause of most accidents. Nunu et al. (2018) focus on decreasing the accident frequencies by implementing the BBSI (Behaviour-based Safety Implementation) card system. This system is proposed to reach zero injuries and zero fatalities. Nunu et al. (2018) point out a significant reduction in accident and injury occurrences after introducing the BBSI card system. Thus, this study corroborates all the previous studies that point to a human factor. If the company invests in a safety model based on the workers' behaviour, that will cause a decrease in that workplace factor. Andriulo and Gnoni (2014) prevent accidents by managing near misses. This study confirms that most hazardous working areas based on injury rates are also characterised by a lower tendency to record precursor events, especially ones based on incorrect human behaviour (i.e., unsafe acts). Nunu et al. (2018) state that BBSI should not be voluntary but mandatory. This study also demonstrates the importance of existing safety programs that could target the behaviour of employees to create a safe working attitude and behaviour, yielding positive results. Human behaviour should be integrated into existing safety programs for optimal results.

Relating to "Equipment", Katsakiori et al. (2010) refer that 57.5% of accidents are due to "operating a machine", 10% due to "working with handheld tools", and 5% due to "driving/being on board a means of transport or handling equipment" (though it may not be totally due to the equipment itself). Eurostat (2020) refers to operating a machine as the main activity being done just before or during an accident. This report also mentions that for the manufacturing industry, "lost control: machine/tool, transport/handling equipment" is the primary type of accident, which corroborates previously presented studies that refer to both "Equipments" and "human element" as two of the main types of accidents. Carrillo-Castrillo et al. (2013) also mentions "equipment" and "safety management" as two of the leading causes in the manufacturing industry. Jacinto et al. (2009) refer to workplace factors, placing poor management in latent conditions as "Procedures and level of supervision" (25%) and in "General management (concerning all-embracing top-management functions)" (13%). The cause "nature of work" can also be found in Jacinto et al. (2009), designated by "problems directly related to the task/job" (48%). As Jacinto et al. (2009) note, in SMEs (small and medium enterprises), the main problem associated with management and supervision was the "non-existence of procedures or no instructions". In contrast, large organisations were more likely to have "inadequate/ badly designed procedures". In this study, a lack of risk assessment is also noted linked with mismanagement and accidents at work. The training was also a concern in SMEs and large organisations (Jacinto et al. 2009). There was a lack of formal training in SMEs, where the oldest workers "taught" the newly hired people. Holcroft and Punnett (2009) also refer to a need for training. Reorganisation of work as an increased risk in manufacturing has been reported with greater labour intensity by Grunberg (1983). Employers must implement education and training in worker safety to prevent accidents, and safety rules should be in place (Cheng et al. 2010).

Regarding the magnitude/number of accidents at work, Yamauchi et al. (2019) refer to 155 injuries reported by 4% of the participants in the past year. Jacinto et al. (2009) refer to 53% of wounds and superficial injuries as the main consequence of accidents at work, followed by 23% of muscular-skeletal injuries (dislocations, sprains and strains). The most frequent affected body parts are upper extremities, with 47 and 13% for lower extremities. Holcroft and Punnett (2009) also confirm sprain/strain joint inflammation as one of the main consequences, with a frequency of 54%, followed by dislocation; fracture (13%).

Katsakiori et al. (2010) refer to the victims' ages between 26 and 35 years. Shannon et al. (1997) also refer to a negative correlation between age and accident rate. Katsakiori et al. (2010) also mention that 57.5% of the accidents occurred to labourers (unskilled workers).

Most accidents occur to unskilled workers. However, the most frequent activity performed by the victim just before the accident was using a machine which requires a well-planned work design and, subsequently, specific training. This fact confirms the first hypothesis of this study: "Accident causation due to training inadequacy in the manufacturing sector indicates the lack of measures in terms of the work design". Ergonomics is crucial to achieve good design and to assure that information on how to work safely is well presented to workers, contributing not only to a decrease in work accidents but also to an increase in productivity, among others (Hovanec et al. 2014; Maudgalya et al. 2008; White 2015). Proper training and refresher training can support the comprehension of work design principles (Fu and Zhu 2013; Katsakiori et al. 2010). Worker participation increases and generates a feeling of ownership of the new ideas and motivates workers into the process, rather than having someone above dictating it (Getty and Getty 1999). This argument can also be used to corroborate the confirmed second hypothesis of Katsakiori et al. (2010): "Accident causation due to provision of unsafe equipment to the employees in the manufacturing sector indicates the lack of measures ensuring active employee involvement in job and task issues". Indeed, there is a negative correlation between the provision of unsafe equipment with employee involvement. In Katsakiori et al. (2010) study, most equipment were old and without safety features. To prevent accidents, employers must implement maintenance (Cheng et al. 2010). Workers can play a pivotal role in participating in decreasing accidents at work. If employees trust the efficacy of safety procedures and approaches, the safety system in an organisation improves (Singh and Verma 2019). Workers' participation is fundamental, but it will only be effective if they feel their opinion is considered by top management and used to improve safety systems (Van Der Schaaf and Kanse 2004). In Holcroft and Punnett (2009), about 50% of participants considered having negative skill utilisation (actual educational levels exceeded the job requirements). Employees' knowledge about accidents at work and their prevention must be regarded as a repository (Kletz 2003). Human capital should be valued.

5 Conclusions

Despite not many "on-field" studies in the manufacturing sector addressing this issue, these six articles demonstrated that it is imperative to characterise accidents in the manufacturing industry.

Similar accidents found were: "falls", "caught in, on and between", and "got cut". The top causes of accidents were the "human element", "nature of work", "poor management", and "equipment".

Once again human factor emerges as essential in an organisation. Workers must be involved in improving their workplace. Thus, they must be adequately trained. Only well-trained employees will be able to participate in decision-making. It is then essential that the leadership embrace the workers' suggestions and be receptive to changes. Thus, workers will feel more motivated to participate. Recommendations of changes in proactive ergonomics, between other safety areas, privileging workers' wellbeing, and reducing work-pace will help ensure that work accidents are eliminated or substantially reduced.

Simulating work and, thus, anticipating risk can lead to system improvements. Preventive maintenance of equipment must be considered.

It is fundamental to characterise work accidents in the manufacturing industry, introducing a systematic terminology to compare the different results in the literature effectively. An adequate record of accidents at work, compatible with the company's safety culture, should be made, interviewing the worker (victim) and/or workers that witnessed the accident. The mandatory workers' or their representatives' consultation must be well-conceived to be effective. Thus, it will provide helpful feedback from workers' know-how. Therefore, risk situations can be foreseen, and proactive actions taken. For future works, it is recommended that more studies on this subject are carried out in the manufacturing sector to consolidate and update the existing ones.

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The Resilience Assessment Grid in Day-To-Day Work

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Abstract The complexity of socio-technical systems (SS) requires tools that facilitate the understanding of their behaviour and daily performance under the perspective of safety management, therefore Resilience Engineering (RE) and its tools can help with this purpose. In this study, a literature review about the application of the Resilience Assessment Grid (RAG) in different sectors in the last decade is performed. The information was selected from the following databases: Scopus, Wos, ScienceDirect and PubMed, guided by the PRISMA methodology using search criteria by title, abstract and keywords. The most used basic tool is the RAG, which applied individually or in combination helps to understand the behaviour of these complex socio-technical systems (CSS) under the perspective of safety management. The tools used in the last decade in RE studies with the RAG in different sectors are presented chronologically. Safety-II could be considered as a suitable management system at present, where the RE helps to measure resilient performance potential in the CSS, but not resilience per se, using the RAG individually or in combination, with the basic number of questions or structured in a customised way.

Keywords Safety I · Safety II · Complexity · Resilience engineering · Tools

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1 Introduction

1.1 Background

Safety management has traditionally focused on adverse outcomes such as accidents and incidents as the result of causality, which can sometimes be true if the system is not complex, but today's socio-technical systems (SS) are complex and involve strong interactions between humans, technical, and the organizational aspects (Patriarca et al. 2018). The safety management has evolved over time from a conception of preventing something from going wrong to now trying to make sure that everything goes right as much of the time as possible, with an approach to daily work starting from Safety I as a reactive safety focused on the absence of unacceptable harm at all costs, a less manageable situation in complex socio-technical systems (CSS) (Hollnagel 2017), and proposing in a second phase a proactive management with Safety II, understanding how CSS mostly succeed but sometimes fail (Martins et al. 2022). It is more protective safety management with a net focus on how things can go right rather than the traditional approach of only eliminating things that go wrong, with the aim of developing an organization's potential for resilient performance from how the organization responds, monitors, learns and anticipates (Hollnagel 2017) and to analyse both what is going well and what is not going according to plan in a holistic approach as is the case with CSS (Ratnitsky et al. 2021).

The term "complex" is related to what is "interwoven" and in a SS there are hardly identifiable patterns with dynamic, non-linear and unpredictable behaviours, therefore a CSS cannot be known in its totality with the impossibility of an exhaustive description (Peñaloza et al. 2020; Stanton 2014), which can be analysed using tools such as the Functional Resonance Analysis Method (FRAM) (Furniss et al. 2016) and which can be understood in the first instance with the concepts of Resilience Engineering (RE) as well as team thinking processes to improve the ability to cope with the unexpected as for example in the activities of the railway sector (Siegel and Schraagen 2017) or the vessel traffic system which analysed the interactions and identified key factors and proposed guidelines for making the system resilient (Xu et al. 2017), in 2018, a framework was proposed to support the design of SS combining knowledge from Lean and RE in the health sector to make this process safe and efficient (Rosso and Saurin 2018), given the complexity of the construction sector, research designs based on surveys of construction project managers were developed to determine the results of psychological, behavioural and contextual resilience in order to evaluate the safety culture with respect to resilience (Trinh et al. 2019), furthermore, it was proposed to conceptualise the resilient safety culture of construction projects by integrating the principles of RE into the concept of safety culture (Trinh and Feng 2019) a meta-model with a focus on the behaviour of the resilience process tested in a crisis was also proposed through a qualitative and quantitative study applying the system dynamics approach that proposed a score to assess the resilience of SS processes and then to rank them (Said et al. 2019), in the aviation sector modern safety theory dealt with the systemic approach supported by several models such as FRAM or System Theoretical Accident Model and Processing (STAMP) with the basis on the concept of functions as used in the theory (Lališ et al. 2019) and in 2021 support was delivered based on the FRAM to generate software to help manage complexity in the CSS with the support of RE (Carvalho et al. 2021), these assumptions about complexity, as well as those about the nature of safety management, have been recognised as the theoretical basis for the definition of the scientific field of RE (Patriarca et al. 2018).

RE is therefore the ability to design systems that are resistant to disturbances. In 2017, it was mentioned that resilient organisations can withstand and learn from internal and external disruptions whose effects can be reduced through process improvement, worker specialisation and information sharing (Darrow and Eseonu 2017), was envisioned as a proactive approach to safety management (Rubio-Romero et al. 2018) that considers the development of capabilities to adapt to complexity (Rigaud et al. 2018) by dealing with variability in day-to-day activities (Patriarca et al. 2018) with studies carried out in the construction sector to improve resilient safety management (Pardo-Ferreira et al. 2020) that at the organisational level, resilience is not measured, but the potential for operational resilient performance against the four key pillars of learning, responding, monitoring and anticipating (Klockner and Meredith 2020) and that despite the studies carried out, the RE is a novelty in the safety of CSS such as in the railway sector where tests were developed to determine an improvement in the resilience of this system (Smoczynski et al. 2020) therefore, the RE helps to learn about the work in everyday CSS as in the health sector what with an interview and qualitative analysis the resilient functioning of people, machines and the organisation as a whole was determined, furthermore a Resilience Mapping Framework (RMF) was developed which basically is a synonym for the Resilience Assessment Grid (RAG) (Hegde et al. 2020) and in the case of health care systems in relation to COVID-19 have been used with the perspective of improving system performance where a survey with the Resilience Analysis Grid (RAGX) was used, in which organisational resilience was analysed based on the four pillars mentioned above that influence patient safety (Bertoni et al. 2021), highlighting technological support as an important element, heuristic models are projected that gathered information from the FRAM method, increasingly adapted to CSS, to obtain functional and non-functional requirements and to be able to build software that fits these systems (Carvalho et al. 2021). RE-related tools are presented according to their chronological appearance:

- Resilience Analysis Grid (RAGX) (Rigaud et al. 2013).
- The Critical Incident Technique (CIT) (Hegde et al. 2015).
- Critical Decision Method (CDM) (Hegde et al. 2015).
- Resilience Assessment Grid—State Assessment Tool (RAG-SAT) (Patriarca et al. 2016).
- Functional Resonance Analysis Method (FRAM) (Hollnagel 2017) (de Linhares et al. 2021).
- Resilience Assessment Grid (RAG) (Hollnagel 2017) (Falegnami et al. 2018).
- Analytic Hierarchy Process (AHP) (Falegnami et al. 2018).

- Resilience Analysis Grid (RAGX) & Functional Resonance Analysis Method (FRAM) (Patriarca 2018).
- Metamodel of Sociotechnical System Processes (MSSP) (Said et al. 2019).
- Technical, Organizational and Environmental (TOE) Framework—(Peñaloza et al. 2020).
- Resilience Mapping Framework (RMF) (Hegde et al. 2020).

Given the importance of RAG by observing its applications in various sectors over the last decade, the following question could be posed to guide this study: How has RAG alone or in combination served to measure organisational resilience in a CSS, considering the system's own characteristics to be used as a decision support tool, when addressing criticalities under the perspective of safety management?.

This chapter first introduce the background of CSS as the starting point to understand how can improve the safety systems with RE and RE's tools. Next a glance to the related works about RAG's application in the last decade. Last part of the chapter summarizes the contributions RE can make to the CSS with RAG's application.

1.2 Resilience Assessment Grid (RAG): A Glimpse on Related Works

RAG aims to measure the potential for resilient performance of an organisation's day-to-day work based on the four key pillars of learning, responding, monitoring and anticipating, that since 2013 RAGX had been used for the generation of tools for profiling the resilient performance of an organisation in offshore oil and gas sectors, in operations and maintenance planning, to assess the impact of the integrated planning process and it has enabled performance to be profiled in terms of the skills that characterise a resilient organisation in order to increase its flexibility and robustness, therefore, the characteristics of resilience in offshore companies could be seen as an indicator of the system's ability to cope with the variability of organisational performance (Apneseth et al. 2013), the use of the RAGX in the railway sector has contributed to a process dedicated to the development of safety performance indicators based on the RE which is given firstly by the RAGX and then by the assessment developed in the context of the train departure process (Rigaud et al. 2013), the RAGX has had as its main objective to support the assessment of the key capabilities of a resilient organisation in the railway sector and has helped to develop an instance to support railway safety management with a set of key indicators and a methodology to collect and analyse the information (Rigaud et al. 2018). Modern CSS have had to be resilient to meet the variability of day-to-day activities considering resilience at the organisational level as a combination of four pillars to achieve resilient performance, therefore, RE is considered as a paradigm for safety management that focuses on coping with complexity to achieve success with the support of tools such as the RAGX especially in initial phases and that from the four pillars it has been possible to define a semi-quantitative analytical framework to measure organisational resilience in CSS as is the case in the health sector by combining RAG with AHP (Patriarca et al. 2018).

In 2015, RAGX in combination with the CIT and CDM has been adapted to develop a health care resilience interview script using the semi-structured multi-stage format of the CIT, this script has been revised based on responses as well as feedback from human factors and RE experts and then successfully applied to doctors and nurses at various levels (Hegde et al. 2015).

In 2016, for the Air Traffic Management (ATM) system, a new perspective on safety management has been required, reinforcing Safety II in which RAG has been used to develop a new method called RAG-SAT that combines the principles of Safety I and Safety II with a semi-quantitative analysis of system performance integrating technical, human, procedural and environmental aspects (Patriarca et al. 2016), in 2017 Erik Hollnagel highlighted the difference between Safety I and Safety II with the aim of developing an organisation's potential for resilient performance by presenting a tool with a holistic approach to Safety II management called RAG, in which he explains the principles and how resilience potentials can be developed by looking at four sets of formative and diagnostic questions that can be adapted to any organisation, underpinned by each of the pillars of the RE principles (Hollnagel 2017), in the same year RAGX in the health sector has been adapted to a survey to assess resilience in healthcare undergoing lean improvements whose findings are beneficial to the external patient wellbeing and financial domain, as well as the internal linked with all employees supporting management to reduce physician burnout (Darrow and Eseonu 2017).

In 2018, due to the evolution of safety and risk, it was felt that technology, human factor and organisation required support from RE and its tools to understand the adaptive dynamic behaviour of systems with tools such as FRAM and from socio-technical perspectives with RAGX in the aviation industry (Patriarca 2018), in order to make the shift from a cause-effect approach to a systemic approach in the health sector, the RE is used with the RAG combined with the AHP to measure resilience potential with a cross-country survey whose data were statistically analysed to confirm the design of the questionnaire, which applied allowed to assess indirect measures of resilience confirming the relevance of a structured weighting approach based on the AHP whose statistical analysis allows to promote the use of the centralised resilience questionnaire to support standardised analyses (Falegnami et al. 2018).

In 2020, RAG was applied in a land transport organisation in Australia, it has been required to improve its resilience potential and has had to start by measuring its operational safety performance against the four fundamental pillars of resilience and then provide recommendations on how to improve organisational resilience potentials to cope with system variability and operational demands (Klockner and Meredith 2020), and even the RAGX could be adapted (tailor-made) to address the lack of organisational resilience indicators in the water sector in England and Wales and proved to be a simple, flexible and easy to use tool whose results can be translated into clear graphs with accurate data (Rodríguez et al. 2020), in the same year, RAG is customised for application in the health sector and the questionnaire was used for focus group interviews to identify strengths and weaknesses in hospital emergency departments that could contribute to the improvement of resilient health care (Chuang et al. 2020a, b), highlighting the importance of RE which has been postulated as an alternative to safety management over the last decade in many areas, using the RAG in a customised way in the health sector whose questionnaire was accepted after a field test and whose results represent a snapshot of organisational resilience under specific conditions (Chuang et al. 2020a, b), on the other hand, RAG combined with the TOE contributes to identifying improvement opportunities for safety performance measurement systems in the construction sector by providing a model that explains the connections between the main constructs covered (Peñaloza et al. 2020).

In 2021, RAG in the Indonesian maritime sector has contributed to the analysis of safety resilience implementation through the use of interview guides in which it was determined that the focus of safety implementation continues to be on accident prevention and control (Djunaidi et al. 2021) in the same year, the RAG in a comparative analysis with STAMP and FRAM have analysed a significant accident of a nuclear submarine from a systemic perspective whose results favour the staggered use of the three approaches throughout the CSS's life cycle in order to maximise the potential of each tool in the treatment of technical and management aspects (de Linhares et al. 2021) in addition, RAG as the third stage within the RE-based framework for assessing safety performance measurement systems (SPMS) in the Norwegian construction sector proposed a questionnaire for interviews, observations and document analysis, the results of which could highlight that complexity can hinder SPMS (Peñaloza et al. 2021), in the same way a study was also carried out with the aim of improving the organisation's response capacity to COVID-19 in the aviation sector, where the RAG was applied and evaluated by 42 experts in the field of aviation safety using the Delphi technique (Kim 2021) in addition, RAGX applied in the health sector under a quantitative methodological approach has made it possible to describe the relationship between resilience potentials and aspects of health and safety, as well as their consequences on quality and resilience in health systems, highlighting anticipation, monitoring, global resilience and occupational safety and health as the variables that need more attention in these health systems including providing inputs for a practical and a theoretical application (Bertoni et al. 2021), therefore, as the CSS are dynamic and changing drastically in this new decade, they must be supported by the RE and its tools, specifically the RAGX and FRAM (Patriarca 2021), finally, RAG in the hospital sector was used to conduct expert interviews and then a focus group to determine the key measures for the integration of the Safety II approach in daily practice, the results of which determined that the departmental teams partially follow the principles of Safety II, while three of the pillars, with the exception of monitoring, were satisfactorily fulfilled (Ratnitsky et al. 2021).

2 Materials and Methods

The databases used were Scopus, Wos, ScienceDirect and PubMed, guided by the PRISMA methodology, the following search criteria were used: title, abstract and key words: “Resilience Assessment Grid” OR “Resilience Analysis Grid”. A second phase of contextualisation was used: “Complex Sociotechnical Systems” AND “Resilience Engineering”.

3 Results

The use of the RAG in offshore companies has made it possible to profile performance in terms of the skills that characterise a resilient organisation in order to increase its flexibility and robustness.

The use of the RAG in the railway sector has contributed to a process dedicated to the development of safety performance indicators based on the RE which is given firstly by the RAG and then by the assessment developed in the context of the train departure process.

The main objective of the RAG has been to support the assessment of the key capabilities of a resilient organisation in the railway sector.

Modern CSS have had to be resilient to meet the variability of day-to-day activities considering resilience at the organisational level as a combination of four pillars to achieve resilient performance from monitoring, responding, learning to anticipating, therefore, RE is considered as a paradigm for safety management that focuses on coping with complexity to achieve success with the support of tools such as RAG especially in early phases.

The RAG in combination with the CIT and CDM has been adapted to develop a script for interviews on resilience in health care using the semi-structured multi-stage format of the CIT.

For the ATM system, a new perspective on safety management has been required, reinforcing Safety II in which RAG has been used to develop a new method called RAG-SAT that combines the principles of Safety I and Safety II with a semi-quantitative analysis of system performance integrating technical, human, procedural and environmental aspects.

The RAG in the health sector has been adapted to a survey to assess resilience in healthcare undergoing lean improvements whose findings are beneficial to the external patient wellbeing and financial domain, as well as the internal linked with all employees supporting management to reduce physician burnout.

In order to make the shift from a cause-effect approach to a systemic approach in the health sector, the RE is used with the RAG combined with the AHP to measure resilience potential with a cross-country survey whose data was statistically analysed to confirm the design of the questionnaire.

Organisations that have been required to improve their resilience potential have had to start by measuring their operational safety performance against the four fundamental pillars of resilience with the RAG applied in a land transport organisation in Australia.

The RAG could be adapted (tailor-made) to address the lack of organisational resilience indicators in the water sector in England and Wales and proved to be

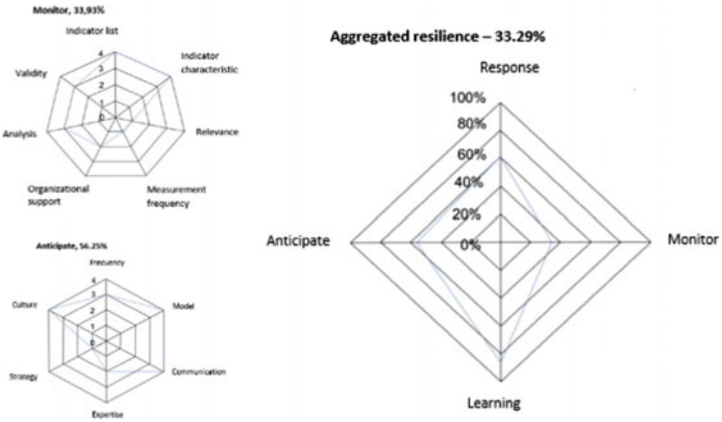

Fig. 1 Examples of potentialities radar charts and general resilience chart (Chuang et al. 2020a, b)

a simple, flexible and user-friendly tool whose results can be translated into clear graphs with accurate data (see Fig. 1).

The RAG is customised for application in the health sector and the questionnaire was used for focus group interviews to identify strengths and weaknesses in hospital emergency departments that could contribute to the improvement of resilient health care.

RE has been postulated as an alternative to safety management over the last decade in many areas, using the RAG in a customised way in the health sector whose questionnaire was accepted after a field test and whose results represent a snapshot of organisational resilience under specific conditions.

The RAG combined with the TOE contributes to identifying improvement opportunities for safety performance measurement systems in the construction sector by providing a model that explains the connections between the main constructs covered.

The RAG in the indonesian maritime sector has contributed to the analysis of safety resilience implementation, through the use of interview guides in which it was determined that the focus of safety implementation continues to be on accident prevention and control.

The RAG in a comparative analysis with STAMP and FRAM have analysed a significant accident of a nuclear submarine from a systemic perspective whose results favour the staggered use of the three approaches throughout the life cycle of the CSS, in order to maximise the potential of each tool in the treatment of the technical and management aspects.

The RAG as the third stage within the RE-based framework for assessing safety performance measurement systems (SPMS) in the Norwegian construction sector proposed a questionnaire for interviews, observations and document analysis, the results of which could highlight that complexity can hinder SPMS.

Table 1 Tools used in the last decade in studies of RE with the RAG in different sectors presented chronologically

Methods				
Sectors	Quantitative	Semi-quantitative	Qualitative	Semi-structured
1—Gas-oil			RAGX	
2—Health				CIT-CDM-RAGX
3—Air traffic management		RAG-SAT		
4—Health	AHP		RAG	
5—Aviation			RAG-FRAM	
6—CSS	MSSP-RAGX		MSSP-RAGX	
7—Construction			TOE-RAG	
8—Health			RMF	
9—Submarine		FRAM-MICMAC-STAMP-RAG		

The RAG applied in the health sector under a quantitative methodological approach has made it possible to describe the relationship between resilience potentials and aspects of health and safety, as well as their consequences on quality and resilience in health systems.

The RAG in the hospital sector was used to conduct expert interviews, which were followed by a focus group to determine the key measures for the integration of the Safety II approach in daily practice, the results of which determined that the departmental teams partially follow the principles of Safety II, while three of the pillars, with the exception of monitoring, were satisfactorily fulfilled.

Nine combinations of the tools analyzed in the RE were presented, involving the following: RAGX, CIT, CDM, RAG-SAT, FRAM, RAG, AHP, MSSP, TOE (See Table 1).

4 Discussion

The characteristics of resilience in offshore companies could be seen as an indicator of the system's ability to cope with the variability of organisational performance that is a fundamental characteristic of CSS.

The RAG helped to develop an instance to support railway safety management with a set of key indicators and a methodology to collect and analyse the information submitted.

Based on the four pillars of resilient performance, it has been possible to define a semi-quantitative analytical framework for measuring organisational resilience in CSS, as is the case in the health sector, by combining the RAG with the AHP.

The interview script on resilience in health care has been revised based on responses as well as feedback from human factors and RE experts and then successfully applied to doctors and nurses at various levels.

The questionnaire applied in the health sector allowed the assessment of proxy measures of resilience confirming the relevance of a structured weighting approach based on AHP whose statistical analyses allow to promote the use of the centralised resilience questionnaire to support standardised analyses.

The use of the RAG in a land transport organisation provided recommendations on how to improve organisational resilience potentials to cope with system variability and operational demands.

The RAG applied in the health sector has shown results that highlight anticipation, monitoring, global resilience and occupational health and safety as the variables that need more attention in these health systems, including providing inputs for both practical and theoretical application.

Safety management has evolved from Safety I to Safety II, where Safety I aims to guarantee the absence of failures at all costs while Safety II is considered to be protective with a holistic approach.

CSS is considered unpredictable because of the number of elements that make it up and have been analysed in sectors such as rail, maritime, health, construction and aviation using FRAM, STAMP and RAG, leading to the proposal of new methods and software to help manage complexity.

The adapted RAG could be tested in each of the proposed sectors to verify their effectiveness and then standardised, the minimum number of questions proposed by Hollnagel in each of the pillars of resilience could be kept as a basis, and there if it is worth increasing them but not decreasing them and it should be considered that the combination of RAG with other tools could be compared simulated in parallel in the same CSS to determine the level of resilience performance in each case.

As a limitation, isolated studies in different areas would not be sufficient to make a comparative analysis by sector.

As a further limitation, some tools such as the RAG and the RMF could lead to confusion, which upon analysis can be considered synonymous since they are based on the four basic pillars of the RE.

And the last limitation, the literature search was based on the RAGX and RAG criteria, which could be extended by using the RMF, therefore it could be considered as future research.

5 Conclusions

The monitoring capacity of an offshore organisation should enable it to identify threats and opportunities in the short term and thus be able to establish an integrated long-term plan by translating them into strategic and tactical plans.

The application of the RAG in the railway sector to study the resilience capacities of railway stations has made it possible to deduce the resilience and fragility factors of the system.

By combining RAG with AHP in the health sector, it has been possible to create a structured framework to define the resilience profile and identify the weaknesses and strengths of the system and thereby increasing the adaptive capacity to manage the system to make it resilient.

RE is still considered novel in 2020 from the railway sector, already used in the construction and healthcare sectors which with RAG and RMF analyse organisational resilience by learning from the variability of daily work in CSS, therefore RE helps to understand daily work with tools such as RAG and FRAM, thus providing an introduction to CSS.

The research reviewed in this study highlights Safety II as an appropriate management system today, in which RE helps to measure the potential for resilient performance in CSS, but not resilience per se. Using the RAG individually or in combination, with the basic number of questions or structured in a customised way, the level of resilient organisational performance can be determined based on the four fundamental pillars of responding, learning, monitoring, and anticipating.

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Designing a Safety Culture Maturity Model

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Abstract Safety culture has received increasing attention during the last decades. A recent critical review compiled previous models established for the evaluation of safety culture. A need still exists for a maturity model that covers the most important factors of the existing validated models and proposes an approach to maturity evaluation. The aim of this study is to design a new maturity model for measuring and analyzing safety culture. Fourteen safety culture maturity models that had been assessed for validity or reliability were selected, analyzed, and compared. The most common themes and evaluation criteria for safety culture were used as a basis for the new model. The five main themes of the model were communication, training, organizational learning, management commitment, and employee commitment and involvement. The model evaluates maturity by combining written descriptions of best practices and the overall satisfaction of employees in the evaluated aspects. The perspective of employee satisfaction with safety culture acknowledges the need to fit the practices into contextual needs. The model is unique because of its balance between rigor (validated content from the literature) and relevance (written evaluation levels). The model can be used as an assessment, audit, benchmarking, and improvement tool.

Keywords Safety and health · Safety performance · Maturity analysis · Performance measurement · Design science

1 Introduction

Safety culture has received increasing attention during the last decades. Studies show that there is a strong link between safety culture and safety performance in the nuclear (Lee 1998), chemical (Carder and Ragan 2003; Vinodkumar and Bhasi

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2009), construction (Molenaar et al. 2009), and mining (Stemn et al. 2019) industries, among others. Safety performance refers to the promotion of safety and health (hereafter, safety) at work (International Organization for Standardization 2018). Safety performance can be measured by organizational indicators such as safety culture or climate (Hale et al. 2010; Singh and Verma 2020). Safety culture is often regarded as difficult to measure as it concerns individual and group attitudes, beliefs, values, and behaviors (Hale 2000). Safety culture or climate are typically measured, e.g., by audits, questionnaires, and maturity models (Goncalves Filho and Waterson, 2018; Grote and Künzler, 2000; Hoffmeister et al. 2014; Vinodkumar and Bhasi 2009).

Maturity models have been presented in many managerial fields, such as information management, strategy management, performance management, and safety performance measurement (Jääskeläinen et al. 2020b; Jääskeläinen and Roitto 2015; Van Aken et al. 2005; Wettstein and Kueng 2002). A maturity model defines maturity levels that assess the completeness of the analyzed objects via different sets of multidimensional criteria and describes essential attributes that would be expected to characterize an organization at a particular level (Goncalves et al. 2018). Maturity models can be used as a tool for both assessment and improvement (Goncalves et al. 2018; Maier et al. 2012) since they can provide information on the desirable characteristics for operation (Bititci et al. 2015).

Maturity analysis is one way to measure safety culture levels in organizations (Goncalves et al. 2018). It can provide information on the present state of safety culture and possible ways to improve it. Evaluating safety culture maturity level can also be used for setting targets and benchmarking, predicting the outcome of proposed safety interventions, and following up improvements. Several maturity models have been established for the evaluation of safety culture. A recent critical review (Goncalves et al. 2018) compiled the previous models established for the safety culture evaluation. However, many of the models have not been assessed for validity or reliability. The review did not present detailed measures to evaluate the level of safety culture maturity. Current models have somewhat limited scope and do not always give adequate insight into the level of safety culture and the various factors affecting it or how they are related to each other.

The aim of this study is to design a new maturity model for analyzing safety culture. There is a need for a maturity model that covers the most frequently recurring factors of the existing validated models and proposes an approach to maturity evaluation. Once this model exists, safety culture measurement could be better utilized in safety promotion. A transparent, objective, and well-validated maturity model could also decrease the need for third parties to evaluate the state of safety culture.

2 Materials and Methods

This study utilizes a design science approach in which the intention is to both develop scientific knowledge and solve practical problems (van Aken 2007). Here, the aim is to design a new maturity model for analyzing safety culture and to give guidelines for its implementation. This study follows the first three phases of the design science process (De Bruin et al. 2005), namely, defining the scope, design, and content of the model; testing, deploying, and maintaining are not in the scope. The testing of the model and related survey tool in two Finnish companies was reported in Pirhonen et al. (2022) study.

In the first phase, the scope and target population are defined. The scope of the model is limited to safety culture, and the model can be applied to different organizations without industry limitations. In the second phase, the design of the model is defined. The idea is that the model could be used as a self-assessment tool by any organization. The model should be suitable for safety culture evaluation at any level of the organization. The evaluation variables are identified by synthesizing existing literature. The model will contain four written maturity stages, in which higher stages build on the requirements of lower stages. The maturity stages are identified by a down-up approach, where the measures are identified first and the maturity levels are then defined to reflect the measures. This approach is suitable in a developed domain where existing evidence representing maturity is available (De Bruin et al. 2005).

The main content of the model is defined in the third phase. The review of safety culture maturity models by Goncalves and Waterson (2018) was used as a starting point. Fourteen safety culture maturity models that had been assessed for validity or reliability were selected, analyzed, and compared (see Table 1). The most frequently recurring themes and evaluation criteria were identified from these models.

Four maturity levels representing the sophistication level in each evaluation criterion were established by applying and adjusting the presentation from existing models. The evaluation approach in the model with its four maturity levels resembles

Table 1 Selected maturity models for analysis

No	References	Industry	Included maturity levels for the items measured
1	Ashcroft et al. (2005)	Healthcare	No
2	Fleming and Wentzell (2008)	Healthcare	No
3	Fleming (2007)	Oil and gas	Yes
4	Goncalves et al. (2010)	Oil and gas	Yes
5	Gordon et al. (2007)	Air traffic	Partial
6	Jabonete and Concepcion (2016)	Healthcare	No
7	Jespersen et al. (2016)	Food	Yes
8	Kirk et al. (2007)	Healthcare	Partial
9	Law et al. (2010)	Healthcare	No
10	Parker et al. (2006)	Oil and gas	Yes
11	Reiman and Pietikäinen (2010)	Nuclear	Partial
12	Saunders et al. (2017)	Construction	Partial
13	Tappin et al. (2015)	Nonspecific	No
14	Vongvitayapirom et al. (2013)	Oil and gas	No

the recent maturity model for measuring safety performance developed and tested in five case companies (Jääskeläinen et al. 2020a, b; Lilić et al. 2020). The third phase included preliminary testing of the developed model as well. Four company representatives from the intended population evaluated the model and questionnaire, and it was further tested by two fellow scholars. Finally, a revised survey instrument was tested with two persons from the intended population.

3 Results

3.1 Maturity Model Framework

The five main themes of the new model are communication, training, organizational learning, management and supervisor commitment, and employee commitment and involvement (see Fig. 1). These themes were selected for this model based on the number of models that covered these themes. The 5 themes presented were identified in at least 8 of the 14 maturity models. The main framework for the developed maturity model is presented in Fig. 1. The analysis of the previous maturity models identified many other themes of minor importance regarding safety culture, such as reporting, investigation of incidents, and rules and procedures. However, these were not included as separate themes in this model as they can be seen as subcategories for the five selected themes.

This study reports a list of areas for evaluation that can be utilized as a checklist in the analysis of safety culture. The study presents an approach for evaluating maturity that combines written descriptions of best practices and the overall satisfaction of employees in the evaluated categories. By capturing satisfaction, the new model highlights the purposeful objectives of developing a safety culture. It acknowledges that more elementary practices may also suffice if employees are satisfied. In this way, the model takes different contextual criteria for safety management practices into account.

The most relevant evaluation criteria were selected for each of the 5 themes. Table 2 describes the selected criteria and related references under the 5 themes of

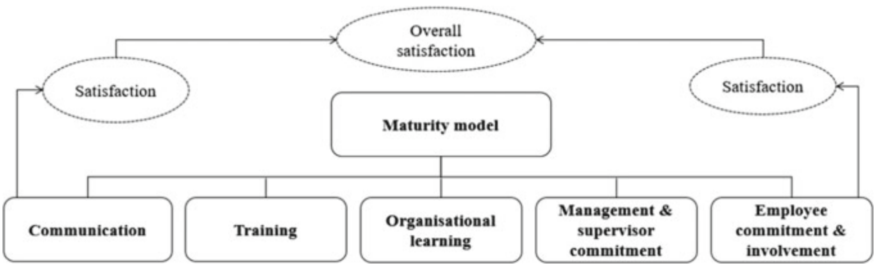

Fig. 1 The main themes of the maturity model for safety culture

the model. Each of the themes had 3 to 7 evaluation criteria and an additional Likert scale question regarding the respondent's overall satisfaction with each theme. Some existing safety culture models have over 100 questions, which may complicate their use in practice. In the design of the new model, an intentional decision regarding the length of the survey was made to balance between comprehensiveness and practicality. The moderate length of the survey enables organizations to focus on the key aspects of safety culture. Also, it keeps under control the time needed to answer it. In any case, the thorough literature review ensures that the selected evaluation criteria cover the most important aspects of each theme.

3.2 Evaluation Instrument

The actual evaluation of the criteria included in the model is carried out with four maturity levels with written descriptions representing the sophistication level for each criterion. The descriptions were based on previous maturity models that included such descriptions and were modified for this study. Most of the previous models had five maturity levels, and therefore each question needed slight revision to fit the four-level scale. An example of the descriptions in maturity levels is presented in Table 3.

Written evaluation criteria were chosen to differentiate the model from earlier maturity surveys using Likert scales and to gain certain benefits. First, written maturity levels provide clearer and more objective alternatives for the respondents than do Likert scales (Cocca and Alberti 2010). Second, the presentation of written maturity levels raises awareness of best practices, generates discussion, and facilitates the identification of areas needing development during the completion of the survey (Maier et al. 2006). Third, written maturity levels decrease the need for respondents to use external consultants and knowledge of practices outside their own organizations in the evaluation (Garengo et al. 2005).

Likert scales have their advantages as well, and they were used to evaluate the respondent's satisfaction with each theme. Satisfaction is highly subjective and thus difficult to measure, and it cannot be put into words as can other cultural measures. Table 4 provides an example of measuring satisfaction with training, which was one of the themes measured.

An evaluation of both the actual safety culture and the satisfaction toward it enables a more comprehensive understanding of the state of safety culture to be achieved.

4 Discussion

The importance of a safety culture has been recognized for decades, but companies still struggle to measure and develop their safety cultures. Regarding measuring safety culture, it may not matter what technique is used to make safety culture discussable (Hale 2000). The literature provides many models of the maturity measurement of

Table 2 Evaluation structure of the model

Theme	Evaluation criterion	References
Communication	1. Supervisor's interest in communicating safety issues with the workforce	Parker et al. (2006)
	2. Organization's way of sharing safety-related information	Fleming (2007)
	3. Attitudes toward safety communication in the organization	Goncalves et al. (2010)
Training	1. Training of supervisors	Fleming (2007)
	2. Training of employees	Fleming (2007)
	3. Employee's attitudes towards training	Parker et al. (2006)
	4. Supervisor's attitudes towards training	Parker et al. (2006), Gordon et al. (2007)
	5. Systematism of the training	Reiman and Pietikäinen (2010)
Organizational learning	1. Existing system for reporting incidents and safety suggestions	Goncalves et al. (2010)
	2. How employees feel about reporting incidents and safety suggestions	Goncalves et al. (2010)
	3. Organizational learning from reported events	Parker et al. (2006)
	4. Support for changes that might affect safety performance	Hale et al. (2010)
Management and supervisor commitment	1. What causes the accidents in the eyes of management?	Parker et al. (2006)
	2. Who is responsible for the accidents in the eyes of management?	Parker et al. (2006)
	3. Management's attitudes toward safety	Gordon et al. (2007)
	4. Balance between safety and profitability	Parker et al. (2006)
	5. Supervisor's active role in safety	Fleming (2007)
	6. Supervisor's commitment to corrective and proactive actions	Reiman and Pietikäinen (2010); Saunders et al. (2007)

(continued)

Table 2 (continued)

Theme	Evaluation criterion	References
	7. Supervisor's views on auditing	Parker et al. (2006)
Employee commitment and involvement	1. Employee's commitment and level of care for colleagues	Parker et al. (2006)
	2. Employee's attitudes towards safety	Goncalves et al. (2010)
	3. Employee's actions to promote safety	Gordon et al. (2007)
	4. Work done under pressure	Saunders et al. (2017)
	5. Rewards for safe performance	Parker et al. (2006)

Table 3 Example of descriptions in four-step maturity levels

Example item	Management's attitudes toward safety
Level 1	Managers consider safety an employee responsibility. Lip service is paid by management to the importance of safety
Level 2	Managers are interested in participating in safety-related issues only when accidents occur
Level 3	The majority of managers are interested in participating in safety-related issues
Level 4	Managers clearly think safety is an important part of general management

Table 4 Example of measuring satisfaction

Sample item	Overall, how satisfied are you with the attitudes toward safety-related learning in your organization?
Level 1	Very dissatisfied
Level 2	Dissatisfied
Level 3	Neither satisfied nor dissatisfied
Level 4	Satisfied
Level 5	Very satisfied

safety culture but inadequate evidence of their validity and reliability (Goncalves et al. 2018). The model developed in this study responds to this challenge by synthesizing the previous models that have been tested for validity and reliability (see Table 1).

The main contribution of this study is the presentation of a new kind of maturity model that can be used as a tool for the analysis of safety culture. The model evaluates maturity by combining written descriptions of best practices and the overall satisfaction of employees in the evaluated aspects. The perspective of employee satisfaction with safety culture acknowledges the need to fit the practices into contextual needs. Sometimes more elementary practices may suffice if the employees are satisfied. This model is unique because of its balance between rigor (validated content from the literature) and relevance (written evaluation levels); this uniqueness reflects the key ideas of design science.

The model can be used as an assessment and improvement tool (Bititci et al. 2015; Goncalves et al. 2018; Maier et al. 2012). The maturity analysis of safety culture provides information on the current level of safety culture and how it could be improved. The analysis specifies best practices and enables benchmarking between organizations with comparable criteria. Based on the analysis, recommendations for improvement measures that will enable higher maturity levels to be reached can be derived and prioritized (Goncalves et al. 2018). The resulting model will benefit both research into and the practice of safety management. It may be used in large-scale surveys and in auditing safety culture, for example, through group interviews or workshops. It may be answered by all the employee groups in a company.

The presented model and related survey tool were tested in two Finnish companies (Pirhonen et al. 2022). The maturity analysis showed that that the level of safety culture and employee's satisfaction with it were relatively high in studied companies. Both companies could still further develop their safety culture based on the analysis. The study identified differences between organizational levels which should be perceived when the model is applied. Further research should test the presented model in different regions and with more case companies to enhance the reliability of the results. Moreover, the results should be statistically analyzed to better understand the differences between respondent groups and the relationships between different dimensions of safety culture.

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Accidents at Work in the Finnish Food Industry Between 2016 and 2020—Analysis of Finnish National Accident Statistics Database

Sari Tappura and Noora Nenonen

Abstract Current international, European, and Finnish regulations, policies and programs emphasize improving safety and health at work, and strategic goals for reducing accidents at work have been set. In general, the accident frequency rate is higher in the Finnish food industry than other manufacturing industry. Hence, there is a need to implement further actions to prevent occupational accidents and improve health and safety at work in the food industry. To guide these actions, up-to-date information on accidents at work is needed. This study descriptively analyzed the circumstances, causes, and consequences of accidents at work in the Finnish food industry between 2016 and 2020 (n = 8481). The data were retrieved from the Finnish official national occupational accident database. The results reveal that most of the injuries were minor, such as wounds and superficial injuries, resulting in 0–3 days of incapacity for the work. The most accident-prone activities were handling objects, movement, and carrying loads by hand. Hands were the most exposed body parts. The most common causes of injury were related to movement and slipping, stumbling, and falling. Focusing on these factors to may support the food industry in preventing and reducing the number of accidents at work.

Keywords Food processing · Safety and health · Accident prevention · Occupational accident · Accident database

1 Introduction

Current international, European, and Finnish regulations, policies and programs emphasize improving safety and health at work, and strategic goals for reducing occupational accidents have been set (European Commission 2021a, 2021b; International Social Security Association n.d.; Occupational Safety and Health Act 2002;

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Sauni 2019). The statistical data and related analyses on occupational accidents are important tools for the further development of prevention policies (Jacinto and Aspinwall 2004).

The food processing industry (hereafter, the food industry) is a large segment of the national economy and employment (The Food Chain Workers Alliance 2012; Zielińska and Bajdur 2019); hence, it is essential to improve occupational health and safety (OHS) in this sector. OHS development is also needed in the food industry to further improve the availability of workforce, employee's well-being and productivity, and companie's competitiveness (Puisto et al. 2010). In 2018, about 14% of all manufacturing enterprises in the European Union (EU) were food and beverage processing enterprises (Cook and Eurostat 2021). Most of them are micro or small enterprises, but a few are very large enterprises characterized by global brands. Based on a previous study conducted in Italy from 2006 to 2013, big companies in the food industry reported a larger reduction in the number of accidents at work than small and micro enterprises; hence, safety improvement policies should be targeted to small companies (Comberti et al. 2018).

Previous studies have highlighted that food industry employees are exposed to several OHS risks, so the resulting frequency of accidents is high (Comberti et al. 2018; Stave and Törner 2007). The food industry includes manually working with sharp tools, production and packing along assembly lines, operating machines, and hazardous work environments, which can increase OHS risks (Kim 2015; Stave and Törner 2007). Although OHS has been studied in the food industry and improvements have been made (see, e.g., Comberti et al. 2018; Kim 2015; Puisto et al. 2010; Shaw et al. 2006; Stave and Törner 2007; Willquist and Örtengren 2005; Zielińska and Bajdur 2019), the number of occupational injuries and diseases are high in comparison to other lines of business (Kim 2015; Newman et al. 2015). In Finland, in general, the accident frequency rate trend has been very positive in the industry during the last 15 years (Finnish Worker's Compensation Center 2021). However, in 2020 the accident frequency rate was 33.9 in the food industry and 27.5 in manufacturing industry in general (Finnish Worker's Compensation Center 2022). Consequently, there is a need to implement further actions to prevent accidents and improve health and safety at work in the food industry. To guide these actions, up-to-date information on occupational accidents is needed. However, recent sector-specific analyses on occupational accidents occurring in the food industry in Finland are not available.

This study aimed to descriptively analyze the circumstances, causes, and consequences of accidents at work in the food industry in Finland between 2016 and 2020 to produce relevant and topical information to support efforts to improve safety at work and enhance the well-being and productivity of the industry's employees. The Finnish official national occupational accident database (Finnish Worker's Compensation Center 2022) was utilized to survey the accidents at work in the food industry in that country. The food industry is the biggest manufacturer of consumer goods and the fourth largest industrial sector in Finland employing about 38,000 people (The Finnish Food and Drink Industrie's Federation, n.d.). Based on the study's results, actions focusing on accident prevention are discussed to guide the food industry in its efforts to reduce the number of occupational accidents and improve safety and health at work. Moreover, priorities are set for the subsequent projects aiming at developing safety culture in the food industry.

2 Materials and Methods

In this study, the food industry includes the food processing industry but not the beverage processing industry. Moreover, the focus is on accidents at work, excluding commuting accidents (accidents that occur on the way to and from work) because the employer has a limited influence on them, and they were not the focus of this study. An occupational accident is typically defined as a sudden incident where injury, ill health, or fatality occurs at work (Worker's Compensation Act 2015).

The Finnish Worker's Compensation Center (2022) provides information about and an official national database of the occupational accidents in Finland, which was used in this study to survey the incidence of accidents at work in the food industry in Finland. The web-based database includes all the accidents reported and compensated through the statutory accident insurance system in Finland (Finnish Worker's Compensation Center, n.d.; Worker's Compensation Act 2015). The coverage of the database is considered good, in common with insurance-based accident registering systems in general (European Agency for Safety and Health at Work 2000). A contractual-based user interface was utilized to retrieve the information from the database.

An analysis was conducted to identify the factors contributing to accidents in the food industry (industry code 10 Food processing industry) between 2016 and 2020 ($n = 8481$). The data were analyzed with descriptive statistics according to European Statistics on Accidents at Work (ESAW) classification, which is an EU-wide methodology for collecting comparable data on occupational accidents (European Commission and Eurostat 2013) and also in use in official national accident database in Finland. The application of ESAW system has changed in Finland in 2016. To avoid inconsistency in the analysis the most recent years with final data and similar use of ESAW classification, i.e., years 2016 and 2020 were chosen for the analysis (Finnish Worker's Compensation Center 2022). The number of accidents at work and the frequency rate (number of accidents per million working hours) were retrieved from the database between 2016 and 2020. The frequency was compared to the frequency rate of manufacturing industry (including the food industry). Variables describing circumstances, causes, and consequences of the accidents at work were selected for the analysis.

3 Results

Between 2016 and 2020, a total of 8481 accidents at work were compensated for through the statutory accident insurance system in the food industry in Finland.

This is 11% of the accidents in the manufacturing industry. The annual number of accidents varied between 1825 and 1492 (average 1696) and the frequency rate varied between 31 and 37 (average 34) between 2016 and 2020 with a slightly decreasing trend both in the food and manufacturing industries (see Fig. 1). The percentages of the severity of the accidents at work (in terms of the number of days an employee was incapacitated and unable to work) were 58% (0–3 days), 35% (4–30 days), and 7% (over 30 days), including one fatal accident. In the manufacturing industry, the percentages of the severity of the accidents at work were 65% (0–3 days), 28% (4–30 days), and 7% (over 30 days) including 13 fatal accidents.

Descriptive analysis was conducted to gain an overall view of the circumstances, causes, and consequences of the accidents at work. The distribution of the most important variables was calculated as follows. According to the ESAW variable, specific physical activity, the most common circumstances of accidents at work were handling of objects (26%), movement (22%), carrying by hand (18%), working with hand-held tools (13%), and operating machinery (9%) (Fig. 2). The injuries caused by the handling of objects included compression of the hand or slash injuries with a knife and blades. Movement-related injuries included falling, slipping, and stumbling injuries to the lower limbs. Carrying loads by hand typically caused back strain when lifting. Working with hand-held tools, typically knifes, caused wounds to fingers and hands. Operating machinery typically caused hand and finger injuries when they were pressed or caught in a strap or a conveyor belt.

The most common causes of accidents related to the ESAW variable, deviation, were body movement without any physical stress (23%), slipping, stumbling, and falling (18%), body movement under or with physical stress (14%), breakage, bursting, splitting, slipping, fall, the collapse of material agent (12%), loss of control of a machine, means of transport or handling equipment, hand-held tool, object (12%) (Fig. 3).

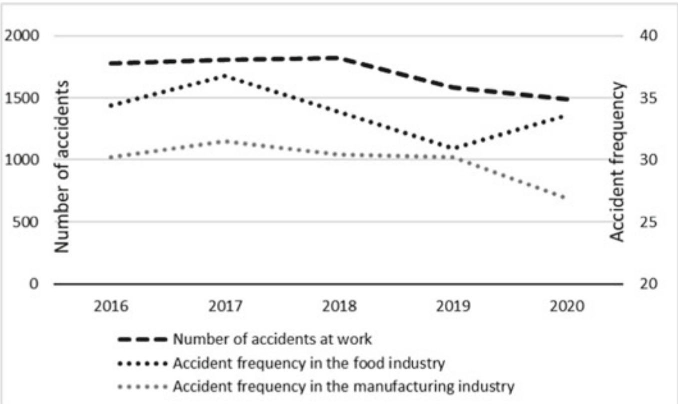

Fig. 1 Trends in the frequency (per million working hours) and number of accidents at work in the food industry and the frequency in manufacturing industry between 2016 and 2020

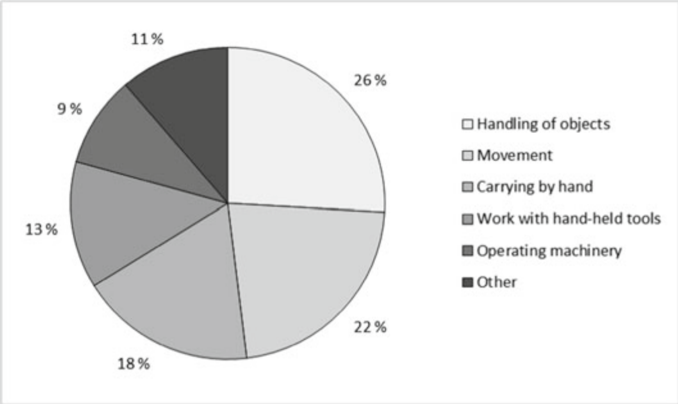

Fig. 2 Percentage of accidents based on the ESAW variable, specific physical activity, between 2016 and 2020 (n = 8481)

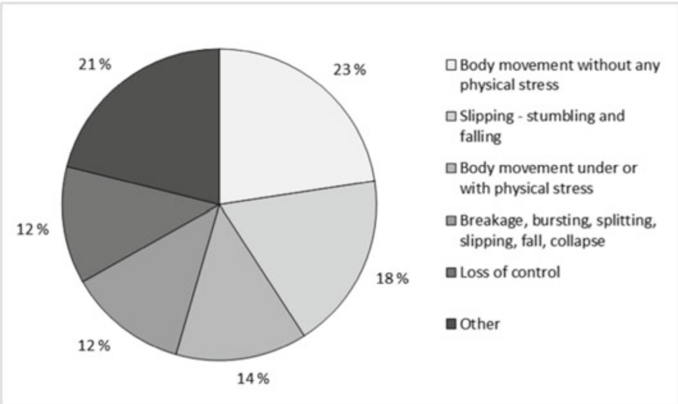

Fig. 3 Percentage of accidents based on the ESAW variable, deviation, between 2016 and 2020 (n = 8481)

The most common causes of accidents based on the ESAW variable, contact-mode of injury, were contact with a sharp, pointed, rough, or coarse material agent, such as knives (23%), impact with or against a stationary object (the victim is in motion), such as stairs (22%), trapped or crushed, for example with machines and/or conveyor belts (14%), sudden physical or mental stress, such as back stain (14%), and struck by an object in motion or collision with, for example, a box or a pallet (12%) (Fig. 4).

The most common causes of accidents based on the ESAW variable, type of injury, were wounds and superficial injuries (44%), dislocations, sprains, and strains (26%), concussion and internal injuries (16%), burns, scalding, and frostbite (5%), and bone fractures (4%) (Fig. 5).

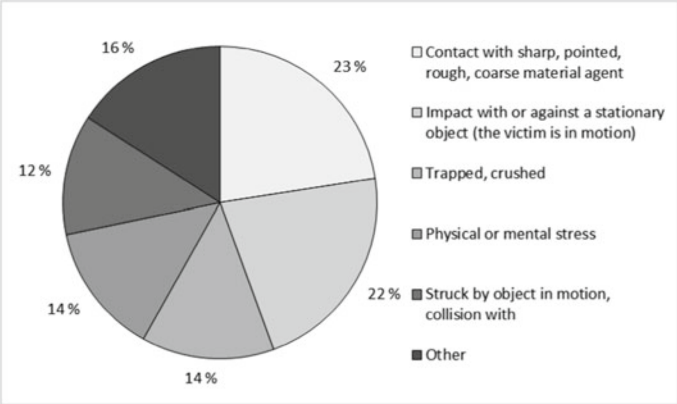

Fig. 4 Percentage of accidents based on the ESAW variable, contact-mode of injury, between 2016 and 2020 (n = 8481)

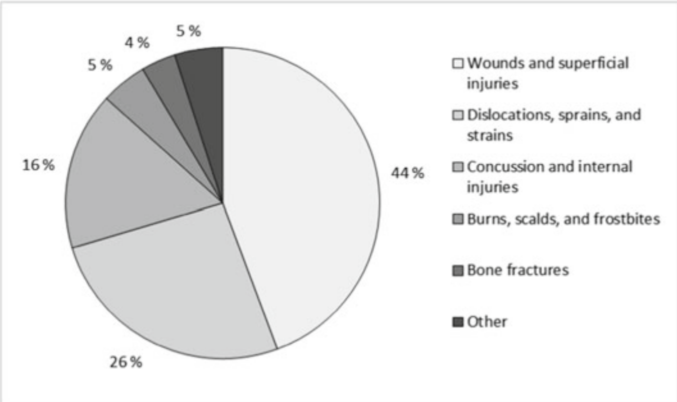

Fig. 5 Percentage of accidents based on the ESAW variable, type of injury, between 2016 and 2020 (n = 8481)

In terms of the ESAW variable, part of body injured, the body parts most commonly injured in occupational accidents were fingers (27%), hands (10%), legs, including knees (10%), ankles (5%), back, including the spine and vertebra (5%), arms, including elbows (5%), eye(s) (5%), and other body parts (32%).

4 Discussion

The results of this descriptive analysis showed that there was a slightly decreasing trend in the number and frequency of accidents at work in the food industry in

Finland during the period under study. However, the frequency rate was higher in the food industry than in the manufacturing industry in general, which is in line with the results reported in previous studies (Kim 2015; Newman et al. 2015). This might be explained by the work tasks requiring manual handling of materials, using hand tools, operating machines, and working along assembly lines (Stave and Törner 2007). In the food industry, the safety emphasis is on food safety (see, e.g., Nayak and Waterson 2017; Newman et al. 2015) and OHS may receive less attention and be allocated fewer resources.

Based on the study's results, employees experienced about 1700 occupational injuries per year requiring compensation for medical treatment and/or lost work time. Most of the accidents were minor causing less than 4 days of incapacity for work, with wounds and superficial injuries. However, the percentage of severe accidents was higher than in the manufacturing industry in general. When the number of severe accidents decreases, more attention should be paid to minor accidents to improve employee's health and safety. Moreover, in the case of minor injuries and hazardous situations, there is often a possibility that severe accidents may occur.

Handling objects and hand-held tools and movement, in general, were the most hazardous work tasks. In line with previous studies (Syron et al. 2017, 2019; Törner et al. 1995) upper extremities (e.g., hands and fingers with wounds), trunk (e.g., back strain), and lower extremities (e.g., strained, wounded, and bruised legs) are the most exposed body parts in the food industry. Focusing accident prevention on these factors may support the food industry in its effort to reduce the number of accidents and improve safety and health at work. However, more information and more in-depth analysis are needed to obtain data about accidents at the company level (Stave and Törner 2007) and regarding the severity of the accidents.

This study has some limitations. The analysis was based on quantitative data from reported accidents; thus, detailed information concerning the causes and possible prevention actions could not be retrieved. Moreover, ESAW classification only provides a superficial understanding of the variables. In future studies, the qualitative data could be analyzed to suggest practical prevention strategies. Future research could also review the analysis at the company level and compare the results to the company-specific statistics and related qualitative accident investigation reports, when available. Particularly, possible preventive actions could be discussed and steps to implement them could be recommended based on the company-specific examples and experiences.

In the present study, all the reported and compensated accidents at work were selected for the analysis. To increase the study's reliability and to better compare the results with other (European) studies, only accidents causing at least 4 days of incapacity for work could be analyzed. However, insurance-based accident registers are considered to have reliable data (European Agency for Safety and Health at Work 2000), and the coverage of the Finnish database is generally considered good. Accidents that are not compensated by an insurance company were not included in this analysis. In the future, studies could analyze minor accidents and incidents in the food industry based on company data (e.g., first aid, near miss and hazardous situation case reports) to identify comprehensive prevention actions.

The results of this study can be utilized in health and safety management in the food industry to determine how to development and implement preventative measures. However, this study is a preliminary analysis on the topic, and further in-depth comparative, correlational of trend analysis could be carried out. The results will be utilized in establishing priorities for the subsequent project aiming at developing safety culture and implementing occupational accident prevention in the food industry. Future analyzes could be conducted to follow-up on the trends in occupational accidents in the food industry and to evaluate the effectiveness of the implementation of prevention activities in the field. Moreover, future studies could analyze the differences of the circumstances, causes, and consequences of the accidents at work between food industry and other industries.

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Occupational and Environmental Hygiene

Occupational Exposure of Firefighters in Non-fire Settings

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Abstract This work assessed firefighters' exposure to particulate matter (PM) in non-fire work settings during pre-fire season, as a baseline for the respective occupational exposure characterization. Indoor and outdoor air sampling was conducted for two weeks in pre-fire season of 2021 in seven fire corporations (FC1-FC7) in north of Portugal. PM fractions ($PM_{2.5}$, PM_{10}) were continuously monitored concurrently in indoors (living rooms, rest areas, truck bays) and outdoors. The results showed low levels of pollution. Indoor PM_{10} was between 2 and 205 $\mu g\ m^{-3}$ (mean 10 $\mu g\ m^{-3}$); $PM_{2.5}$ were 2—115 $\mu g\ m^{-3}$ (8.5 $\mu g\ m^{-3}$). Both indoor PM fractions were highly and significantly correlated ($r_s = 0.959$–0.997). $PM_{2.5}$ accounted for 85% of indoor PM; indoor to outdoor ratios (I/O) of $PM_{2.5}$ ranged between 1.4 and 3.0, thus emphasizing the contribution of indoor emission sources for fine fraction. Outdoor PM_{10} were 2–6 times higher than indoors (6–894 $\mu g\ m^{-3}$; mean 21 $\mu g\ m^{-3}$); and 2–9 times higher for $PM_{2.5}$ (5 – 169 $\mu g\ m^{-3}$; 5 $\mu g\ m^{-3}$). Outdoor PM were moderately correlated

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($r_s = 0.584 – 0.878$), most likely due to meteorological conditions. Coarse particles contributed the majority of ambient PM_{10} and accounted for 79%.

Keywords Firemen · Particulate matter · Indoors · Air quality · Indoor/outdoor

1 Introduction

Global warming and climate change have been substantially contributing to rise of forest fires over the last decades, with longer fire seasons and more potent episodes (San-Miguel-Ayanz et al. 2018). In the European context, Portugal (along with France, Spain, Italy and Greece) is among the Southern European countries that are the most affected ones by forest fires (San-Miguel-Ayanz et al. 2021). Specifically, considering the 2010–2019 decade, Portugal ranked as the country with the most consequences; the North and Centre are the predominant regions with the most severe consequences due to the forest fires (i.e., number of fire occurrences and burnt area). Nevertheless, the projections of European Environmental Agency (EEA) showed that in foreseeable future weather-driven forest fires may become a large public risk in most of the European regions (EEA 2020; EC 2018).

Forest fire emissions release large amounts of several health hazardous pollutants, such as particulate matter, carbon monoxide, nitrogen dioxide, various volatile organic compounds and polycyclic aromatic hydrocarbons (PAHs). They represent a public health risk not only for the general population but also for occupationally exposed workers. The negative consequences of firefighters' occupational exposure have been recognized by International Agency on Research on Cancer (IARC)

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and, consequently classified as possibly carcinogenic to humans – group 2B (IARC 2010). Active and repetitive involvements in fire combats have been linked with adverse health outcomes in firefighter populations, including increased morbidity and mortality (with the cardio-respiratory diseases being leading causes of death) (Gianniou et al. 2016; Gaughan et al. 2014a, b, c; IARC 2010), and risk of cancers (in lung, kidney and bladder, skin melanoma, leukaemia, testicular, and urothelial cancer; IARC 2010; Daniels et al. 2014; Glass et al. 2016; Stec et al. 2018).

Monitoring of firefighters' exposure (Oliveira et al. 2020a, b) during a fire combat is a rather challenging (Barros et al. 2022, 2021) due to unpredictability of the respective environment (in terms of atmospheric conditions or rapidly changing situation) and inaccessibility of the locations. Studies on firefighters' exposure using biomonitoring assays have been emerging (Adetona et al. 2017; Fernando et al. 2016; Gaughan et al. 2014a, b; Keir et al. 2017; Park et al. 2015; Wingfors et al. 2018; Andersen et al. 2018). Nevertheless, the large part of the available information come from USA and Canada, and those findings may not be directly applicable to European context (due to the organization of the firefighting associations, dissimilar regional and geographical conditions, and biological diversity). Furthermore, the repetitive involvement in firefighting combats throughout the fire season may lead to cumulative exposure of the internal dose for individual subjects. Thus, a correct characterization requires, first of all, understanding of the levels of exposure. In that view, this work aimed to study the exposure of firefighters to particulate matter in non-fire work settings during the pre-fire season, determining a baseline for the respective occupational exposure characterization.

2 Materials and Methods

2.1 Sites and Region Description

The sampling was conducted consecutively for two weeks in pre-fire season in 2021 in the north of Portugal in seven fire corporations (FC1-FC7). All corporations were situated in different municipalities in Bragança district (the sub-region of Alto Trásos-Montes; north of Portugal). The area of the district is 6599 km^2 (i.e., 7% of the Portuguese territory; ANEPC 2019) and it is one of the most predicted regions for the forest fires hazards (San-Miguel-Ayanz et al. 2021). The region is characterized by hot and dry summers (average temperature of 29.1 °C, precipitation: 0.44 mm) with absolute maximum temperature exceeding the 30 °C; winters are long and cold with (absolute minimum temperatures reaching values below 0 °C); the annual average air temperature was 19 °C, and precipitation was 684.6 mm (IPMA 2021).

Typically, the fire stations were located directly within each city/village centre. Some of them were near the commercial areas and with easy access to main national roads. Detailed checklist of all indoor and outdoor (station layout, size, area, design, used material, age and reconstruction, equipment, outdoor surroundings, etc.) parameters and relevant sources were collected for each fire corporation. In terms of general layout, each station had three main sections. The technical part of the firehouse included vehicles garages and truck bays, various storages for protective gear and equipment, and places for equipment and car repairs. The administrative part of the fire station was composed of the operational centre, several offices, and study rooms; some firehouses were equipped with refectories and cafeterias. Private quarters consisted of the social spaces to pass the time, kitchens with eating areas, bedrooms, showers, etc.

2.2 Sampling

The study was approved by the Ethics Committee of University of Porto (reference number 92/CEUP/2020), with all participants being informed and providing written consent prior to the sampling. The air sampling was done consecutively during 1–2 days in each station, concurrently in indoors (living rooms, rest areas, etc., truck bays) and outdoors. PM fractions (PM_1, $PM_{2.5}$, PM_4, and PM_{10}) were continuously monitored by Dustrak™ Aerosol Monitor (model 8532, TSI Inc., Shoreview, USA); logging interval was one min leading to allowing a significant amount of the data collected (n = 26,880). The particle size distribution (particle range 0.3–25 m) was recorded over the same period by the Lighthouse Handheld particle counter (model 3016 IAQ; Lighthouse Worldwide Solutions, Fremont, USA), also using one min logging interval. During the sampling, a researcher was present to provide an additional information concerning potential emission sources, occupants' activities and patterns, and other relevance occurrence for the air sampling.

2.3 Statistical Analyses

Statistical analyses were conducted in SPSS (IBM Statistics 20). Data were compared through the Mann–Whitney U test, since normal distribution was not verified by Shapiro–Wilk´s test. Spearman correlation coefficients (r_s) were used to evaluate the possible relation between the PM fractions. Statistical significance was defined as $p \leq 0.05$.

3 Results

The overall statistics for PM at the seven fire corporations are presented in Fig. 1. The results showed that PM distributions were significantly different ($p < 0.05$) across the seven fire stations, with concentrations between 2 and 205 $\mu g\ m^{-3}$ for PM_{10} (overall mean of 10 μg m^{-3}). Considering means per each FC, PM_{10} ranged between 8 and 15 μg m^{-3}. The corresponding indoor $PM_{2.5}$ ranged between 2 and 115 μg m^{-3}, while it was between 6 and 13 μg m^{-3} (overall mean of 8.5 μg m^{-3}) for the individual means at each FC. It needs to be emphasized that there were large design and architectural differences between the stations; the level of sophistication in firehouses also differed greatly due to different "in-house" management and administration of each station. In some stations, truck bays were directly connected to the operational control centre, whereas in others, these spaces were apart.

In outdoor air (Fig. 2), PM concentrations were significantly higher ($p < 0.05$) than indoors (2–6 times for PM_{10} and 2–9 times for $PM_{2.5}$). Specifically, PM_{10} concentrations were between 6 and 894 μg m^{-3} (overall mean of 21 μg m^{-3}); across seven FC PM_{10} means ranged between 16 and 27 μg m^{-3} The corresponding outdoor $PM_{2.5}$ concentrations range between 5 and 169 μg m^{-3}. The observed means per each were between 2 and 6 μg m^{-3} (overall 5 μg m^{-3}).

As shown in Fig. 1, average indoors concentrations in all FCs fulfilled the PM protective thresholds (50 and 25 μg m^{-3} for 8 h period, for PM_{10} and $PM_{2.5}$, respectively; margin of exceedance 100%) designated in the Portuguese legislation on indoor air quality of public buildings. Specifically, the Ordinance No. 138-G/2021 establishes the requirements for the assessment of indoor air quality in commercial and service buildings, including protection thresholds, reference conditions and compliance criteria, and the respective methodology for measuring pollutants and for monitoring compliance with approved standards. The PM values are based on the past

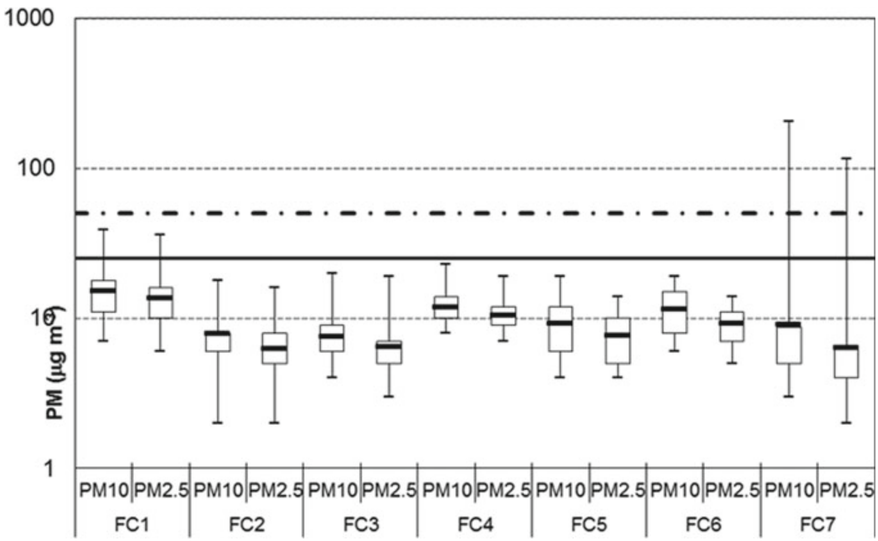

Fig. 1 PM_{10} and $PM_{2.5}$ (■ median, □ 25–75%, ⌶ range) in indoor air at seven fire corporations (FC1-FC7). The horizontal lines represent Portuguese protective thresholds for PM_{10} (50 μg m^{-3}) and $PM_{2.5}$ (25 μg m^{-3}) as established in Ordinance No. 138-G/2021

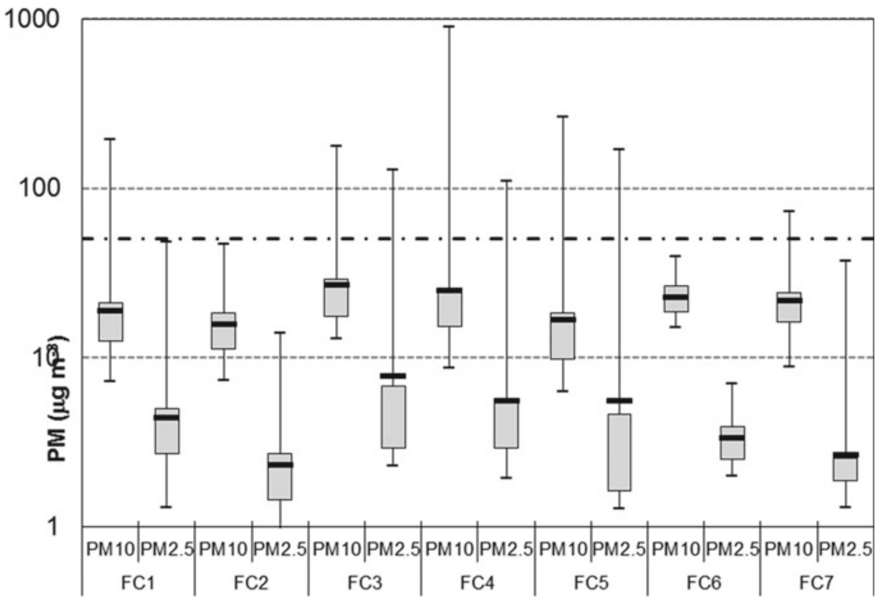

Fig. 2 PM_{10} and $PM_{2.5}$ (■ median, □ 25–75%, ⌶ range) in indoor air at seven fire corporations (FC1-FC7). The horizontal lines represent protective thresholds for PM_{10} (50 µg m^{-3}) and $PM_{2.5}$ (25 µg m^{-3}) as established in Decree-Law n.º 102/2010

WHO recommendations for PM in ambient air (2005 edition) in view of "no conclusive evidence concerning the hazardousness of indoor-emitted PM in a comparison of the ambient one" (WHO 2006). Nevertheless, it needs to be emphasized that in 2021 WHO updated its recommendations with different ambient air quality limits (AQL). Concerning the daily PM values in ambient air, the proposed figures are 45 and 15 µg m^{-3} for PM_{10} and $PM_{2.5}$ respectively (WHO 2021); the new annual guidelines values are again lower: 15 and 5 µg m^{-3} for PM_{10} and $PM_{2.5}$, respectively (as opposed to 20 and 10 µg m^{-3} in 2005 edition). The concentrations summarized in Fig. 2 show that 24 h ambient air quality limit set by current EU legislative was met (Directive 2008/50EC; 50 µg m^{-3} for PM_{10}). This directive has been transposed into the Portuguese law through Decree-Law n.º 102/2010 and establishes the regime for the assessment and management of ambient air quality in Portugal. Additionally, the observed levels show, the 24 h AQL for both ambient PM proposed in the WHO 2021 were also fulfilled, thus indicating low pollution levels over the sampling period.

The indoor and outdoor comparison showed that ambient PM concentrations were significantly higher ($p < 0.05$) than indoors one (2–6 times for PM_{10} and 2–9 times for $PM_{2.5}$). Finally, the results in Table 1 showed that indoor PM_{10} and $PM_{2.5}$ were highly and significantly correlated (at 0.01 level; two tailed). These results indicate that indoors both PM fractions originated from the same emission sources. In addition, indoor $PM_{2.5}$/PM_{10} ratios were rather high as fine particles accounted for 85% of indoor PM (range of 80–88%). These results are relevant considering that

Table 1 Spearman correlation coefficient (r_s) of PM_{10} and $PM_{2.5}$ in indoor and outdoor air of seven fire corporations (FC1–FC7)

r_s	FC1	FC2	FC3	FC4	FC5	FC6	FC7
Indoor	**0.977**	**0.993**	**0.996**	**0.991**	**0.997**	**0.980**	**0.959**
Outdoor	**0.725**	**0.780**	**0.717**	**0.782**	**0.878**	**0.867**	**0.584**

Note Values in bold indicate significant correlation at 0.01 levels

apart from the smaller aerodynamic diameter (therefore a deeper deposition in the respiratory tract; Feng et al. 2016), $PM_{2.5}$ surface area is larger and is predominant carrier for toxic components (such as heavy metals, carcinogenic compounds, organic pollutants and pathogenic microorganisms; Li et al. 2017; Oliveira et al. 2016). In agreement, indoor to outdoor ratios (I/O) of $PM_{2.5}$ ranged between 1.4–3.0 (results not shown), with a mean of 2.1 across seven FC, thus further emphasizing the contribution of indoor emission sources for fine particles. On contrary, mean indoor I/O of coarse PM was 0.50 (range 0.28–0.80) suggesting the penetrations of ambient emissions to indoors. As expected, in ambient air, the correlations between both fine and coarse fractions were only moderately strong (Table 1). The Spearman correlation coefficient r_s ranged between 0.584 and 0.878, most likely due to the impact of the meteorological parameters. Coarse particles, in a form of resuspended dust, contributed the majority of ambient PM_{10}, as $PM_{2.5}$ accounted for 21% of outdoor PM (range between 12 and 33%).

4 Conclusions

Firefighters represent one of the riskiest occupations, yet the exposure monitoring strategies are rather challenging. Surveillance based on (bio)monitoring programs may be a possible to solution in the countries severely affected by forest fires, in order to better characterize and understand the risks and their direct (short- and long-term) health impact along the fire-fighter´s life. This is especially relevant as during last decades wildland fires have been becoming more intense due to the unusually high temperatures driven by climate change. Thus, in a view of the future possible risk scenarios, climate change mitigation on international scale is essential. This includes not only development and implementation of solutions for production and distribution of clean and renewable energy, but achieving zero net emissions, both encouraged by forward-looking public policies.

Specifically, this study characterized the exposure of firefighters to particulate matter in non-fire work settings during the pre-fire season, as a baseline for the respective occupational exposure characterization. However, the present extent of the work is based on air quality measurements only. The future (already ongoing) research will require more comprehensive studies of individual exposure assessment, preferably in large groups of subjects directly involved in firefighting events to characterize the levels of exposure. Further, considering the seasonal variability of the forest fires, follow-up assessment of the subjects throughout the fire seasons, as well as during different years will allow for more comprehensive understanding of fires and their true implications for exposure and health of occupational and general public populations.

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Distribution and Exposure Levels to Particulate Matter in Gyms Located in Shopping Malls

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Abstract Suitable indoor air quality is of utmost importance in places where physical activities are performed in order to maximize the related health benefits. This study evaluated the exposure to different particulate matter (PM) fractions and characterized thermal comfort parameters in three fitness centers (FCs) located in shopping malls. PM was continuously (n = 216,000) monitored for 34 days in three FCs situated in urban-background and urban-traffic zones of Porto Metropolitan Area, Portugal. Human occupancy and the respective activities increase indoor PM in all FCs; when occupied PM levels were 1.3–10 times higher than when places were without people. $PM_{0.3–2.5}$ composed the majority of indoor PM (46–64%), but outdoor infiltrations lead to a higher proportion of coarse fractions (~54% of the total PM). Finally, PM_{10} means exceeded the Portuguese protection threshold, whereas comfort parameters were generally within the indicated guidelines. Elevated levels of PM_{10} in studied environments may promote possible risks for the respective occupants, both professionals, and exercisers.

Keywords Indoor air · Air quality · Sports facilities · Comfort parameters · Environmental exposure

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1 Introduction

Physical activities are of utmost importance to nowadays society. This relevance has been recognized by the United Nations Agenda, in which sport has played a vital role in enhancing other goals. Even in the most socially difficult times, some form of exercising shall be practiced to maintain the aspect of normalcy; exercise has been linked to improvements in self-esteem and self-confidence and positive effects when struggling with depression and anxiety (Chen et al. 2020; Nyenhuis et al. 2020; Rubin and Wessely 2020). During the COVID-19 pandemic, the importance of physical activity was especially highlighted to maintain both physical and psychological wellbeing (Chen et al. 2020; Nyenhuis et al. 2020; Rubin and Wessely 2020; United Nations 2022). While sport can be practiced outdoors and indoors (Qin et al. 2019), the latter is especially relevant for the current population that spends most of its time indoors. In general, the quality of air indoors (IAQ) depends on many factors. Among the main parameters are: (i) presence and concentrations of air contaminants (such as particulate matter—PM, volatile organic compounds—VOCs, various gaseous compounds, and pollutants precursors); (ii) thermal and comfort parameters (air temperature and humidity, carbon dioxide—CO_2) of an environment; (iii) room characteristics (size, layout, design, and used materials); and (iv) ventilation and air exchange rates on indoor and outdoor built interface (Fanger et al. 2003). Concerning the possible health impacts, particular attention has been given to the particulate matter.

PM represents a mixture of solid and/or liquid particles suspended in the air, which vary in their physical characteristics (mainly in size and chemical composition) (Polednik 2003; Rogula-Kozlowska 2016). Considering the deposition in the respiratory system, PM can be defined in different forms (Polednik 2003; Rogula-Kozlowska 2016). Inhalable dust represents the mass fraction of total airborne particles inhaled through the nose and mouth (Hodas et al. 2016). Typically, it contains particles with an aerodynamic diameter (da) below 100 μm. Thoracic and respirable fractions are then the fractions of inhaled particles capable of passing beyond the larynx and ciliated airways, respectively, during inhalation (50% penetrations at da of 10 and 4.0 μm, respectively) (Polednik 2003). When exercising rate and depth of breathing increase. At the same time, depending on the fitness level of a subject, it is more common to employ mouth breathing and, as such, bypass the nasal passages that generally filter airborne particles. In that view, the understanding of levels and distribution of airborne particles is relevant in sports facilities (Wagner and Clark 2018). Nevertheless, the available data indicates a lack of comprehensive PM assessment in these spaces (Kuskowska et al. 2019). Thus, this study aims to evaluate the levels and distributions of PM in the indoor air of fitness centers.

2 Material and Methods

The study was carried out in three fitness centers (FC1–3). All clubs were located in the urban-background and urban-traffic areas of Porto metropolitan area (north of Portugal), and they belonged to a chain of low-cost fitness centers. Specifically, they were situated inside of shopping centers, without any outdoor facilities or swimming pools. FC1 was located on the ground floor of a commercial area (directly next to the main entrance to the galleries) but without any protective closing or main entrance. FC2 was located on the 2nd floor of a commercial area. FC2 had a rather unusual architectural layout. Its main areas (bodybuilding and cardio fitness areas) were located on the shopping mall's mezzanine, directly above the restaurants and food areas; no barriers were separating the aerial environment of FC functional spaces from the rest of the mall. FC3 was located in a large shopping mall but with two floors and with an independent entrance. In general, all FCs employed similar organization and structure. They consisted of three studios for group classes, the main area with cardio fitness and bodybuilding activities, changing rooms with bathrooms, support offices for the staff, fitness and nutrition assessment, and a small food/social area equipped with vending machines. All FCs were equipped with HVAC ventilation systems. However, as this study was carried out during the period of epidemiological restrictions due to COVID-19 pandemic, at the time of air sampling, the ventilation system was constantly switched off (even when group activity classes took place).

The measurement protocol of air sampling was conducted during 34 days in May–June 2021. In each FC, the sampling was done continuously (24 h) for all weekdays (Mon–Fri) and weekends (Sat–Sun) during 10–12 days. Particles in a range of 0.3–25 μm were continuously monitored by Lighthouse Handheld particle counter (model 3016 IAQ; Lighthouse Worldwide Solutions, Fremont, USA); logging interval was 60 s, resulting in a large set of PM measurements ($n = 216{,}000$). Equipment was positioned on support at approximately 1.3 ± 0.2 m above the floor surface and at least 1.5 m from walls to minimize the influence on particle dispersion (Holmberg and Li 1998; Jin et al. 2013). All direct emission sources that might interfere with data acquisition (i.e., air conditioners, ventilation points, entrance exits) were avoided. Comfort parameters (temperature—T, and relative humidity—RH,) were continuously monitored by a multi-gas sensor probe (model TG 502; GrayWolf Sensing Solutions, Shelton, USA). Before the sampling campaign, all equipment was calibrated by the manufacturers; during the whole sampling period, zero value of the particle monitor was verified daily. A research team member was always present at the site to register all relevant data (such as gym occupancies, class activities, etc.) or any pertinent information related to potential emission sources and ventilations. When necessary, the staff of the fitness center clarified further details. Statistical analyses of the data were conducted using Microsoft Excel 2013 (Microsoft Corporation).

3 Results and Discussion

The overall statistics for the different fractions of PM collected in the three gyms (main bodybuilding and cardio fitness areas) are summarized Fig. 1. As demonstrated, for each fraction, the concentrations of particulate matter were significantly higher ($p<0.05$) when occupied (OC) than during the periods when the places were without people (NOC).

The results showed that PM levels were approximately 1.3 to 10 times higher during the occupied periods than non-occupied. As shown in the Figure 1, these differences between both periods were higher for coarse particles, most likely due to increased coarse dust from human activities (Sack and Shendell 2014a, b; Slezakova et al. 2019; Qian et al. 2014).

The distribution profiles of six different fractions in each FC are summarized in Fig. 2, considering the occupied periods. These results showed that PM distribution profiles were similar in FC2 and FC3, whereas another trend was observed in FC1, namely in terms of a higher proportion of coarse particles (~54% of the total PM). FC1 was situated on the ground floor directly next to the shopping mall's main entrance, without any additional barriers/doors. Though the overall PM levels were up to 5 times lower than in the other fitness clubs, the different PM distribution may be due to contribution of the resuspended dust from outdoor emissions. Therefore, PM chemical characterization to provide emissions sources identification shall be

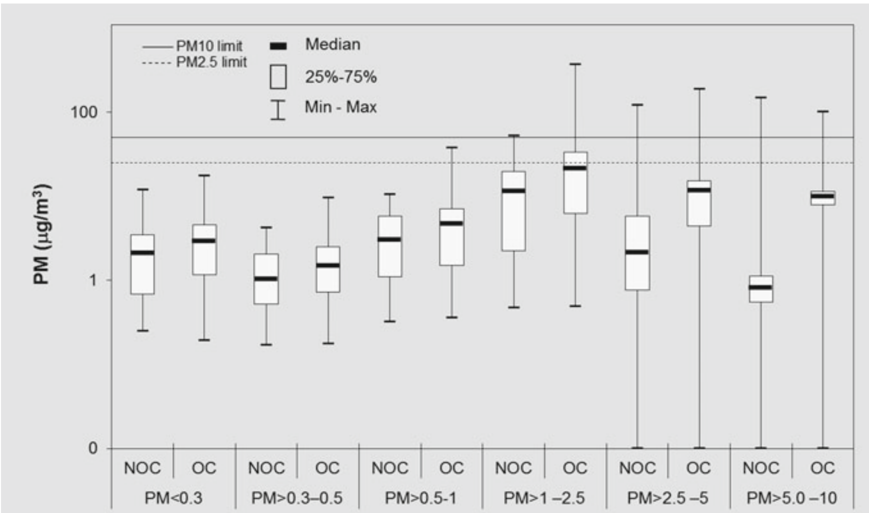

Fig. 1 Concentrations of different fractions of particulate matter ($PM_{>0.3}$, $PM_{>0.3–0.5}$, $PM_{>0.5–1}$, $PM_{>1–2.5}$, $PM_{>2.5–5}$ and $PM_{>5.0–10}$) at three fitness centers (NOC = non-occupied; OC = occupied period). The horizontal lines represent Portuguese protection threshold (Decree law 118/2013) for PM_{10} (50 µg/m^3; continuous line) and $PM_{2.5}$ (25 µg/m^3; dashed line). *Note* Contrary to the protection threshold values, PM fractions in the graphic are presented in non-cumulative form

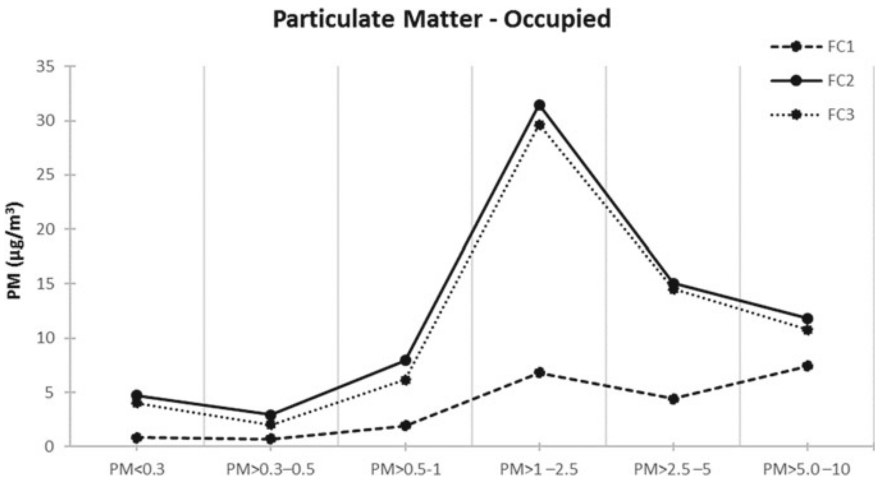

Fig. 2 Concentration profiles of six different fractions of particulate matter in three fitness centers (FC1-FC3) during occupied periods (OC). *Note* PM fractions in the graphic are presented in non-cumulative form

conducted. In addition, it needs to be highlighted that fine fraction accounted for the majority of the indoor PM. These findings are highly relevant in view of the fine particles ability to penetrate the lung barrier and enter the blood system (Board on Population Health and Public Health Practice 2016). Specifically, in FC2 and FC3, $PM_{0.3–2.5}$ contributed 62–64% of the total PM; this proportion was somewhat lower in FC1 (46%). Still the data on detailed PM distribution in sport facilities is extremely limited (Bralewska and Rogula-Kozłowska 2020, Bralewska et al. 2019).

The results of correlations between different PM fractions (non-cumulative) are summarized in Table 1. Spearman correlations was used due to the non-normal distribution of the data. As demonstrated, the positive correlation coefficients (r_s) were obtained for 99% of all tests.

The result showed that strong associations were obtained for PM fractions with particles of similar sizes (note that strong association with $r_s > 0.700$ are marked in bold), most likely caused by the similar origin of the particles and the impact of the physico-chemical atmospheric formation processes.

In terms of legislation, all FC fulfilled the $PM_{2.5}$ and PM_{10} limits set by Portuguese legislation (25 and 50 $\mu g/m^3$, respectively) during the periods when without clients. However, human presence and the corresponding activities subjects had a high impact on indoor PM levels (Table 2). When occupied, PM_{10} means were 3.0 times higher in FC1, 1.5 times in FC2 and 2.4 times in FC3 than when not occupied. $PM_{2.5}$ followed this trend with 1.6 times increase in FC1, 1.3 times in FC2 and 1.5 times in FC3. Concerning the obtained values, it needs to be emphasized that with the exception to FC1, PM_{10} concentrations means exceeded the Portuguese limits of 50 $\mu g/m^3$ (Decree law 118/2013), thus indicating possible risk for the respective occupants. In FC2 and FC3, PM_{10} levels were similar to indoor air of gyms with natural ventilations

Table 1 Spearman's coefficient (r_s) for different PM fractions (non-cumulative) at three fitness centres FC1-FC3

r_s	$PM_{>0.3–0.5}$	$PM_{>0.5–1}$	$PM_{>1–2.5}$	$PM_{>2.5–5}$	$PM_{>0.5–10}$
$PM_{<0.3}$	FC1: **0.909** FC2: 0.519 FC3: 0.464	FC1: 0.651 FC2: 0.105 FC3: 0.196	FC1: 0.179 FC2: 0.097 FC3: 0.170	FC1: −0.005 FC2: 0.002 FC3: 0.223	FC1: −0.030 FC2: 0.085 FC3: 0.278
$PM_{>0.3–0.5}$		FC1: **0.884** FC2: **0.798** FC3: **0.852**	FC1: 0.454 FC2: 0.648 FC3: 0.716	FC1: 0.207 FC2: 0.271 FC3: 0.454	FC1: 0.179 FC2: 0.266 FC3: 0.461
$PM_{>0.5–1}$			FC1: **0.743** FC2: **0.891** FC3: **0.912**	FC1: 0.475 FC2: 0.460 FC3: 0.530	FC1: 0.446 FC2: 0.309 FC3: 0.464
$PM_{>1–2.5}$				FC1: **0.832** FC2: **0.747** FC3: **0.744**	FC1: **0.790** FC2: 0.530 FC3: 0.629
$PM_{>2.5–5}$					FC1: **0.841** FC2: **0.775** FC3: **0.889**

Note Values in bold indicate Spearman's coefficients $r_s > 0.700$

(i.e., by windows opening; Slezakova et al. 2018), which typically reflect in overall much higher indoor particulate pollution (Montgomery et al. 2015). On contrary, $PM_{2.5}$ fulfilled the existent limit of 25 $\mu g/m^3$ (Table 2), with values in a similar range to those previously reported for Lisbon (Almeida et al. 2016; Ramos et al. 2014) or Porto (Slezakova et al. 2018).

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 shall be maintained below 65% (ANSI ASHRAE 2013). However, specifically for sport facilities the existent guidelines for temperature range (for summer season) are 18–25 °C, whereas the RH should be maintained between 55 and 75% (SEJD 2008).

The indoor T was within the recommended guidelines in all gyms studied (Table 3). Concerning the RH, observed values were within the recommended range in FC1

Table 2 Results of $PM_{2.5}$ and PM_{10} in the three gyms when non-occupied (NOC) and occupied (OC)—comparison with Portuguese legislation

	FC1		FC2		FC3		Legislation
($\mu g/m^3$)	OC	NOC	OC	NOC	OC	NOC	
PM2.5	3.4	2.1	15.6	12.1	12.2	8.4	25
PM10	14.7	4.9	62.7	41.3	56.3	23.9	50

Table 3 Results of T (ºC) and RH (%) in the three fitness centers when occupied (OC) and non-occupied (NOC)

	FC1				FC2				FC3			
	T (ºC)		RH (%)		T (ºC)		RH (%)		T (ºC)		RH (%)	
	OC	NOC	OC	NOC	OC	NOC	OC	NOC	OC	NOC	OC	NOC
Mean	22.8	22.9	56.9	55.6	23.6	24.0	50.0	44.9	21.5	22.6	62.5	59.7
Minimum	19.9	20.9	42.0	44.1	21.4	22.3	41.7	41.1	20.0	19.9	52.2	51.8
Maximum	25.7	25.2	73.4	66.1	25.0	25.4	59.7	58.2	23.9	24.0	70.5	65.8

and FC3. In FC2, RH was below the guidelines, which may cause potential discomfort to exercise practitioners (drying of mucous membranes in the nose, throat, and skin; (Bélanger et al. 2014; Sylvester et al. 2016).

4 Conclusions

This work assessed particulate pollution in indoor air of three fitness centers situated in shopping malls. The obtained results showed that human presence and activity lead to increased PM concentrations for all analyzed fractions. Fine particles $PM_{2.5}$ accounted for main part of total PM. Furthermore, two fitness centers (FC2 and FC3) exhibited a similar PM distribution profiles. Positive and strong correlations were observed for PM fractions with similar size class of particles. In terms of legislation obtained PM_{10} were higher than the limit of 50 $\mu g/m^3$, which indicates possible risks for indoor occupants. In addition, RH was below the mean values existent guidelines, causing possible discomfort for the respective occupants (Kim et al. 2019).

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Impact of Metallic Particle Contamination in Relation to Product Requirements in the Automotive Industry (Case Study)—Part 1

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Abstract The trend expected for the automotive future is autonomous driving, which has motivated the reduction of breakdowns caused by factors traditionally considered uncontrollable. Contamination, more specifically particle contamination, is one of the most significant factors. In the case of electronic components, the greatest concern is contamination by metallic particles, because these directly affect the functions of these components. Therefore, technical cleanliness has been assuming an increasing importance in the automotive industry. The aim of this work is to investigate the influence of logistics and assembly processes on the level of metallic particles contamination of electronic products, in this case, automotive antennas, and to find solutions for its reduction. It has been established as a minimum requirement, according to the automotive industry, that all metallic particles found in electronic components should have dimensions less than 500 μm. Using the pressure rinsing and ultrasonic method, particles were extracted from a randomly selected antenna and components and analysed by optical microscopy. The particles were found to

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be non-compliant, so solutions were applied to packaging processes and component soldering in the product assembly, and another product was analysed. The results confirm the influence of the factors studied and the effectiveness of the measures applied.

Keywords Technical cleanliness · Metallic particles · Assembly · Logistics · Optical microscopy

1 Introduction

In the 1990s, industry, particularly the automotive industry, began to be concerned about something that was referred to as "residual contamination". Throughout that decade, the concern grew, and it became known as "technical cleanliness". Technical cleanliness was being evaluated and propelled not only in the automotive industry and its suppliers, but also in several other industries, such as the medical, pharmaceutical and chemical industries. The automation and robotization of processes have been increasing in several industries, which promotes the need to minimize the factors that cause failures (Oravec et al. 2019).

In the specific case of the automotive industry, the growing interest in the study of technical cleanliness has been motivated by several reasons, among which, the desire for more powerful engines, with lower emissions of pollutants and with reduced consumption values, the use of new materials, the compliance with new legal requirements and the desire for autonomous driving. This desire implies that all failures of the automobile, even the smallest ones, are minimised because they can affect the entire system. In addition to failures in mechanical components, failures in electronic components have been the focus of great concern since the functions of these components are quite sensitive to small contaminations. One of the types of contamination that has deserved more attention is the particle contamination, as these can cause problems not only during production, but also during the use of the equipment later on (VDA 2015), which can have direct or indirect impact on human life (Keyence 2022). Particles can be of various types such as sands, metals and abrasive debris and can result in increased wear and tear on components and products and faster corrosion of the components and equipment in which they lodge (Dzetzit and Nagit 2017; Stathis et al. 2014).

Thus, the main objectives of technical cleanliness are the elimination of contamination in sensitive areas, the removal of unavoidable particles and the protection of components from the ingress of particles from the environment (VDA 2011).

Hence, the need arose to develop and define methods and techniques to evaluate particle contamination and implement specific technical cleanliness criteria (IPA 2022). To this purpose, standards 19.1 (Quality Management in the Automotive Industry—Inspection of Technical Cleanliness) and 19.2 (Quality Management in the Automotive Industry—Technical cleanliness in assembly) were defined by the Automotive Industry Association (VDA) and ISO 16232 (Road vehicles—Cleanliness of components and systems) and ISO 14644 (Cleanrooms and associated controlled environments) were defined by the International Organization for Standardization (ISO) (Faber et al. 2021). None of these standards establish limit values for the technical cleanliness of the most diverse components and products, being these values defined by the customers, in this case, the automobile brands (VDA 2015).

On the other hand, the ZVEI (Zentralverband Elektrotechnik und Elektronikindustrie) has published guidelines related to technical cleanliness in electrical engineering. These guidelines are intended to guide the production of electronic components (Gruszka and Misztal 2017). Thus, technical cleaning has played an important role not only in the classical mechanical industry, but especially in the automotive electronics industry, such as in the assembly of printed circuit boards (PCB), since particle contamination in this process can lead not only to failures in the product, but also in the entire system (ZVEI 2019). The ZVEI guidelines then provide specific recommendations for the testing, measurement and evaluation of this type of contamination in these products (Johnson et al. 2004).

The higher the demand regarding technical cleaning, the higher the associated costs will be, whether due to the level of filtration required, the time spent on cleaning, the quality of materials and equipment or the training of the employees involved. Thus, the VDA establishes as a principle of technical cleanliness that a certain component or product should be as clean as necessary and not as possible (VDA 2015).

In order to apply the concepts and techniques of technical cleanliness more correctly, the VDA defines four influence factors which are the assembly, the environment, the logistics and the human resources. To these influence factors are associated various sites and processes, as is the case of the assembly and packaging processes (VDA 2011), studied in this work. These two sources of contamination were studied because the particles are mostly introduced into the process as a result of the high number of worked components or are generated in the production process itself (Dzetzit and Nagit 2017).

Therefore, there are two commonly used ways to satisfy the technical cleanliness requirements of components and products: avoiding the generation and induction of contamination and eliminating contaminations at the end of the production process (Calata et al. 2005). These two distinct methods can be used in electronic components and products (Agarwal and Dhar 2017), separately or in combination (Pecman and Luptak 2021). The first approach implies knowledge and planning from the supplier to transportation to the end customer, as well as the existence of cleanrooms (it may be necessary that all production is carried out in this type of room) and the training of employees. In a first step, an audit should be carried out with the objective of knowing the level of technical cleanliness of the production. In a next step, a survey is conducted on the measures to improve technical cleanliness to be applied throughout the production chain (Zhang et al. 2010). The second approach implements a process of cleaning the products at the end of production, before transportation to the customer. This approach can only be used if the contaminations present do not cause problems for the production chain itself. A combination of the two methods is possible which is generally applied when the technical cleanliness requirements are very strict (Pecman and Luptak 2021). It may also be necessary to clean some production systems as part of the production process in order to satisfy the technical cleanliness requirements (Conlon and Matta 2001).

Regarding packaging, there is a growing trend to reduce the use of single-use packaging signed by the European Union, which has become concerned about packaging waste (EU 2018). These demands associated with the technical cleanliness requirements have led to the implementation of packaging washing lines and the control of its cleanliness and condition in the various stages. On the other hand, existing regulations concerning technical cleanliness determine that wood and paper should not be used in packaging. One of the most frequently used types of packaging are blister trays that allow the individual packaging of components or products. However, if these are not properly screened and cleaned, they can lead to contamination of the packaged products (Pecman and Luptak 2021). Blister trays must be placed inside KLT boxes (standardized rigid plastic box for transport and storage according to the VDA (Rotom 2022) and then transported (VDA 2011).

In turn, regarding assembly, there are usually three scenarios: the generation of particles due to the process, the release of particles during the process and the entry of particles into the assembly area. The generation of particles due to the assembly can result in particle displacement to functional areas of the component, emission and subsequent sedimentation of particles in functional parts of the component or disconnection of joints. Particle release during the process can occur due to mechanical abrasion or due to years of service of the equipment. Finally, the entry of particles into the assembly area is also related to the material feeding technology, contaminated external surfaces either of components, tools or packaging and human resources (VDA 2011). Thus, several measures can be taken, from the design of the assembly equipment to the cleaning of the integrated assembly. On the other hand, it is important to know the influence of the various production processes in order to apply specific additional measures (ZVEI 2019). The VDA states that the most prevalent cause of contamination is the joining processes (VDA 2011).

This work was developed in the company "Continental Advanced Antenna". This company produces antennas for automobiles. Car antennas are made of an extensive set of components, including electronic components, such as PCBs.

The main objective of this work is to study specifically the contamination by metallic particles both at the assembly and logistics level in electronic products and components and to verify possible ways to fight it in this specific case. However, the results obtained can be generalised to other similar cases.

It was possible to conclude that the changes implemented in the packaging used for the components, as well as the measures applied directly in the assembly of those same components, allow achieving a higher level of technical cleanliness.

2 Materials and Methods

As previously mentioned, in this study, assembly and logistics were investigated as influencing factors. To this purpose, a production line of the company where the research was developed was selected. This selection was based on the fact that the line is recent, that it is an important line in terms of production volume and that it contemplates assembly processes, including welding processes, which, in principle, are sources of contamination by metallic particles. Initially, an automobile antenna assembled on this production line was randomly selected in order to investigate the contamination by metallic particles present in the product (finished automobile antenna). Figure 1 contains a schematic representation of the studied antenna and its constitution.

The particles existing in this antenna were extracted in two parts (top and bottom, identified with blue arrows in Fig. 1) and, afterwards, the metallic particles were analysed to know their dimensions.

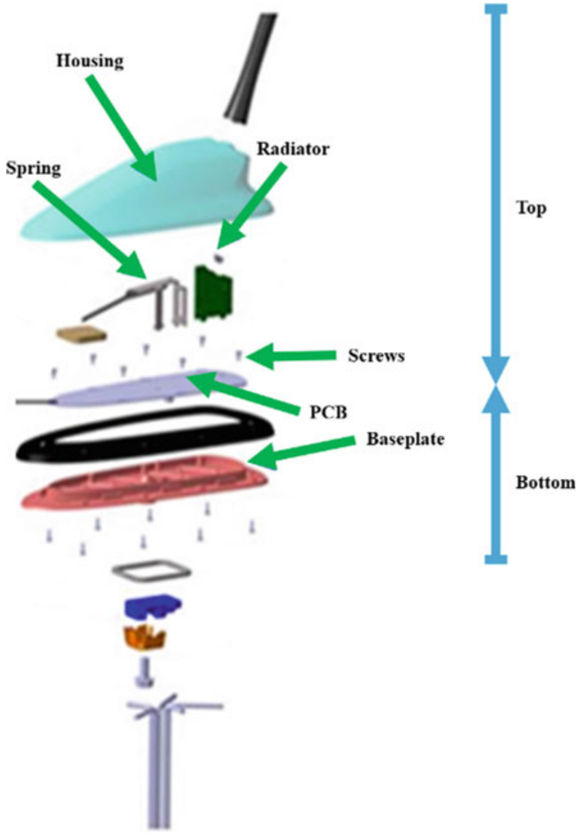


Fig. 1 Representative scheme of the analysed antenna and its components. *Source* Continental Advanced Antenna Portugal

Among the several existing extraction methods, the extraction method used was pressure rinsing. In this method, a liquid jet is applied on the component under test which must be located on an analysis filter which, in turn, must be on a collecting surface. Thus, the jet of liquid will make the particles present in the component deposit on the analysis filter due to the momentum transited by the jet to the component (ISO 2018), which will then be analysed (Flexclean™ 2012).

ISO 16232 defines the procedure to be followed for extraction by pressure rinsing, as well as the initial conditions to be adopted (ISO 2018).

Once the particles are extracted, the mass of particles per filter is determined by gravimetric analysis and then an optical analysis is performed by optical microscopy.

In the optical microscope, the objective lens forms a real image of the sample near the tube and the eyepiece magnifies this image in the form of a virtual image that is projected onto the eye or the surface of an image recording device (Kaufmann 2003). This technique allows particles to be mapped onto the camera chip and, through image processing, it is possible to detect particles by contrast and determine their dimensions. The particle length is considered as the longest possible perpendicular distance between two parallel lines touching the particle and the particle width is considered as the smallest possible perpendicular distance between two parallel lines touching the particle (VDA 2015).

In the company in which the study was conducted, it was set as an internal requirement that the limit value for the size of metal particles is 500 μm, since it is necessary to ensure compliance with the requirements set by all the company's customers. This limit value was maintained in the present study.

In order to understand which components or processes most influence the values obtained in this first analysis, the most critical components of the antenna were analysed separately. The analysed components were then the housing, the spring, the radiator, the screws, the PCB and the baseplate (identified with green arrows in Fig. 1). These components were taken directly from the warehouse (before reaching the production line), randomly. The particles present in the housing, PCB and baseplate were extracted by pressure rinsing, as in the first analysis. The particles present in the radiator, the spring and the screws were extracted by ultrasound.

Extraction by ultrasound consists of the effect of mechanical vibrations exerted by a fluid on the surface of the component under test (GMBH 2013), which range between 20 kHz and 400 kHz (ISO 2018). This procedure is performed in tanks whose sides and bottom contain vibration elements or else using ultrasonic sonotrodos. This method then relies on the high-pressure peaks that occur when implosion of the cavitation bubbles occurs, leading to particles being released (GMBH 2013). The particles extracted from the components were then analysed by optical microscopy and their dimensions were known.

A number of hypotheses were raised for the results obtained from the component analysis that related to the packaging and handling of the components. Improvement measures associated with the packaging of the various components were applied.

However, the results obtained for the analysis of the components did not denote any evident relationship with the results obtained from the analysis of the product. Since robot soldering processes take place on the production line in question, it is possible that contaminations resulting from these processes spread through the antenna. Therefore, solutions were implemented at this level and a new antenna produced on this line was randomly selected and analysed in order to verify the effectiveness of the applied measures.

3 Results and Discussion

The first analysis performed on the randomly selected antenna after being produced on the production line under study (top and bottom parts) provided the results shown in Table 1 for the length of the largest metallic particle found.

Analysing Table 1, it can be seen that metallic particles larger than the value established as requirement (500 μm) were detected at the bottom of the antenna.

As previously mentioned, the critical components identified in Fig. 1 were then analysed in order to try to understand the possible origins of the contaminations and thus take the appropriate improvement measures.

In this way, Table 2 shows the results of the analysis performed to the referred components.

Analysing Table 2, it can be seen that the components where particles larger than the value established as limit value were detected are the case and the radiator. Neither of these components is located at the bottom of the antenna, so the causes of the contamination found in the first analysis are not directly related to the causes of the contamination found in this second analysis, as mentioned above.

Table 1 Results of the first product analysis

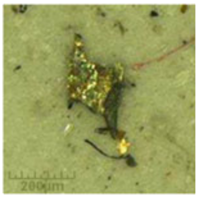
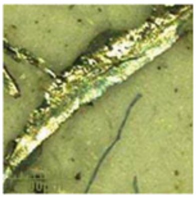
Description	Length of the largest metallic particle (μm)	Optical microscopy image
Top	453	
Bottom	1145	

Table 2 Results of the analysis of the antenna components of the production line under study

Description	Length of the largest metallic particle (μm)
Housing	738
Radiator	1002
Spring	167
Screws	198
PCB	130
Baseplate	153

Regarding the results of this second analysis and taking into account that it concerns components taken from the warehouse before reaching the production line, it was concluded that the contaminations are due to packaging and handling. Specific measures were taken with regard to the packaging of these same components. Thus, specific packaging was created for these components, following the guidelines established by the VDA for their internal transport. The components are now transported in blister trays, placed in layers in a KLT box, separately by component.

Regarding the results obtained in the first analysis and since it was not possible to relate these results to the results obtained in the second analysis, it was decided to take measures regarding the assembly, more specifically the welding processes, as it is possible that the contamination by metallic particles detected in the analysed antenna originated from these processes. Therefore, soldering masks were designed to be placed over the PCB—before it enters the soldering robot. These masks almost completely cover the PCB, leaving only openings for the points to be soldered in each process. Figure 2a shows a schematic of one of the masks applied and Fig. 2b shows a photograph of the mask schematic in (a) applied to a PCB.

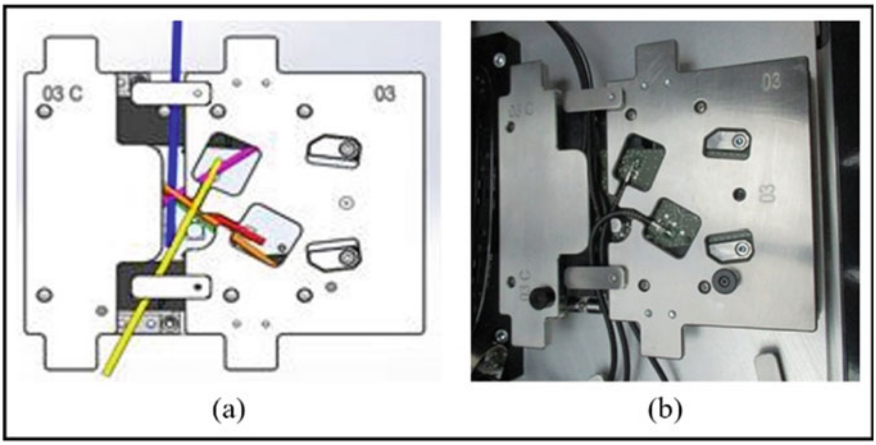


Fig. 2 **a** Schematic example of the soldering mask to be used on the PCB during the soldering process. **b** Example of soldering mask placed over the PCB for the soldering process

Table 3 Results of the second product analysis (third analysis)

Description	Length of the largest metallic particle (μm)	Optical microscopy image
Top	381	
Bottom	379	

Once the above-mentioned improvement measures were applied, the third analysis was then performed to understand if they had had the desired effect (metallic particle size less than 500 μm) by randomly selecting a new antenna produced on the same production line. The third analysis was then performed to the top and bottom parts just like the first analysis.

The results of this analysis are presented in Table 3.

Analysing the values presented in Table 3, it is perceptible that both parts of the antenna have metallic particles whose maximum dimensions are lower than the 500 μm established as limit value. Cumulatively, these values are lower than the values obtained in the first analysis for both parts. For the top part of the antenna, an improvement of approximately 19% was obtained and for the bottom part an improvement of approximately 202%. Therefore, it is accepted that the improvement measures implemented regarding logistics, in the specific case of packaging, and assembly, more specifically the soldering processes, had the desired effects, reducing the contamination level found.

4 Conclusions

From this work it was possible to confirm the strong influence of logistics and assembly on the level of contamination of a product or component.

The use of appropriate packaging, especially blister trays, prevents contamination during the transportation of components, not only small components, but also critical components of a product. It should be noted that regular cleaning of this type of packaging must be guaranteed so that the effect is not completely opposite to the one intended.

In addition, the protection of electronic components during soldering processes with soldering masks, even using a robot for soldering, avoids possible contamination from these processes.

These measures can be replicated for cases identical to those studied in this work.

As technical cleanliness is subject to continuous improvement, with regard to future work, further improvement measures can be implemented with regard to these influencing factors, but also with regard to the analysis of components and products. Regular optical microscopy analyses should be carried out on randomly selected products (antennas) to ensure that the technical cleanliness level is as intended. If higher than desirable contaminations are detected, more powerful analysis methods can be used, such as SEM/EDX, since they allow identifying the chemical elements that constitute the contaminations present in the analysed products. This analysis will enable a more precise identification of the sources of contamination, making it possible to apply more specific and precise improvement measures.

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Skin Follicles Dispersion Within a Hospital Operating Room—How to Predict and Reduce the Contamination

Nelson Rodrigues, Inês Teixeira, Ana Ferreira, Ricardo Oliveira, and Senhorinha Teixeira

Abstract Assess the skin follicle distribution within an operating room, by tracking particles and analyzing their propagation. Surgical site infection (SSI) is one of the most relevant infectious problems in hospitals, which can occur in 2.6% of all surgeries. According to the literature, the main source of SSI is flakes released from the exposed skin of the surgical staff or patients. A very effective strategy to control the bacteria carried by airborne partitions responsible for SSI is to ensure proper ventilation. For the study, numerical simulation was used, namely the Ansys Fluent® program. For this, two mannequins were modelled inside an operating room, whose HVAC system incorporates an insufflation grid and three extraction grids. The simulation takes into account turbulence, radiation, the thermal exchanges between boundaries and fluid, as well as the DPM for particle tracking. The mannequins have an associated follicle skin release which is tracked in the operating room. Laminar flow is essential to promote the removal of contaminants and protect the surgeons and patients. The peripheral region shows the accumulation of airborne particles, requiring attention from Nurses and other medical staff. After the surgery, an interval of 20 min showed to considerable reduce contaminants concentration and avoiding possible contamination among patients.

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Keywords CFD numerical simulation · Operating room · Particle tracking · Hospital contamination

1 Introduction

Studies have shown that patients' suffering can be reduced, and their hospital stay shortened due to a good indoor thermal environment. In addition, the risk of disease infection can be reduced with good air quality (Zhang et al. 2017; Teixeira et al. 2021; Rodrigues et al. 2015; Pereira et al. 2020).

Spaces in hospital buildings, especially operating rooms are a challenge for building services engineers who have to ensure indoor environmental conditions that satisfy all occupants and guarantee safety (Teixeira et al. 2021; Rodrigues et al. 2015).

Surgical Site Infection (SSI) is one of the most important and potentially protectable causes of remedy duration increment and even death of the patients (Memarzadeh and Manning 1993). The contamination risk is increased by the proximity and position of the surgeon regarding the patient. During surgery, the surgeon is bending over the patient and between the clean air flow, becoming a source of airborne particles, as many as 1000 per minute. The risk of SSI depends on several factors, including the patient (susceptibility to infection), staff (practices) (Wernham et al. 2018), operating room (cleanliness), and HVAC system (air changes per hour and airflow pattern) (Zhang et al. 2017). It is believed that the major number of SSI cases are due to airborne bacterial particles, which may be minimized using an optimum ventilation strategy (Sajadi et al. 2019). The application of an appropriate ventilation system is well known as the most effective way to control harmful microbiological agents responsible for SSI (Sajadi et al. 2019; Jarvis 2020; Kim and Augenbroe 2009; Elsaid et al. 2021).

Surgical clothing has an essential role in keeping the release of skin particles. Impervious and sterile surgical gowns, the use of gloves, tucked in clothing and worn boots have proven to be efficient methods. Additionally, scrubbing exposed body parts to remove skin follicles prior to entering the operating room decreases the skin particles released. Once the particles are in the air, ventilation is an important factor to reduce the bacterial load. The position of air inlets and outlets, the quantity of airflow, and a laminar profile with a high level of uniformity assure their effective performance (Wolkoff 2018; Markel et al. 2018).

Within an operating room, the ventilation can be complex and the use of numerical tools has shown to bring detailed information on airflow, particle spreading, ventilation effectiveness and the overall indoor air quality.

From the numerical tools, Computational Fluid Dynamics (CFD) techniques can solve the complexity of the airflow derived from the room geometry with restrictions on the location of inlet/outlets, diffusers' characteristics, the occupation and location of the surgical staff, surgical equipment that can block the airflow such as the surgical lamps, the frequency of opening and closing the doors, air temperature and also space asymmetries (Sadrizadeh et al. 2018; Sajadi et al. 2020).

Several factors influence the number of particles, such as the number of people inside the room, the mobility status of these people, whether the room is clean or unclean, and the opening and closing of the door of the operating room affect the number of particles (Ufat et al. 2018). The risk of carrying infections from particles larger than 5 mm is quite high (Hansen et al. 2005) and it is necessary to reduce the number of particles of this size as much as possible.

In this paper, the airflow distribution within an operating room and the resultant skin follicle spreading over the space is numerically studied. The effect of inlet air velocity, velocity distribution, and airborne particles dispersion in the operating room is evaluated. The results of the present study provide a better understanding of the airflow pattern in the operating rooms to find more applications for developing more effective ventilation strategies to reduce infections after surgeries.

2 Materials and Methods

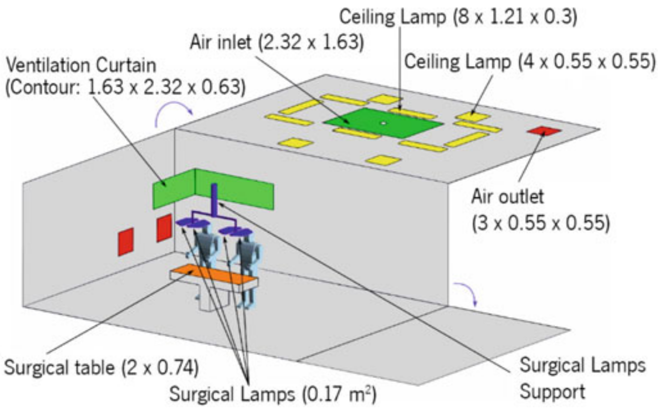
In this section, the operating room geometry, considerations for the mesh generation and simulation setup conditions are presented regarding the Ansys Fluent® numerical simulation. For this, it was considered an HVAC system, which incorporates an insufflation and three extraction grids.

2.1 Geometry and Mesh Generation

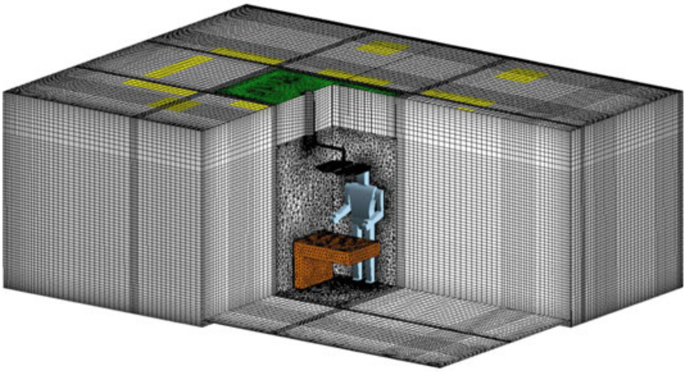
The domain of this computational study consists of an operating room which is represented in Fig. 1a, with the following dimensions: 3 m x 7.9 m x 5.9 m for height, length and width, respectively. On the ceiling of the operating room, there are several lamps marked in yellow. There are 2 outlets on the sidewall, and one air outlet on the ceiling, all marked in red. The air inlet for ventilating the room is located in the centre of the ceiling and immediately above the surgical table, identified by the colour dark green.

In the centre of the room are included surgical lights and bellow is the surgical table where the operations are performed. Next to the surgical table, two mannequins were placed in order to see the influence of the human body on the airflow. Around the air inlet, it is also possible to verify the existence of a thin curtain, represented in light green, that directs and aligns the airflow. The purpose of this curtain is to try to maintain a laminar airflow over the area where the operation takes place.

Figure 1b represents a section of the mesh used in the present study for the operating room. The generation of this type of mesh is facilitated in simple geometries with little or no curvature. In the present study, although the mannequins drawn are already simplified, they still have many irregularities in their shape, which makes the



a)



b)

Fig. 1 **a** Representation of the modelled operating room geometry. **b** Representation of the generated mesh for the geometry under study, considering the location of the refinements near to the mannequins and surgical table (Rodrigues 2017)

creation of a regular mesh a complex and slow process. Despite this, the remaining parts of the room are composed of regular geometrics. It was therefore decided that when creating the mesh for the geometry in question, it would be tetrahedral in the central area near the mannequins, and hexahedral for the remaining geometry. In total, the mesh produced had a total of 1.8 million elements.

2.2 CFD Model

The CFD simulation was elaborated using Fluent 2021 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 the water vapour diffusion, and a Discrete Phase Model (DPM) for particle tracking. For viscosity, the k-ϵ Realizable was selected since this model is robust in simulating turbulence (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

After selecting and defining the models it is important to characterize the conditions by which the problem is bounded. The boundary conditions are necessary to define and impose limits in certain regions that influence the problem. The values for the air inlet boundary conditions were obtained by in field measurement in an operating room, together with the environmental variables.

Regarding the lamps in the room, the thermal energy they produce was stipulated based on their characteristics (glass with 50 W/m^2), defined as a heat flux. The surgical lights were also defined as heat flux, but their defined characteristics were glass with 239 W/m^2.

The air outlets in the operating room had as boundary condition a relative pressure of 5 Pa, defined with pressure-outlet. The air inlets took the value of 0.27 m/s, with a turbulence intensity of 4.3%, with a hydraulic diameter of 1.91 m, supply temperature of 19.3 ºC, and relative humidity of 56.6%, and were defined with velocity-inlet. The directional curtain was considered an adiabatic interior wall with associated heat flux, set with coupled (the temperature of one face of the wall is passed to the other). In terms of heat transfer, all surfaces that were not considered as boundaries, such as the room walls and surgical table, were considered adiabatic to simplify the problem.

The skin follicles have a density equal to 850 kg/m^3, a minimum diameter of 9.00×10^{-10} m, a maximum diameter of 5.00×10^{-12} m, and an average diameter of 1.00×10^{-5} m for a total mass flow of 7.12×10^{-14} kg/s. Regarding the properties used in the definition of the different materials, these are represented in Table 1.

Table 1 Characteristics of the thermal properties of the materials considered in the CFD model definition

Material	Density (kg/m^3)	Heat capacity (J/kg K)	Conductivity (W/m K)	Emissivity
Concrete	2400	750	1.70	0.85
Glass	2600	840	1.05	0.93
Aluminium	2720	871	202.4	0.1
Clothes (cotton)	1500	1200	0.16	0.77
Skin	1200	7800	0.21	0.95

3 Results and Discussion

Due to small size of the skin follicles, their trajectory is greatly influenced by the air flow within the operating room, and the velocity fields within the operating room are of great relevance. The hotter colours, yellow and orange shades of Fig. 2, represent regions with higher velocities, which are predominant in the central region.

This is an expected behaviour since this region is directly located below the air inlets. Additionally, the air flow mostly follows one direction, creating a curtain of laminar air flow in the central region that later spreads to the surroundings. This is the ideal scenario since laminar flow is better suited to carry the skin particles and remove possible contaminating sources from the patient and surgeons. However, it is possible to observe that the surgical lamps promote changes in the flow direction and cause turbulence which is not ideal. Nonetheless, the surgical lamps are essential for the surgeons to perform their work and need to be placed above the operating table to provide better illumination.

The particles are released from the surgeon face as it is the least protected part with the forehead and eyes region exposed. To simplify the simulation, the patient geometry was not designed and the particles were released directly from the operating table. Figure 3 shows the particle distribution within the operating room at 3600 s of simulation time. This was considered the duration of the surgery and is the time when the particles ceased from entering the domain. Considering that the particles input was constant, this is also the moment when the particles concentration is higher. Regarding the particle's distribution, it is possible to observe the tendency of the particles of moving from the centre region to the surrounding. This follows the ventilation movement, indicating that the ventilation is promoting the surgeons and patient's safety by dragging the particles away.

Additionally, the colour distribution shows low mixture of particles from different sources, demonstrating the advantage and effectiveness of the laminar flow. One point to take notice is that although the laminar flow in the central regions helps protecting

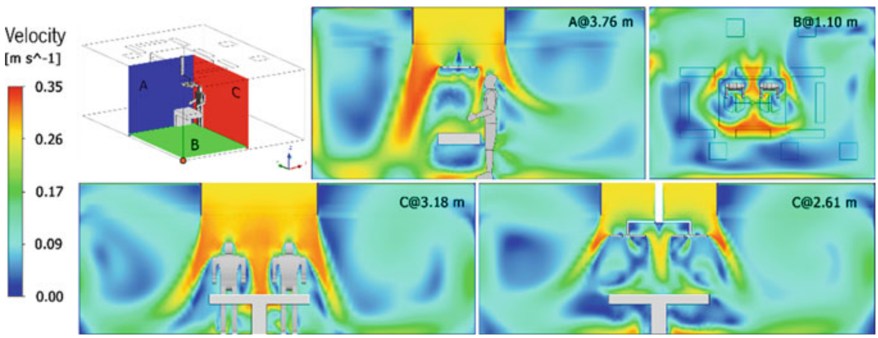


Fig. 2 Velocities field within the operating room at different projection planes. The reference point for the planes locations is demonstrated at the top left point of the figure. The orientation of place C has two locations, showing the air flow above the surgeons and the operating table

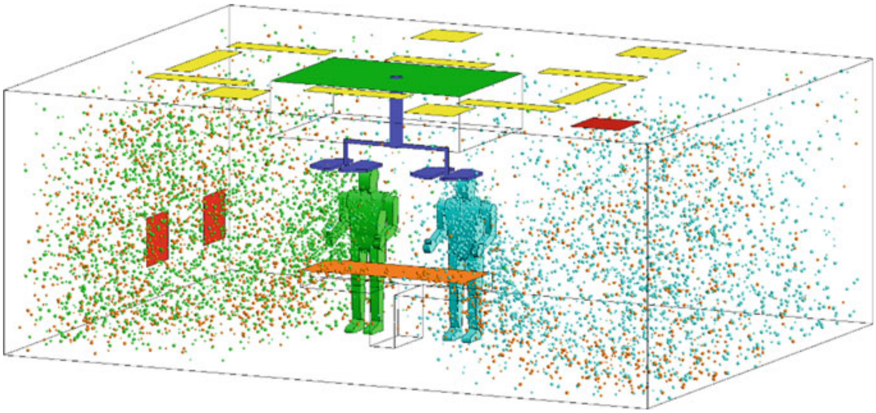


Fig. 3 Particles distribution within the operating room at 3600 s simulation time. The colour of the particles matches their respective source

the occupants, in the peripheral regions, the air flow is no longer laminar and the particles concentration is higher. This indicates that airborne pathogens can have a great impact for nurses and other medical staff who are generally located around the central region.

Once the particles are no longer being injected into the domain, their concentration begins to dwindle, and at 4800 s of simulation time, the particles concentration is considerable reduced as seen in Fig. 4.

This result points that a 20 min interval promotes a good air renovation and efficient elimination of the contaminants.

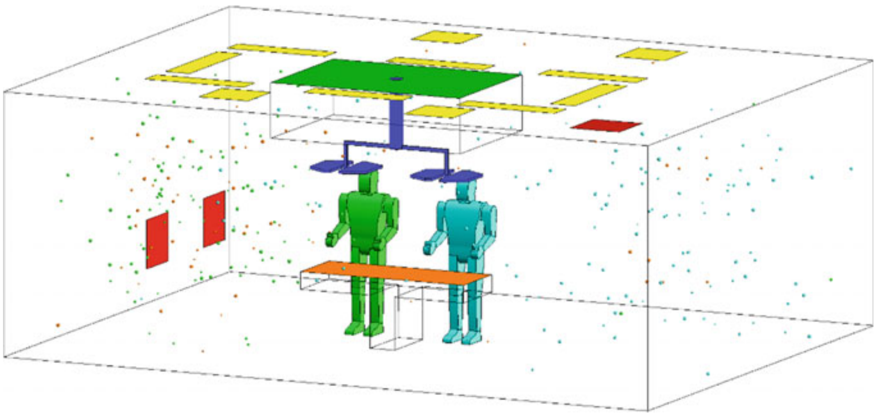


Fig. 4 Particles distribution within the operating room at 4200 s simulation time. The colour of the particles represents their respective source

4 Conclusions

In general terms, the ventilation of the studied operating room showed efficiency in protecting the patient and surgeons, which reduces surgical site infections. At the same time, numerical simulation showed that the peripheric regions suffer from turbulence and the staff that is generally positioned in this region may have greater exposure to airborne particles and thus infections from this source.

The laminar flow also proved to be an essential method of avoiding the mixing effect on the particles and consequent deviations in their intended trajectory, this is, away from patient and surgeons, strengthening its need. The surgical lamps, although essential, cause the development of turbulent flow and further studies on their geometry and effects on the patient safety could provide greater safety. The present simulation also showed that an interval of 20 min after a surgery greatly reduces the number of particles suspended within the operating room, avoiding possible contamination between patients.

Further development of this study should focus on better representing the particles release, this is, instead of a regular flow of particles, the release could be function of the air velocity near the surgeons and operating table, as greater air velocity promotes the release of particles. To better understand the efficiency of the particles' removal, the outlets' location and size could be studied in order to provide solutions for a better air flow. To improve accuracy of the simulation, more mannequins should also be introduced as they influence the air flow and represent a source of particles.

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Bioburden Assessment in Lisbon Groceries

Sílvia Moreira, Marta Dias, Bianca Gomes, Renata Cervantes, Pedro Pena, and Carla Viegas

Abstract *Objective* This study aims to characterise the occupational exposure to the bioburden of groceries workers and to identify the most critical workstations. *Background* To our knowledge, this is the first study performed in Portugal that intends to characterise the microbial contamination in this specific setting. *Method* This study was conducted between November and December of 2020 in fifteen groceries stores (M) located in the municipality of Cascais. Passive sampling methods (Electrostatic dust cloths—EDC) and surface swabs were used at three different locations (checkout, fruits/vegetable and warehouse/dispenser areas). EDC and surface swabs were inoculated in four standard culture media, namely, malt extract agar (MEA), dichloran glycerol (DG18), tryptic soy agar (TSA) and violet red bile agar (VRBA) for further characterisation. *Results* The prevalence of bacterial contamination was higher than fungal contamination in both sampling methods. The highest prevalence was in the fruits/vegetable area regarding fungal and bacterial contamination. *Conclusion* The sampling methods employed effectively identified the most critical workplaces regarding microbial contamination. *Application* This study will be useful for industrial hygienists since it is the first held in small grocery shops focusing in the occupational exposure assessment of microbiological contamination.

Keywords Bioburden · Occupational exposure assessment · Groceries · Critical workplaces

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1 Introduction

The environmental conditions of workspaces are predominant factors for workers' comfort and their daily health and well-being (Cincinelli and Martellini 2017; Tran et al. 2020; Śmielowska et al. 2017). Microbiological contaminants are omnipresent and essential to various forms of life. Their origin alters depending on the type of microorganism and how it was carried (people, animals, soil, plants) (Górny 2020). When deposited on surfaces, microbiological contaminants can maintain their viability for an extended period, representing a threat to workers and all occupants because inhalation or ingestion of microbiological contaminants can be related to numerous adverse health situations. However, their survival decreases when indoor air is deprived of nutrient sources or when there is a variation in humidity and temperature (Górny 2020). Workers are often exposed to microbiological agents as their working environment are generally indoors. However, legal criteria for occupational exposure to microbiologic agents are still unavailable in Portugal (Shan et al. 2019). The workplace microbiological contamination may be essentially due to the presence of bacteria and fungi, which under proper conditions their growth and proliferation can be boosted (Leppänen et al. 2017). The microbiological characterisation of the air, quantified through surface analysis, can identify sources of contamination and thus assess the effectiveness of the cleaning procedure (Viegas et al. 2016).

To adequately evaluate the potential health impacts of occupational exposure to bioburden, comprehensive data on exposure sources and all variables that potentially influence exposure is essential (Viegas et al. 2021a). A multi-approach regarding sampling methods (combining active and passive sampling methods) is useful for revealing a more realistic scenario of bioburden exposure (Viegas et al. 2019, 2020, 2016).

Although the use of only active sampling (air sampling) is the current trend, passive approaches allow for data collection over a longer period time (weeks or several months) (Viegas et al. 2021a). It also provides a valid risk assessment since it permits measurement of the harmful part of the airborne population, which falls onto a critical surface, and it is a readily available, economical, and unobtrusive method (Ribeiro and Faria 2017).

To our knowledge, there has been no research on the exposure of grocery employees to bioburden. The goal was to perform an expanded study to characterise the exposure of grocery employees to microbial contamination identifying the most critical workstations regarding fungi and bacteria in local grocery stores.

2 Material and Methods

This study was conducted between November and December of 2021 in fifteen groceries stores (M) located in the municipality of Cascais.

Passive sampling methods (Electrostatic dust cloths (EDC) and surface swabs were used at three different locations (checkout, fruits/vegetable and warehouse/dispenser areas). EDC and surfaces swabs were inoculated in four standard culture media, namely, malt extract agar (MEA), dichloran glycerol (DG18), tryptic soy agar (TSA) and violet red bile agar (VRBA) for further characterisation (Viegas et al. 2021b). EDC was collected in three different locations (fruits/vegetable, checkout and warehouse/dispenser areas) and extracted in a 50 mL Falcon tube with 20 mL of 0.05% Tween™ 80 saline solution (NaCl 0.9%) for 30 min at 250 rpm on an orbital laboratory shaker (Edmund Bühler SM-30, Hechingen, Germany) (Quendera et al. 2016). After incubation of MEA and DG18 at 27 °C for 7 days for fungi and TSA and VRBA at 30 and 37 °C for 5 and 7 days for mesophilic bacteria and coliforms (Gram-negative bacteria), respectively, fungi and bacteria densities (colony-forming units, CFU m^{-2} g) were calculated.

3 Results

Total bacteria (TSA) presented a higher prevalence in checkout with swabs and on fruits/vegetables with EDC. Regarding Gram—bacteria (RB), fruits/vegetables location presented higher prevalence in both sampling methods (Fig. 1).

The highest prevalence of fungal contamination was in the fruits/vegetables area in both sampling methods and culture media (Fig. 2).

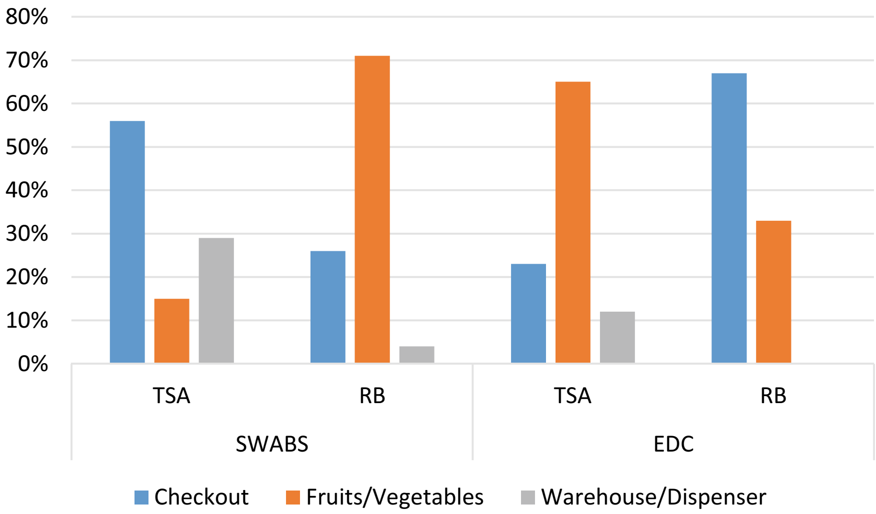

Fig. 1 Bacterial distribution in both environmental samples

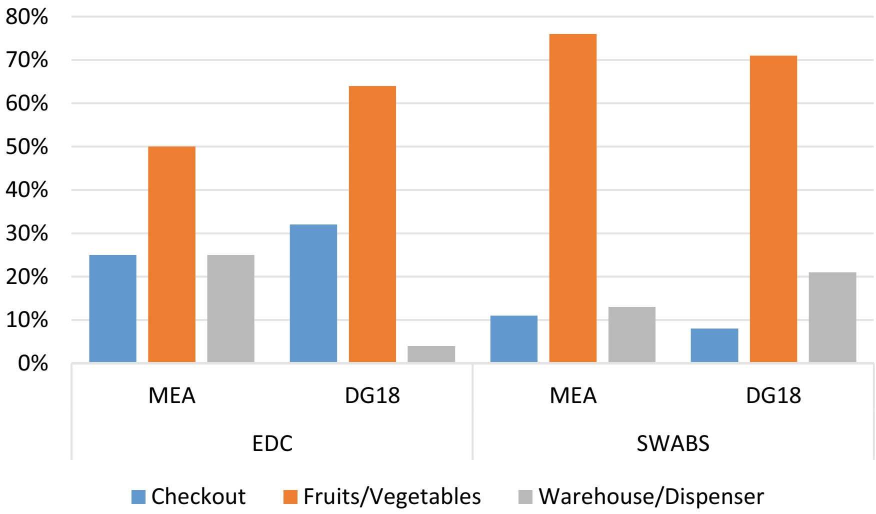

Fig. 2 Fungal distribution in both environmental samples

4 Discussion

The sampling approach applied was useful to screen the most critical workstations in what concerns bacterial and fungal contamination occupational exposure. In fact, EDC presents several advantages already reported in different studies, such as overcoming the limitation of overloaded plates through extracts dilution before inoculation and selecting the best culture media depending on the microorganisms to be assessed (Viegas et al. 2018; Badyda et al. 2016). However, to place EDC in locations where the sampling devices are not disturbed or damaged during working activities (e.g. elevated, surfaces) can lead to a collection of particles that may never contribute to human exposure through inhalation (Viegas et al. 2018; Madsen et al. 2012). Surface swabs are used to direct sample critical points and identify potential sources of contamination (ISO 18593:2018; Viegas et al. 2017, 2020). The use of selective culture media allowed one to understand the growth of the existing microbial contamination and identify potential contamination sources. Despite concerns about bacterial contamination of food in supermarkets (Lakicevic et al. 2015; Quendera et al. 2016; Reynolds et al. 2005; Calle et al. 2020), there has been little research published on the surveillance of specific food contact surfaces at the retail level (Calle et al. 2020). Bacterial contamination was higher in checkout and that may have several reasons such as handling and hygiene behaviors that may increase the risk of disease transmission (Paulin et al. 2017). It is well recognized that contaminated hands can spread infections (Paulin et al. 2017; Chung et al. 2008), since tasting and handling vegetables could raise the possibility for foodborne illness. Bacteria on a customer's hand can be transferred to and remain on the product, whether it's chosen for personal use or returned to the shelf for the next customer. Additionally, numerous customers may be touching and returning the same or multiple pieces of the product (Paulin et al. 2017). Other reason that can justify both bacterial and fungal high contamination in checkout is the fact that many fuits/vegetables may get contaminated at any stage of production and supply chain, through direct contact with fecal waste during farming, such as wastewater irrigation and the use of biosolids or animal manure as fertilizer (Chee-Sanford et al. 2009; He et al. 2020; Rahman et al. 2022). Aditionally, it is important to highlight that fruits and vegetables, particularly raw leafy greens, are rapidly becoming recognized as key vehicles for the spread of human infections previously associated with animal-derived diets (Rahman et al. 2022). In fact, the fruits and vegetables can be indoor contamination sources, since fungi are commonly associated with the spoilage of these food commodoties (Moss 2008).

5 Limitations

Since the EDC must remain intact for 30 days, the choice of locations for placing the sampling devices may not be the most effective for the collection of particles that reflect exposure through inhalation.

6 Conclusions

This study emphasizes the need for the surveillance of microbial contamination in this occupational environment. Since it is the first held in small grocery shops it will be useful to raise awareness among employers, workers and other stakeholders. The passive sampling methods were effective in identifying the most critical workstations. However, further studies should combine active and passive sampling methods and ensure species identification to ensure a better risk characterization and management.

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Covid-19—Effects and Mitigation Measures in Stone Industry

J. Gonçalves, C. M. Reis, Paula Braga, and C. Oliveira

Abstract In Portugal there are more than 2500 companies and 15,000 people who work directly in the stone industry. In addition to all the known risks in this type of industry, the critical in terms of safety and health that companies and people linked to the stone sector have faced in recent years has been COVID-19, given that, in addition to all the damage that this disease on people's health has (and still does) lead to a reduction in business productivity, an increase in labour costs and a delay in product delivery times. The research in this study intends to investigate safety and health measures to be implemented by the stone industry and their usefulness to mitigate the effects of COVID-19 in the stone industry and analyse how COVID-19 pandemic affected the stone industry.

Keywords COVID-19 · Stone · Safety and health · Social distancing · Construction · Industry

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1 Introduction

Stone industry and the construction industry are two closely linked sectors as one produces goods for the other to use. In December 2019 was discovered a new kind of coronavirus disease (COVID-19). SARS-CoV-2 is a virus that causes a respiratory disease that spreads from person to person primarily through respiratory droplets produced by infected people when they cough, sneeze, or talk (Centers for Disease Control and Prevention (CDC) 2020). This, associated with high mortality in the stone industry, has a negative effect, bringing losses to companies in the sector. Each year, the construction industry faces over 55,000 fatal injuries worldwide, making it one of the sectors with one of the highest mortality rates) (Elsafty et al. 2012) Quarry employees must take extra care in protective measures against COVID-19 because due to their activity, there is an increased risk associated with the inhalation of dust particles, namely silica, which are released, which will have serious consequences for the health of workers (Braga et al. 2019). In March 2020, this pandemic, and its ability to cause severe symptoms, leading to possible fatalities for some, led to a complete lockdown throughout the world and brought the world to a halt and companies had to adapt to this new reality (Alauddin et al. 2020). The concerns about outbreaks and contamination control caused many projects and companies to cease all work. The need for improved danger management methods to process safety in industry was obvious. As with most regulations and safety measures, awareness and implementation are influenced by organizational demographic factors, such as company type, size, and location (Lin and Mills 2001).

The current research firstly presents mitigation measures adopted by the stone industry to reduce the impact of COVID-19 on their activities. Then are presented the results of an in-depth interview conducted on companies related to the stone industry to measure the effects of COVID-19.

2 COVID-19 Mitigation Measures

When implementing prevention and mitigation policies at work, companies must balance policy interventions with measures to limit the potential impact on socio-economic well-being, including access to services and loss of income. In order to contain and limit the spread of COVID-19, mitigation strategies have taken effect (locally and worldwide). One of the most important mitigation strategies is social (physical) distancing. Studies suggested that social distancing would effectively decrease the transmission of COVID-19 by about 60% (Anderson et al. 2020).

To know what measures can be taken in order to control coronavirus spreading is necessary to define the danger situations, the risks and the possible damages or consequences for the workers (Table 1).

Table 1 Dangers, risks and damages or consequences for the workers

Biological risk (COVID-19)		
Danger situation	Risks	Damages or consequences
Failure to use adequate protective masks Protective masks in poor condition of cleaning or conservation Workers with symptoms and/or infected and reporting to work	Exposure to viruses harmful to the health of the worker	Fever above 38 °C Persistent cough or worsening of symptoms Fatigue, extreme tiredness Muscle aches Difficulty breathing Loss or reduction of appetite, taste and smell Pneumonia Death

According to Resolution of Portuguese Ministers Council No. 92-A/2020, Portuguese National Healthcare System orientations and measures already implemented by companies the following measures are suggested to mitigate COVID-19 in stone industry:

- The company must prepare and implement its Contingency Plan, in accordance with the guidelines, standards and other information from the health authorities and/or health delegate, and/or local health entity;
- All workers must be aware of the company's Contingency Plan as well as all preventive measures to prevent the transmission of the SARS-CoV-2 virus (COVID-19);
- Workers must be informed of all safety procedures and mode of action in a suspect case in the workplace;
- All company personnel must wear the appropriate Covid-19 protective mask;
- Workers must have enough protective masks at their disposal throughout the working day;
- All workers must receive instructions and instructions to use them correctly;
- Protective masks are objects for individual and non-transferable use;
- Used disposable masks must be placed in a suitable waste container and never abandoned at the workstation or discarded on the floor/ground;
- Covid-19 surgical masks must be replaced after 4 h of use, or when they are damp or dirty;
- AVOID as much as possible the contact of workers with people external to the company (suppliers/commercials/external maintenance teams, etc.);
- Prevent workers from outside the company from using workers' machines/equipment, as well as how frequent the company's social facilities;
- Keep workers at workstations with a distance of 2 m;
- Sensitize workers to self-monitoring of Covid-19 symptoms, and in case they appear;
- Avoid that more than 5 workers gather at the same time during break times, take shifts for breaks/meals;

- Ventilate break/meal spaces, restrooms and changing rooms very well after each use;
- Increase the frequency of cleaning and disinfection operations in spaces occupied by workers;
- Provide frequent cleaning of surfaces in common use or touched by several workers;
- The user of machines and utensils in common use must clean and disinfect after using the appropriate solution for disinfecting surfaces;
- Place hand sanitizer solutions in strategic locations at work stations;
- Raise awareness among workers of the importance of frequent hand disinfection;
- Keep the alcoholic solution dispensers in a good state of cleanliness and hygiene;
- Check the status of the alcohol solution dispensers daily and keep the containers always with product inside;
- Post instructions on how to properly disinfect your hands next to the alcohol solution dispensers.

3 Methodology

This study utilizes the embedded mixed design method, in which qualitative and quantitative research methods were used together. To collect information for this project, we interviewed companies related to the extraction and transformation of ornamental rocks.

The embedded mixed design method uses qualitative/quantitative data to support findings that were gained via quantitative/qualitative studies. Embedded mixed design can be used by the researcher with different data types to examine the main purpose of the research and improve the applications of quantitative and qualitative methods (Creswell and Plano Clark 2011) (Table 2).

The interview consisted in 9 open questions related to the respondents' experience, perceptions, and its opinions. During the testing, the topics of the interviews were

Table 2 Results of the first product analysis

Number	Question
1	How many permanent employees do you have?
2	What is the number of masons, factory workers, drivers and office staff?
3	Have you struggled with shortage of workers and what was the reason?
4	Have you dismissed permanent staff?
5	How did you protect your employees on the quarry/factory/office?
6	Which parts of the staff has been assigned home office?
7	Has the pandemic affected your production times?
8	Have any orders been cancelled during the pandemic period?
9	Has the pandemic affected the price of your products?

verified with redundant questions. Firstly, we tested 3 company's representants to verify the quantity and quality of results Following this small sample, it was possible to continue the research (Martínez et al. 2016). The interview was conducted with a total of 25 company's represents in North of Portugal employing a total of 750 workers. There was no need for more interviews, as the same data, including identical experience, were repeated in the outputs.

4 Results and Discussions

In question 1 we ask the number of employees to define the type of company. According to (Portuguese Ministry of Economy and Innovation 2007) a micro, small and medium-sized company comprises companies that employ less than 250 workers and whose annual turnover does not exceed 50 million euros or whose annual balance sheet does not exceed 43 million euros. A micro company is defined as a company that employs less than 10 workers and whose annual turnover or annual balance sheet total does not exceed 2 million euros. A small company is defined as a company that employs less than 50 workers and whose annual turnover or annual balance sheet total does not exceed 10 million euros. Among the 25 companies contacted we can divide 12 into micro, 10 into small and 3 into medium-sized companies.

Question 2 had as main objective to divide the company's employees according to their function. The purpose of this is to verify the staff number in the company and to study the sector where COVID-19 appeared more (Fig. 1).

Question 3 refers to the shortage of workers. According to the interview, 55% of employees worked regularly during the pandemic period. Main reasons for the ones that stayed home are: 40% due to quarantine, 10% due to illness and 50% for other reasons.

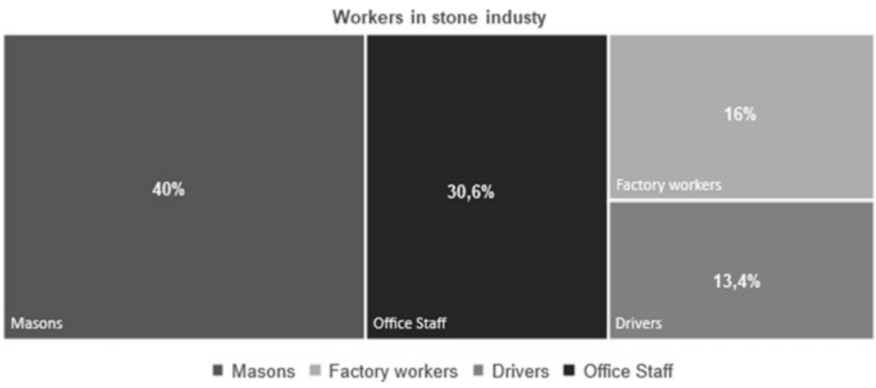

Fig. 1 Workers in stone industry

Question 4 focused on the dismissing of permanent staff. During COVID-19 in stone industry there were no layoffs in this industry. At the beginning of the pandemic, the hiring of new employees was in most cases suspended, having been resumed when the perception that the pandemic did not affect the sector.

Question 5 concerned the introduction of protection measures to protect the workers. To reduce the impact of COVID-19 most of the companies used many of the mitigation measures that were presented previous. Most common measures were mandatory use of masks, provision of hand sanitizers, a more regular facility disinfection, sensibilization to use social distance and, when possible, work from home.

Question 6 examined the values regarding the numbers of workers who worked from home. When the mandatory lockdown was in place, only factory personnel, drivers and masons went to their place of work normally. With the relaxation of the measures, some people from the office began to go to work personally (and generally the commercials, accountants and directors remained in telework).

Question 7 dealt with production times. During the period when there were more cases of infected and quarantined, material delivery times were longer as there were fewer people performing their duties. It was reported that deliveries had to be delayed as critical sectors (such as material packaging) had all employees absent at one point.

Question 8 classified if there were cancellations in the orders. At the beginning of the pandemic due to the fear of customers, there was a reduction in orders. When stone stocks in warehouses began to reduce, orders returned to normal, and in many companies they were even reinforced. Question 9 described how the selling prices to the consumer changed. At an initial stage, prices remained the same, but over time they increased between 2 and 10%. When asked about this price increase, many mentioned the increase in the cost of transport, the same work for less available employees and the increase in energy costs.

5 Conclusions

In this work, mitigation measures for COVID-19 were presented, and we realized how companies in the stone industry sector can prevent contagions and spreading of this virus. Although the measures presented are simple to implement, they are being successfully applied, thus reducing the transmissibility of the virus. The results of the interviews carried out with several companies in the sector allowed us to verify that the sector was not severely affected by the pandemic, with the biggest problems coming from the increase in costs associated with the transport of goods and the amount of essential personnel who had to stay at home. The data obtained are in agreement with the report "Portugal: A quick analysis of the impact of COVID-19 on the economy and in the labour market" (Mamede et al. 2020), since this author states that the construction industry maintained its activity level with few limitations, and is still benefiting from investment decisions taken before the pandemic, which may explain the relatively moderate unemployment registered in the sector until the end of April (+14.7% on year).

Acknowledgements This work was financially supported by: Programmatic funding—UIDP/04708/2020 of the CONSTRUCT—Instituto de I&D em Estruturas e Construções—funded by national funds through the FCT/MCTES (PIDDAC)

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Women Radiation Exposure Prevention: The Effect of Distinct Radiological Literacy Levels

Beatriz Barros and Florentino Serranheira

Abstract The support that radiological examinations provide for medical diagnosis is essential. Over time, an increase in the performance of these exams has been observed and, consequently, an increase in people exposed to X-rays. For biological reasons, women are most sensitive to X-rays. It becomes important to analyse their health literacy levels, safeguarding radiological protection in the future. An online questionnaire was developed, and disseminated on the digital platforms of three associations, aimed at women aged between 18 and 57. A sample of 502 women was obtained. It was possible to observe gaps in health literacy, namely in dose, as well as in the X-rays presence in some exams, such as "Mammography" and "Bone Density". Variables such as "Age" and "Academic Qualification" are shown to directly influence the literacy levels presented. On the other hand, the information provided by the Healthcare Professionals did not reveal to exert any influence on the levels of women's radiological knowledge. Betting on greater and better communication in radiology for this target audience, considering the sociodemographic variables of each one, will promote greater interest and participation of Health Users in the process, helping to increase radiological protection and safety.

Keywords Radiology · Radiological protection · Public health · Knowledge · Health promotion

1 Introduction

Radiology value in medical diagnosis is undeniable. Radiodiagnostic has had a great evolution in terms of equipment and protocols, which over the years has led to an increase in the number of radiological exams performed by the population (Al

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Ewaidat et al. 2018; McCollough et al. 2015; Naqvi et al. 2019). The increasing of X-rays exams contributes to a boost on population's exposure to ionizing radiation, mainly due to the Computed Tomography (CT) exams (Al Ewaidat et al. 2018; Frush and Applegate 2004; McCollough et al. 2015).

In Portugal, according to the Organisation for Economic Co-operation and Development (OECD), it was found that in 2017 the number of CT exams performed in hospitals was higher (189 CT per 1000 population) than the average (148 CT per 1000 population), stipulated by the OECD (2019).

This increase means that the population is more exposed to the ionizing radiation and higher risks arising from X-rays exposure. Within the general population it is possible to identify groups that are more sensitive to these effects, such as women and children. It is known that women use health services more often throughout their life and when in childbearing age, their reproductive system is more susceptible to damage (greater probability of stochastic effects) (American College of Radiology 2018). For example, an 80-year-old woman has 2.4 times more risk of cancer associated with ionizing radiation than a man of the same age and a 20-year-old woman is 23 times more at risk of developing a cancerous pathology associated with X-rays than an 80-year-old man (Street et al. 2009).The female population should have greater attention and concern on the part of the healthcare system (Hricak et al. 2010; Shyu and Sodickson 2016; Silva and Guerra 2017; Takakuwa et al. 2010). So, it is important to identify women X-rays literacy, mainly on exposure adverse effects and radiological protection needs (Health Literacy in the Radiological context).

The concept of Health Literacy is related to the mobilization of a set of "cognitive and social skills and the ability to access, understand and use information in order to promote and maintain good health", according to the World Health Organization (WHO) (Direção Geral da Saúde 2018; Goske and Bulas 2009). It is a concept that relates to several individual and collective variables, such as: education, age, presence of chronic diseases and income (Direção Geral da Saúde 2018; Lumbreras et al. 2017). According to the data obtained in the "Health Literacy Survey in Portugal in 2016", Portugal is the country with the lowest percentage of people (8.6%) with an excellent level of literacy in the European Union (16.5%). With regard to the problematic level of Health Literacy, Portugal, shows a higher percentage value than the European Union average (38.1 and 35.2% respectively) (Direção Geral da Saúde 2018).

Applying this concept to the Radiology context, it is known that healthcare users with low levels of literacy do not know how to identify which exams or when they have undergone through, what is the clinical justification that motivated the performance of radiological exams, as well as they do not know how to identify radiological protection measures used or needed (Al Ewaidat et al. 2018; Lumbreras et al. 2017). This difficulty in transmitting information about the radiological process, is a risk factor for a new appointment, leading to an overexposure of the healthcare user to the X-rays (Silva and Guerra 2017).

For the system to meet the needs of this specific group (women of childbearing age), it is important to assess what this target population knows about Radiology and what kind of knowledge gaps occur in this area. This is the only way that the system and the Healthcare Professionals (main promotors of Health Literacy) can adjust their practices, so that the user is increasingly the centre of the entire process (Alhasan et al. 2015; Almaghrabi 2016; Chiesa et al. 2007; Ukkola et al. 2015).

As the main objective of this study, it was intended to assess the level of literacy that women of childbearing age have on radiological exams hoping that will result on appropriate radiological protection measures.

The specific objectives defined were to:

- Identify the existing knowledge of exposure to X-rays and radiological protection in the group of women of childbearing age;
- Analyse which sociodemographic variables influence the level of literacy in Radiology and the understanding of the information provided to the target population;
- Analyse the influence of information provided by Healthcare Professionals on Radiology Literacy.

2 Materials and Methods

In order to meet the previously defined objectives, a cross-sectional, retrospective and exploratory-descriptive study was carried out.

An online questionnaire was built, based on previous studies (Al Ewaidat et al. 2018; Costa et al. 2015; Aldossari et al. 2019; Jończyk-Potoczna et al. 2019; Lumbreras et al. 2017; Sin et al. 2013). Questionnaire was adapted in the Portuguese context and a pre-test was carried out with 10 women, to possibly identify words, phrases or structure of the data collection instrument that did not allow a good understanding of what was intended to be investigated. All points identified in the pre-test were analysed in order to favour a better understanding, ensuring that the facial validity of clarity was fulfilled.

The questionnaire was aimed at Portuguese women from 18 to 57 years old and the participation was voluntary (no sampling process was followed) and was divided into three dimensions: sociodemographic information; information about the radiological examination performed; and health literacy in Radiology (American College of Radiology 2018). All terminology used in the questionnaire (interval between years and denomination of geographic areas is in accordance with NUTS II (used in the National Health Survey) (Instituto Nacional de Estatística 2016).

The digital platforms of three associations supported the questionnaire dissemination via internet:

- APAMCM (Portuguese association to support women with breast cancer): Is dedicated to health promotion with special focus on women with breast cancer;
- EVITA (Association of support for carriers of changes in genes related to hereditary cancer): It's mission is to inform, raised awareness and support health users in making share decisions in their Health (EVITA 2019);

- NUCLIRAD (Development nucleus of Radiographers): Has a main objective to value and help projects developed by radiographers (NUCLIRAD 2019).

The questionnaire was available for 1 month (from 13 January 2020 to 13 February 2020). Taking into account the objectives outlined, it was stipulated that the sample value should be greater than 500 participants.

A statistical analysis was done using the software Statistic Package for the Social Sciences IBM (SPSS 24 Version), firstly in a univariate way and after through statistical tests: Chi-Square Test and Binary Logistic Regression Model. With the Chi-Square Test, it was intended to understand whether the dependent variables linked to radiological literacy had any association with the independent variables. After applying this test, it was intended to build a mathematical model to assess the percentage of influence between the variables under analysis (Binary Logistic Regression Model), in order to corroborate the results obtained in the previous test and determine which independent variable influences the most results of the dependent variables.

In order to understand the influence of information and sociodemographic variables on the levels of radiological literacy, the Chi-Square test was applied.

Based on the results obtained in the statistical test previously designated, the binary logistic regression model was applied, using the method "Enter".

For all statistical inferences, a significance level of 5% ($\alpha = 0.05$) was considered.

3 Results

After one month, we obtained a total of 502 responses. The main sociodemographic characteristics of the sample are represented on Table 1.

We observed that the vast majority of women (91.24%) have already undergone radiological exams. The exams most performed were ultrasound (31.1%) and conventional radiography (24.7%).

Regarding the provision of information before the radiological procedure, by the Healthcare Professional, 92.4% of the participants indicated that the reason for the examination was explained to them. Also, 70.7% of the respondents indicated that they clearly understood the information provided, against 10.3% of the sample to indicate that they had difficulty to understand the information. It should be noted that 19% of women indicated that they were not provided with any type of clarification about the radiological examination to be performed.

Through the statistical analysis (Chi-Square Test) it was possible to understand that schooling influences ($p = 0.027 < 0.05$) the understanding of information (women with lower levels of education have more difficulty in understanding the information provided). Women with a bachelor's degree or that attend or frequented "University" (21.2%) were the ones who most reported that they had not been provided with any information regarding the procedures associated with the radiological examination to be performed.

Table 1 Sociodemographic characteristics

Variables		N (%)
Age	18–27 years	206 (41%)
	28–37 years	119 (23.7%)
	38–47 years	113 (22.5%)
	48–57 years	64 (12.7%)
Education qualification	Primary School	1 (0.2%)
	Secondary School	7 (1.4%)
	High School	16 (3.2%)
	College	146 (29.1%)
	University	332 (66.1%)
Marital status	Single	294 (58.6%)
	Married	173 (34.5%)
	Divorced	30 (6.0%)
	Widow	5 (1.0%)
Geographic area	North	62 (12.4%)
	Lisbon	290 (57.8%)
	Center	111 (22.1%)
	Alentejo	12 (2.4%)
	Algarve	7 (1.4%)
	Madeira	9 (1.8%)
	Azores	11 (2.2%)

Almost 56.2% of the participants said that they would not question a Healthcare Professional about X-rays (effects). Crossing this fact with the variable "Education Qualification" allows to realize that 54.2% of women with qualification equal to "University" did not address their queries on this topic, as well as 60% of women with lower level of education. In spite of everything, it would be the women with "University" who more frequently questioned this subject to a Healthcare Professional. Analysing the variable "Age", it was possible to observe that, with percentages greater than 50%, at both age levels, women would also not question a Healthcare Professional on this matter. However, women between 38 and 57 years old would question more frequently (47.5%) about this topic.

It was possible to understand that 97.2% of the sample referred that Healthcare Professionals should be trained for transmitting information aimed at women of childbearing age on exposure and radiological protection.

The variable "Radiological Literacy", composed of several points of analysis was subdivided taking into account the aspects that compose it: radiological exams using X-rays; radiological examinations that can be performed by a pregnant woman; radiation protection measures and radiation dose.

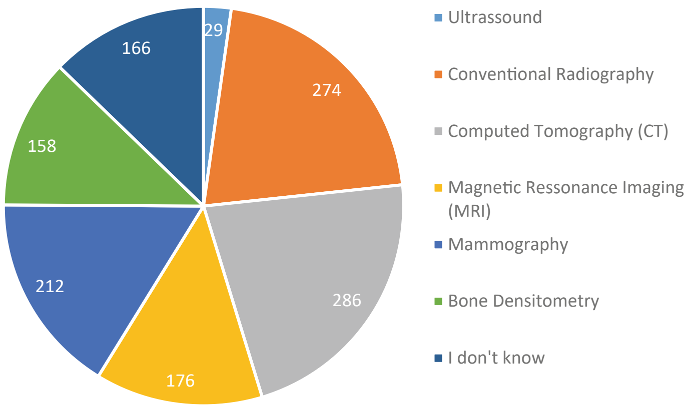

Fig. 1 Identification of radiological exams using X-rays

The three most identified exams that respondents believe used X-rays were: Computed Tomography (CT); Conventional Radiography; and Mammography (Fig. 1).

Those who obtained prior information from the Healthcare Professional, were able to better identify the radiological exams that use ionizing radiation (X2 = 16.012; p = 0.000).

The level of education also influenced the identification of X-rays exams. Women with more academic qualifications selected the option "Conventional Radiography" and "Computed Tomography" more often and less often the option "I don't know". But with regard to "Mammography" and "Bone densitometry" exams, it was possible to understand that the percentages of considering these exams as "free ionizing radiation" are higher than 50%, with greater expression in the lower educational levels, which demonstrates information needs about these radiological exams.

Women with higher levels of education identify almost 75 more exams correctly using X-rays (Table 2a).

The variable "age" did not prove to be statically significant ($p > 0.05$) for the responses made at this point of analysis.

For the variable "identification of the exams that can be performed by a pregnant woman" (Fig. 2), the most selected option was "Ultrasound" (54.61%), followed by the option "I don't know" (13.08%) and thirdly appears the option "Magnetic Resonance (MRI)" (12.95%). This placement of the MRI allows, from now on, to identify the existence of a lack of knowledge and beliefs regarding this diagnosis method.

It was possible to notice that the prior provision of information is independent (p = 0.094 > 0.05) of the identification of the exams that can be performed by pregnant woman.

Table 2 Binary logistic regression model applied to several variables

a. Binary logistic regression model applied to identification of radiological exams using x−rays and "education level"					
	B	Sig	Exp (B)	95% C.I: Exp (B)	
Education level	−1.395	0.000	0.248	Lower	Upper
				0.143	0.431
b. Binary logistic regression model applied to identification of the exams that can be performed by a pregnant woman with "age" and "education level"					
	B	Sig	Exp (B)	95% C.I: Exp (B)	
Age	−0.627	0.016	0.534	Lower	Upper
				0.320	0.891
Education level	−1.441	0.000	0.237	0.125	0.449
c. Binary logistic regression model to identification of radiological protection measures with "education level" and "age"					
	B	Sig	Exp (B)	95% C.I: Exp (B)	
Education level	−1.088	0.000	0.337	Lower	Upper
				0.222	0.512
Age	−0.415	0.034	0.660	0.450	0.969
d. Binary logistic regression model in a relation to the considering of BMI as a relevant factor for the level of the radiation dose taking into account the variable with "education level" and "age"					
	B	Sig	Exp (B)	95% C.I: Exp (B)	
Education level	−0.453	0.019	0.636	Lower	Upper
				0.435	0.928
Age	−0.476	0.621	0.013	0.426	0.905

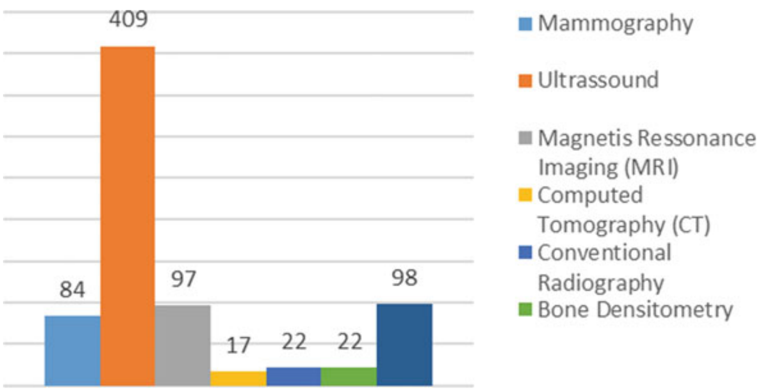

Fig. 2 Identification of the exams that can be performed by a pregnant woman

"Age", on the other hand, proved to be a variable influencing "Magnetic Resonance Image (MRI)" response. More than 50% did not select MRI as an exam that can be performed by a pregnant woman.

However, it was women in younger age groups (22.8%) who most identified this valence as being able to be performed by a pregnant woman.

The binary logistic regression model applied to this variable at this point in the study demonstrated that "age" (Table 2b) is a statically significant variable for the answers provided. It has been shown that women in younger ages are 53.4 times more likely to correctly identify which radiological tests can be performed by a pregnant woman.

Also, the level of education proved to be a variable that influences responses in this dimension. Women with education equal to "University" are almost 76 times more likely to correctly identify the exams that can be performed by a pregnant woman (Table 2b).

Analysing the variable "identification of radiological protection measures", it was possible to observe that the three correct measures in the responses were the most identified by the sample (Fig. 3).

The existence of prior information by the Healthcare Professional proved to be independent ($p = 0.094 > 0.05$) of the identification of the radiological protection measures.

The "academic degree" and "age", on the other hand, proved to be variables that influence the responses indicated in this study point.

It was observed that women with academic levels equivalent to "university" found it easier to select the correct answers, as well as they were those who least choose the option "I don't know". It was noted that for women with higher levels of education it was 66 times easier to identify the correct radiological protection measures (Table 2c).

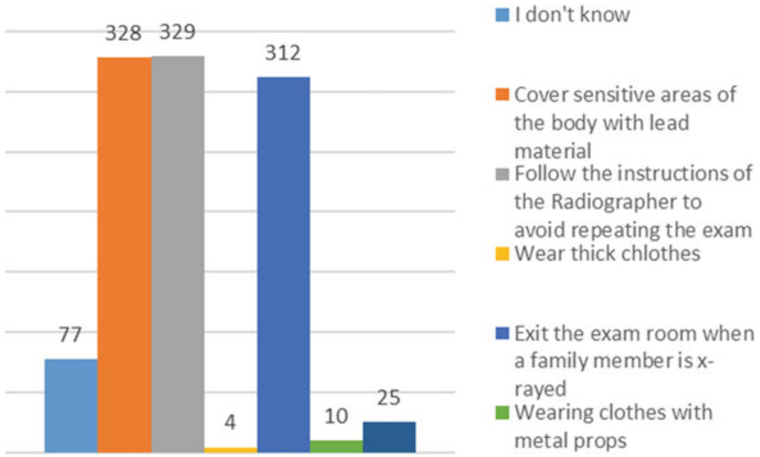

Fig. 3 Identification of radiological protection measures

"Age" proved not to be independent in the option "I don't know" and in the options: "Cover sensitive areas of the body with lead material" and "Follow the instructions of the Radiographer to avoid repeating the exam".

It was women in younger age groups who most chose de option "I don't know" and also the option to follow the instructions of the radiographer. The use of lead material in sensitive areas of the body was the least selected option by these women.

"Age" is a significative statistical variable to this point of the study. It has been shown that women in younger ages are 66 times more likely to correct identify radiation protection measures (Table 2c).

The last point of study of the variable "Radiological Literacy" was related to the dose. In this topic, we tried to understand, in a first phase, if the sample considered that the Body Mass Index (BMI) was related to the radiation dose. It was observed in this study, 56.4% of women indicate that there is no relationship between these two factors.

It was possible to understand that, once again, information given did not prove to be a variable with influence ($p = 0.135 > 0.05$) in the answers given in this study of point.

The "education level" demonstrated not to be independent of the answers provided by women when considering BMI as an important factor for the radiation dose. The highest percentages (over 50%) were associated with a non-consideration of the relationship between these two factors, this non-consideration being lower (52.4%) in women with higher academic degree. Women with "University" degree are 36 times more likely to considerer BMI as a relevant factor for the level of radiation dose (Table 2d).

"Age" also proved to be an influential variable in the responses given to this point of study ($p = 0.013 < 0.05$). It was noticed that women in younger ages were who most recognized (47.7%) BMI as a relevant factor for the level of radiation dose. Even so the higher percentages (greater than 50%) are related with a non-consideration this factor as something important for the level of radiation dose, which further demonstrates the existence of a knowledge gap in this area.

It was possible to observe that women in younger ages are 62.1 times more likely to considerer BMI as an important factor for the level of radiation dose (Table 2d).

The last question in the questionnaire was related to the comparison of the dose between two radiological exams in three points:

- Chest X-Ray versus Chest TC
- Chest X-Ray versus Head CT
- Chest X-Ray versus Abdominal and Pelvic CT.

This question was intended to distinguish those who actually had knowledge in this area from those who not (Fig. 4).

In relation to the first point, 38.25% of the sample selected the correct option ("40 times") against 61.75% of women who chose the wrong hypothesis of response.

In the second comparison, only 25.70% of respondents identified the right answer ("100 times") compared to 74.30% of participants who indicated the remaining incorrect answers.

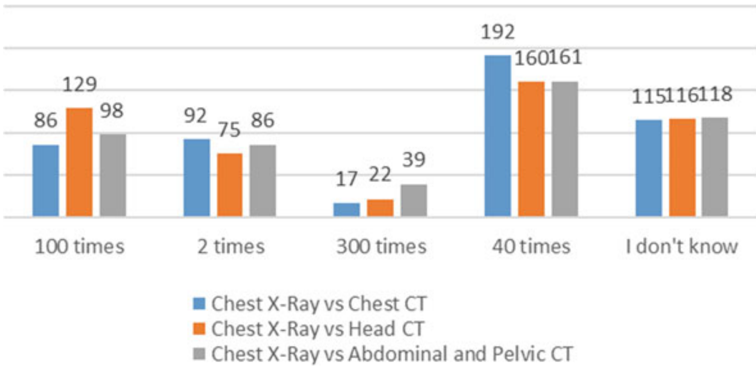

Fig. 4 Comparison of the dose between two radiological exams

In the third question, which had the option "300 times" as the correct answer, it was only selected by 7.8% of the participants. The majority (92.2%) indicated the remaining dose values for this comparison point.

Through the statistical analysis it was possible to observe that the information provided by the Healthcare Professional did not reveal to be an influential variable in the answers indicated in this point of analysis, a fact demonstrated, also, in most of the points analysed.

The variable "age" showed only influence on the answers given in the comparison between Chest X-ray versus Abdominal and Pelvic CT. The highest value corresponds to the choice of the "40 times" option by women in older ages (38–56 years). In other words, there is as underestimation of the dose levels of radiological exams. "Age" is not a statistically significant variable, which demonstrates that it does not play a major role in the responses selected by the sample.

The educational qualifications proved not to be independent in the three points:

1. $p = 0.011 < 0.05$
2. $p = 0.017 < 0.05$
3. $p = 0.002 < 0.05$

Based on these results, it is noticeable that the answers reveal just chances to be correct. However, there is a major underestimation of the radiation dose level.

The results obtained with the application of the binary logistic regression model are shown in Table 2.

4 Discussion

It is known that the sociodemographic variables in the sample establish a strong relationship with the level of literacy of the participants, which can lead to a variation in the results obtained compared to studies carried out in other countries, in which the sociodemographic variables are different (Alhasan et al. 2015; Asefa et al. 2016; Yücel et al. 2009). In terms of sociodemographic variables, it is important to note that some characteristics of the sample in this study do not correspond to the reality of the Portuguese population (PORDATA 2020b, 2020d, 2020a). For example, at the level of education, it is the basic education that has the greatest (47.5%) representation in the population (PORDATA 2020c).

It is also important to note the presence of a bias associated with the sample (memory, profession, years of profession activity, frequency with which radiological exams were performed, number of times that the participants have been exposed to ionizing radiation and if the sample have ever been given some type of explanation about the risks and benefits associated exposure to X-rays in the context of medical practice) (Alhasan et al. 2015; Schuster et al. 2018) and the way that data collection was gathered.

The results showed that there are still gaps in radiological knowledge. The percentage of women who indicated "Mammography" and "Bone Densitometry" as exams using X-rays is low, a fact that has been portrayed in previous studies (Aldossari et al. 2019; Lumbreras et al. 2017; Singh et al. 2017; Yücel et al. 2009). When identifying the exams that can be performed by a pregnant woman, the "Magnetic Resonance (MRI)" is not identified by the sample as an examination that can be performed by a woman at this stage of her life cycle. This situation may be due to doubts and beliefs that still exist in addition to this radiological examination (Aldossari et al. 2019).

Regarding the dose, there was a depreciation of dose levels in the second (comparison between Chest X-rays and Head CT) and third (comparison between Chest X-rays and Abdominal and Pelvic CT) comparisons (Skromov de Albuquerque and Mastrocola 2017). In addition, it was possible to notice that the answer "I don't know" has the same behaviour in the comparison between Chest X-rays and Chest CT; Chest X-rays and Head CT and Chest X-rays and Abdominal and Pelvic CT (corresponding to the second most selected option in the comparisons between Chest X-rays and Chest CT and Chest X-rays and Abdominal and Pelvic CT). This situation demonstrates the existence of an information gap in this topic, something already described in a previous study carried out in Nigeria in 2013 (Skromov de Albuquerque and Mastrocola 2017), as well as in a systematic review carried out in 2015 (Lam et al. 2015). These results may be related to the level of complex and imperceptible technical language for the health user associated with the subject of the dose, as well as the fact that the numbers presented in the dose reports are difficult to understand and translate (Ukkola et al. 2015).

Through statistical analysis, it was possible to verify that the variables "Education Level" and "Age" are the ones that exert the greatest influence on literacy levels.

In terms of understanding the information about radiological procedures previously provided by the attending physician to women of childbearing age, it was observed that women with lower academic degrees have greater difficulty in understanding the information provided. It is therefore important to focus on the need to create adequate information for women with lower levels of education, as well as to ensure that there is a good understanding of it (Alhasan et al. 2015; Almaghrabi 2016).

In this same topic, it was possible to verify that women with "University" have the highest percentage (21.2%) regarding the lack of information given by their Physician. This percentage may be related to the fact that this educational level is the one that has the greatest expression in the characteristics of the sample, influencing and giving more weight to the result at this point of analysis. One of the reasons that may explain this lack of information, may be related to the establishment of the Paternalist Paradigm (Fazenda 2006).

The "Education Level" also showed a non-independence in different points of Health Literacy in the Radiological context. It was noticed that women with education equivalent to "Primary School", "Secondary School", "High School" and "College" have lower percentage values in identifying the right answers for each topic of analysis. To overcome this point, it is important to have a greater investment in the Healthcare Professional Health User dialogue, so that it is possible to meet the patients doubts and beliefs, to provide adequate (oral and/or written) and clarifying information (Lam et al. 2015; Pahade et al. 2012; Ukkola et al. 2015) on topics associated with Radiological Literacy (Ukkola et al. 2017). In order to facilitate the communication and understanding of the message, examples of such as the comparison of exams, with the time of exposure natural radiation or with the risk of everyday accidents and the risk of cancer associated with exposure of ionizing radiation, can be useful to increase the Radiological Literacy levels of this group and reduce the existing asymmetry with the group of women with higher levels of education (Ukkola et al. 2015).

With regard to the influence of the variable "Age" on Health Literacy levels in the Radiological context, it was possible to observe that this is a variable with influence in the identification of some aspects related to Health Literacy applied to Radiology. It turns out that this association is not always established, revealing itself in some points as being a statistically significant variable. This statistically behaviour of the variable "Age" is already represented in the bibliography, since there are studies that state it is a relevant variable for the level of literacy (Khadem-Rezaiyan et al. 2016; Takakuwa et al. 2010) and another ones that indicates, at a quantitative level, it is a variable that has no influence on the levels of literacy presented (Lumbreras et al. 2017).

Based on the results obtained, it is mostly women in younger age groups who have an easier time selecting tests that can be performed by a pregnant woman, identifying radiological protection measures and considering BMI as a relevant factor for the dose level. As a reason given for this situation, it may be the fact that in this study there is a grater representation of women in younger ages groups, giving a greater expression to their responses.

As for the influence between the information transmitted by the Health Professional and the levels of Radiological Literacy, it was only possible to verify the existence of a non-independence between the information provided and the identification of the radiological exams that use X-rays. It was notice that the less information influences the correct identification of the radiological exams using X-rays.

Statistical analysis carried out it shown that the topics associated with the dose are independent of the information given by Healthcare Professional, it may be due to the fact that they do not provide information on the dose levels associated to the exam (Alhasan et al. 2015; Lam et al. 2015; Ukkola et al. 2017), which may be related to the depreciation presented.

In the remaining topics of Radiological Literacy, it appears that the information provided is not statistically significant. As a reason pointed to the lack of association between the information transmitted by the Healthcare Professional and his understanding of the study topics associated with the levels of Health Literacy applied to Radiology, it may be due to the fact that many times for Healthcare Professionals it is difficult to translate technical and specific language into a common and easily understood language (Shyu and Sodickson 2016). This issue may translate in the misunderstanding of the information transmitted and increase the confusion between the previous information that the user already had and the new information provided (Shyu and Sodickson 2016). In addition, the workflow of Healthcare Professionals is often high, making the process of communication with the Health User more difficult (leading to no communication relationship between the actors being established) (Shyu and Sodickson 2016).

The existence of gaps in knowledge in Radiology may also be due to the diversity of information sources, which are not always the most credible, leading beliefs, doubts and uncertainties in this area (Corbett 2000; Aldossari et al. 2019).

In practical terms, greater knowledge of radiological examinations will allow a better identification of them, reducing the exposure of this sensitive group to X-rays.

5 Conclusions

Women education level influence radiological literacy (the higher level of education, the easier it is to correctly identify the answers in the present study).

The variable "age", on the other hand, shows influence in some points of analysis, but in others it has no expression.

Regarding the information provided by the Healthcare Professional, it was possible to understand that is does not influence the levels of literacy presented by the sample.

The identification of the radiological exams that use X-rays and the radiological protection measures were done correctly; nevertheless, it is still possible to highlight some gaps in radiological literacy levels, such as radiation dose and the factors that may influence it. It should be noted that the number of women who selected the option "I don't know" is considerable.

It would be important to expand this study with a more representative sample of the population, in order to understand better women radiologic protection knowledge.

For the future, it would be important to create an online platform, developed by Health Professionals, to promote clear and accessible communication for this target group. Initially, these data would be disseminated and as contact with this means of knowledge took place, it would be perceived through a questionnaire whether radiological literacy would increase.

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Assessment of Infrasound and Low Frequency Noise—Case Study in a Community of Inhabitants Near Wind Turbines

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Abstract Technological advances in the construction of wind turbines with lower noise emission have been many, however they continue to be responsible for producing infrasound and low frequency noise that can affect the quality of life of human populations (hypertension, discomfort, sleep disorders, among others). Assess the levels of infrasound and low-frequency noise at which residents in the vicinity of the wind turbines were taking into account wind direction, air speed and distance to the source. The analytical collection was carried out inside houses in the district of Viana do Castelo, using a CESVA SC420 sound level meter. The distance to the noise source was not a relevant factor in the attenuation. The wind speed and direction were responsible for the noise expression. The southernmost dwellings in the region under study were more exposed to higher levels of this types of noise. It is important to adopt territorial management measures taking into account the protection of public health, environmental impact studies within the scope of the types of noise and safety distances, taking into account the population.

Keywords Infrasound · Wind turbines · Noise pollution · Vibroacoustic disease · Sound pressure level

1 Introduction

The World Health Organization defines health as complete physical, psychological and social well-being and not merely the absence of disease (WHO 1980). Currently, the concept of quality of life has emerged in several contexts, namely in health, politics and environment. It is understood as a general concept that encompasses

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environmental factors, income levels, health, lifestyle, satisfaction, and self-esteem (Cassou 2001). This is affected by several factors, including population growth, stress, social status, but also pollution (Santos et al. 2000). Among the various forms of pollution that affect humans is noise pollution. This fact is considered to be the responsibility of the growth of cities and the change in mobility behaviors (WHO 2012; Tang and Wang 2007).

In recent years, the need for alternative energies has found in wind energy an inexhaustible source of electricity production. This fact, combined with technological development, has led to an exponential growth of both the equipment and its implementation, neglecting the negative impacts they cause in their area of influence (Maia 2010).

Wind energy represents the use of the kinetic energy contained in the wind, which is captured by the blades of the wind turbine engine and converted into mechanical energy. Later, the mechanical energy is transformed into electrical energy in the generator. The electrical energy is then injected into the electrical distribution, or transmission (Fernandes et al. 2009). Despite the advantages in using wind energy for electricity generation, this type of wind energy use also has significant disadvantages and impacts mainly in the use of large wind turbines, wind farms and turbines (ENEOP s.d.).

Despite the advantages in using wind energy for electricity generation, this type of wind energy use also has significant disadvantages and impacts mainly in the use of large wind turbines, wind farms and turbines (Stewart 2006). Since there is a wide difference in individual tolerance levels to noise, there is no completely satisfactory way to measure its subjective effects, as well as the corresponding annoyance reactions (Filho and Azevedo 2013).

It is empirically known that noise exposure can cause a wide range of disorders, such as hypertension, annoyance, sleep alterations, and most exponential deafness (Alves-Pereira and Branco 2009, 2007b).

Hearing loss is the most studied effect and the only one considered in the Portuguese legislation. Hearing loss manifests itself particularly in the sound frequencies in which the ear has greater sensitivity. However, when exposed to Infrasound and Low F, there are other effects of exposure, such as loss of sleep quality, stress, cardiovascular disorders, gastrointestinal complications, endocrine disorders, changes in respiratory rate, central nervous system, fatigue, harmful effects due to the resonance frequency of internal organs, among others (Alves-Pereira and Branco 2007a; Antunes 2009; Bento 2011).

The objectives of the present study were to measure and understand the levels of Infrasound and Low Frequency Noise (ILFN) that residents living near wind farms are exposed to, and also to understand how some variables, such as distance to the source, wind direction, air speed, and geomorphology of the region are related to the propagation of sound pressure levels.

2 Materials and Methods

The present study is of the observational type of transverse timeline. As regards the level of knowledge, it was classified in level II (descriptive-correlational). In terms of duration, the study took place from October 2020 to July 2021, and data collection took place between May and June 2021.

The sample was of the non-probabilistic type and, as for the technique, for convenience. The study population consisted of the residents of the three dwellings (located in the district of Viana do Castelo) where 124 measurements were taken. Of the total number of comprised the sample, 46 were made in Housing A, 40 in Housing B and 38 in House C.

For data collection, a CESVA sound level meter equipped with the FFT module for Fast Fourier Transform analysis, was used, with 10,000 lines from 2 to 20,000 Hz (2 Hz/line). This equipment was calibrated before and after measurements using a CESVA acoustic calibrator, model CB006.

Measurements were taken inside the three houses, in the "Kitchen", "Living Room" and "Bedroom" divisions. For a better understanding of the data obtained and their treatment, the divisions of the dwellings were classified according to their location and exposure to wind turbines.

The sound meter was positioned 1.5 m from the floor, in the center of the divisions facing the nearest PE and as far away from infrastructure and furniture as possible. The measurements were taken for 60 s (maximum time allowed for the sound meter with the FFT analysis module). In each room, at least 4 measurements were taken, for three days, during the same time period (Kitchen: 12:00–14:00; Living Room: 18–20 h; Bedroom: 20–22 h) representative of the longest stay of the inhabitants in the respective divisions.

The data measured with the sound level meter were transferred using CESVA lab software (version 3.2). Based on the frequencies collected, the following types of noise were calculated: Infrasound from 2 to 20 Hz; and RBF from 20 to 500 Hz.

The climatic data collection was made through the website of the Portuguese Institute of The Sea and Atmosphere and was corresponding to the measurement period. This data collection was made through the hourly summary of the meteorological station of "Viana do Castelo". The variables "Air Speed", "Wind Direction" and "Temperature" were collected. During the period of measurements was not verified occurrence of precipitation.

Google Earth pro Software (version 7.3.3.7786) was used for georeferencing the dwellings and the location of the wind turbines.

Data obtained were statistically treated using IBM SPSS Statistics version 27 software. For this purpose, the 1-Factor ANOVA, Brown-Forsythe, Kruskal–Wallis and Pierson Linear Correlation Coefficient test were applied for statistical inference. For the estimation of statistical inference, a 95% confidence level and a random error of less than or equal to 5% were taken into consideration.

3 Results

Regarding the location of the dwellings, Dwelling A is located in the parish of São Pedro d´Arcos (municipality of Ponte de Lima), 7 km south of the wind farm of the Serra de Arga. North of the house (300 m) is located on the A27 motorway and south (2.20 km) a wastewater treatment plant. Dwelling B is located 11 km south of the Serra de Arga wind farm, in the parish of Lanheses (municipality of Viana do Castelo). To the north of the dwelling is the A27 highway (2.27 km) and the national road 202 (325 m), to the west is the national road 305 (150 m). North of it is located the Lanheses Industrial Park. Dwelling C is located in the parish of Arcozelo (municipality of Ponte de Lima), 9 km east of the Serra de Arga wind farm. At 150 m north of the dwelling is the A27 highway (tunnel area), three quarries (2 km) and also the bituminous plant (725 m).

After identifying the dwellings (geographically) we sought to compare the levels of Infrassounds between the different dwellings evaluated (Table 1). It was found that the infrasound do not differ between the dwellings, regardless of their location and distance from the emitter source (p-value > 0.05).

The same analysis was performed for the variable "RBF" (Table 2). Also in this type of noise it was found that there were no differences between the dwellings regardless of location and distance from the source of emission a (p-value > 0.05).

The variation of Infrasound and RBF was also evaluated as a function of air velocity. In Dwelling A, according to the results obtained, it can be seen that the noise type "RBF" ($r = 0.369$; p-value $= 0.012$) and "Infrasound" ($r = 0.699$; p-value < 0.001) showed to be correlated with air speed. Also in Dwelling C, there was a

Table 1 Expression of infrasound (dB) by dwelling under study

Dwelling	N	Average	Standard deviation	*p*-value
A	46	57.63	7.59	0.172
B	39	59.73	10.10	
C	37	56.51	3.41	
Total	122	57.96	7.65	

Test: Brown-Forsythe

Table 2 Expression of low frequency noise (dB) by dwelling under study

Dwelling	N	Average	Standard deviation	*p*-value
A	46	42.78	9.73	0.809
B	39	43.28	6.82	
C	37	42.17	5.34	
Total	122	42.75	7.64	

Test: ANOVA 1 Fator

significant (inverse) correlation between air speed, regarding RBF ($r = -0.431$; p-value $= 0.008$) and Infrasound ($r = -0.435$; p-value $= 0.007$). However, in Dwelling B there was no correlation pattern.

As for the variation of the noise level as a function of the wind direction per dwelling (Fig. 1) we found that in Dwelling A, when the measurements were taken, wind directions from NW and S did not present any significant effect on the levels of Infrasound and RBF. As for Dwelling B, wind directions from NW, S, N and W were verified, with a significant impact on the levels of Infrasound. Finally, in Dwelling C there were differences in terms of Infrasound and RBF when the direction of the wind came from NW, SW and E.

It was also intended to analyze the behavior of the sound pressure level of Infrasound and RBF to which each dwelling is exposed. Based on Fig. 2, there was a similar behavior in Dwellings A, B and C. There were several increases in the sound pressure level (peaks) common in the three dwellings along the frequency spectrum, namely, at 40, 62, 102 and 302 Hz.

4 Discussion

The distance of the dwellings from the noise emission source did not influence its propagation. The reduced energy loss of this type of noise (infrasound and low-frequency noise) over distance is due to a very particular characteristic of this type of noise: extremely long wavelengths. This feature makes noise transmission occur over long distances without energy loss (Berglund et al. 1996).

In the transversal elevation profiles of the houses to the nearest wind farm, it was found that, compared to Dwelling A and B, the turbines of the Serra de Arga wind farm are located on the extensive plateau, with no morphological structures that constitute obstacles to the propagation of the wind noise. Regarding air speed, it was found that the influence on sound propagation is significant, presenting a positive correlation in Dwelling A and C.

In fact, it was possible to verify in these dwellings that the higher the air speed, the higher the sound pressure levels. As the air speed increases, the wind turbine rotor rotates more, and the higher frequency of the blade passing through the tower, therefore, leads to more infrasound (Van Den Berg 2005). In Dwelling B there was no correlation, which may be due to other external variables, namely the presence of highway.

As for the wind direction, it was found over the period of measurement wind from several cardinal points. However, the points where significant differences in the expression of Infrasound and RBF stand out were when they had a North (N) and Northwest (NW) direction, a worrying fact due to the most characteristic wind direction in Mainland Portugal, from North (Almeida 2018).

Given the impact of these exposures to different noises in homes, it can give rise to a set of symptoms and pathologies in its inhabitants, namely headaches, sleep disorders, changes in the respiratory system, changes in the cardiovascular system,

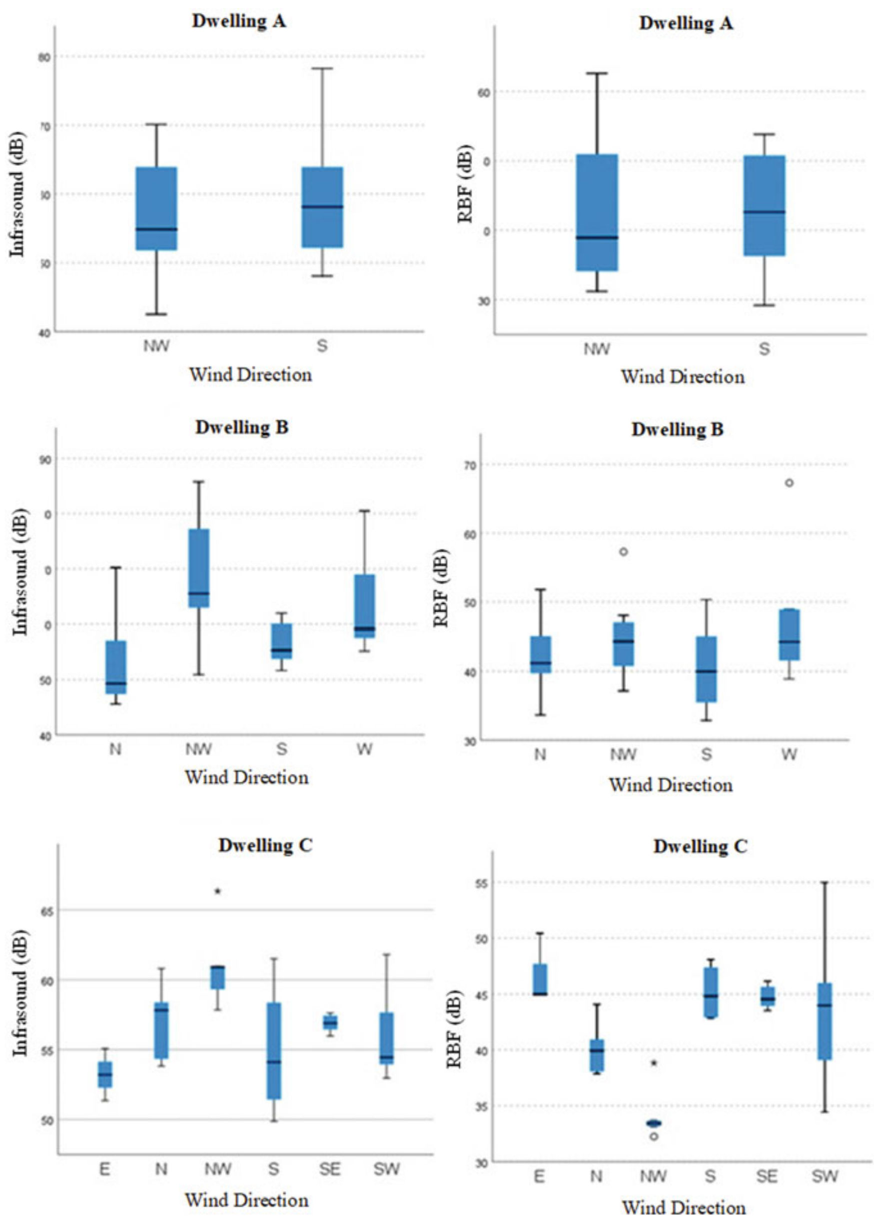

Fig. 1 Correlation between infrasound and RBF against wind direction and housing

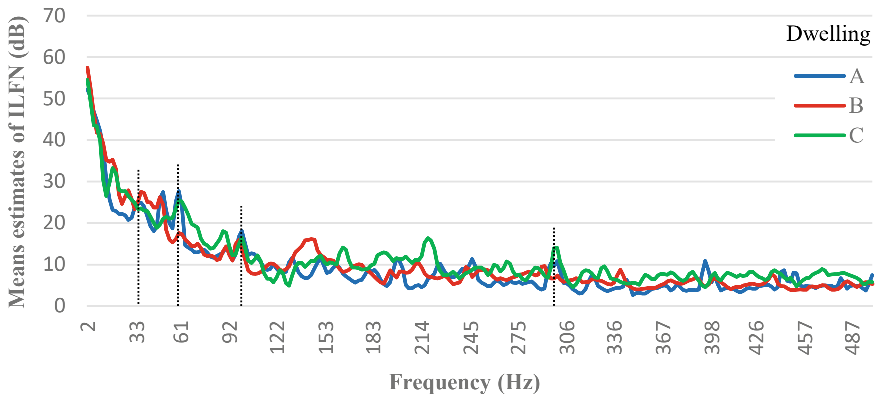

Fig. 2 Sound pressure level (dB) by frequency (Hz)

changes in the gastrointestinal system, increased of muscle tension, irritability and aggression, increased fatigue, decreased attention span, concentration, learning and memory (Stansfeld and Matheson 2003; EEA 2010; Carvalho and Rocha 2008; Freitas and Cordeiro 2013; Mendes and Silva 2017).

5 Conclusions

It was concluded that the residents of the houses under study are exposed to considerable sound pressure levels, and the distance to the emitting source is not significant in their expression. It was possible to conclude that air speed and wind direction are directly related to the noise levels recorded. There are also other variables, including the existence of highways, forests, geomorphological structures and terrain topography between the dwellings and the wind turbines that influence the propagation of infrasound and low frequency noise.

Throughout the study, some limitations were identified, which despite not putting into question the scientific veracity of the same could improve its execution. In particular at the level of noise measurement equipment, limited to the level of the measurement time.

In view of the above, it becomes increasingly important a greater planning and land-use planning, with regard to the implementation of Wind Farms, and also the adoption of measures to mitigate the propagation of noise in existing farms. The environmental impact study is a tool that should be taken into account for the protection of the population living near wind turbines, as also, the study of the consequences of their implementation, and the dose–response relationship in the population.

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Comparison of Methods for the Assessment of Exposure to Whole-Body Vibration

María L. de la Hoz-Torres, Antonio J. Aguilar, Diego P. Ruiz, and M. D. Martínez-Aires

Abstract Several epidemiological studies have provided evidence of a causal relationship between the development of work-related musculoskeletal disorders (MSDs) and whole-body vibration exposure. EU Directive 2002/44/EC was published by the European Parliament to ensure the health and safety of each worker and create a minimum protection basis for all community workers by timely detection of adverse health effects arising or likely to arise from exposure to mechanical vibration, especially MSDs. This standard defines the methods for assessing daily vibration exposure (defined in ISO2631-1:1997). ISO 2631-5:2004 defines the method for assessing long-term exposure. Recently, this standard has been modified by ISO 2631-5:2018. This study analysed the differences between the assessment methods defined in the three standards and determined the contributions made by the last standard. The consideration of posture and anthropometric characteristics, the vertebral levels as well as not only considering the acceleration transmitted through the seat are the most important considerations provided by ISO 2631-5:2018. This fact makes the assessments more precise, providing personalized assessment of long-term WBV exposure, determining the effects on the exposed individuals and the way of working.

Keywords Whole-body vibration · Directive 2002/44/EC · ISO2631-1:2008 · ISO2631-5:2004 · ISO2631-5:2018

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1 Introduction

The European Agency for Safety and Health at Work (EU-OSHA) highlights that a high percentage of workers are exposed to whole-body vibration (WBV). There is epidemiological evidence that relates this exposure to the onset of musculoskeletal disorders (MSDs), which has high costs for companies and society (EU-OSHA 2019, 2022; Russo et al. 2020). In fact, the report published as the first preview of the results obtained in the European Survey of Enterprises on New and Emerging Risks (ESENER) 2019 survey revealed that MSDs were among the greatest concerns of European companies (EU-OSHA 2020).

Among the MSDs, degenerative disorders of the spine are the most frequently reported by workers in the construction industry (Bakusic et al. 2018). Intervertebral disc degeneration is the most important risk factor associated with low back pain (Livshits et al. 2011); furthermore, overweight and obesity increase the risk of its onset (Liuke et al. 2005; Shiri et al. 2009). Of those affected by low back pain, between 5 and 10% will develop a chronic pain disorder, the prevalence of which increases linearly from 30 to 60 years of age (Meucci et al. 2015). These occupational diseases have a great impact on individuals and social care systems, as well as high costs associated with their treatment and absence from work due to illness (EU-OSHA 2019; Woolf & Pfleger 2003). In 2020, the percentage of individuals in Spain who declared being exposed to factors that could negatively affect physical health in this sector reached 86% (Eurostat 2022).

According to EU-OSHA, preventing workers from being affected by MSDs and promoting their musculoskeletal health throughout their working lives from their first job is essential to address the long-term effects of demographic ageing, an objective that is in line with those of the European Strategy 2020–2022 (EU-OSHA 2022). The European Union has already established limits on the exposure of workers to WBV in Directive 2002/44/EC (defined in ISO2631-1:1997, modified in 2014). However, recent studies have indicated that there was still high risk of MSDs related to low back pain caused by WBV exposures, even below the limit values (Bovenzi & Schust 2021).

Different studies have highlighted that long-term WVB assessment is necessary (de la Hoz-Torres et al. 2021a, 2022). Standard ISO 2631-5, which is not mandatory in all countries, provides the tools for this assessment. ISO 2631-5:2018 has recently been published, incorporating modifications with respect to the 2014 version. In the present study, a comparison is made of the assessment methods defined by the different standards, i.e., ISO 2631-1:1997, ISO 2631-5:2004 and ISO 2631-5:2018, as well as by Directive 2002/44/EC. A comprehensive analysis is carried out in order to identify the differences between the standards and their impact on the risk assessment methods that they provide.

2 Materials and Methods

The present study was conducted by means of a shared analysis of the assessment methods described in the following standards:

- Directive 2002/44/EC. Minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration).
- ISO 2631-1:1997. Mechanical vibration and shock. Evaluation of human exposure to whole-body vibration. Part 1: General requirements.
- ISO 2631-5:2014. Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration—Part 5: Method for evaluation of vibration containing multiple shocks.
- 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.

3 Results

3.1 Directive 2002/44/CE

The European regulatory framework for the prevention of exposure to vibration is addressed in Directive 2002/44/EC, i.e., minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within Article 16(1) of Directive 89/391/EEC). In this standard, vibrations are classified according to the part of the body they affect, namely:

- *Hand-arm vibration*: the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bones or joints, and neurological or muscular disorders;
- *Whole-body vibration* (WBV): the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower back morbidity and spine trauma.

On the other hand, two methods are defined to assess exposure to WBV. On the one hand, the root mean square (*rms*) or A(8) assessment method provides an average value of normalised vibration exposure for a period of eight hours. It is calculated as the largest effective value of the frequency-weighted accelerations determined according the three orthogonal axes.

The vibration dose value (VDV) assessment method provides the cumulative vibration exposure during the working day. It is defined as "a cumulative dose based on the fourth root of the acceleration to the fourth power, and its unit is $m/s^{1.75}$". It is calculated as the largest of the VDV of the frequency-weighted accelerations determined according to the three orthogonal axes.

Normally, the use of the VDV method instead of the A(8) implies obtaining different results when assessing the risks to the workers' health. The VDV method is more sensitive to peaks, since it uses the fourth power instead of the second power of the acceleration time history as the basis for the average.

On the other hand, Directive 2002/44/EC establishes exposure limits, namely:

- The daily exposure limit value standardised (ELV) to an eight-hour reference period should be 1.15 m/s^2 or a VDV of 21 $m/s^{1.75}$.
- The daily exposure action value standardised (EAV) to an eight-hour reference period should be 0.5 m/s^2 or, at the choice of the Member State concerned, a VDV of 9.1 $m/s^{1.75}$.

3.2 ISO 2631-1:1997. Mechanical Vibration and Shock. Evaluation of Human Exposure to Whole-Body Vibration. Part 1: General Requirements

This standard defines methods for the measurement of periodic, random and transient WBV. In addition, it provides information on the possible effects on health, well-being, perception and movements in the individuals. It does not provide exposure limit values. Depending on the characteristics of WBV exposure and the effect to be analysed in the individuals, different frequency weightings are defined to be used. When establishing the assessment criteria, this standard is based on the *rms* method of weighted acceleration. The magnitude should be expressed as the *rms* of the weighted acceleration. The units used are m s^{-2} if the vibration occurs on a translational axis, and rad s^{-2} if it occurs on a rotational axis. This standard establishes that the crest factor (CF) of the signal should first be determined for assessing the effects of vibrations and repeated shocks on health.

The peak value is determined as the maximum instantaneous peak in a given period of time, which will be the same for which the acceleration rms has been calculated. Depending on the module obtained, the standard establishes two different methods, namely:

- If CF $\leq$ 9, the standard defines that the basic assessment method, i.e., the *rms* of the acceleration time history, should be applied.
- If CF > 9, it implies that the signal contains multiple shocks, and the basic method could underestimate the severity of the exposure for the individuals' health.

In this case, the standard defines the VDV method, which is also referred to in Directive 2002/44/EC. The standard defines this value considering that it is more sensitive to peaks, because it starts from the average of the fourth power of the acceleration time history instead of the second (as is the case of rms).

The standard includes multiplication factors in third-octave bands to weight the transmitted signal in the frequency domain. Applying these factors requires that the data obtained from the measurement (the equipment stores the sampled signal in the time domain) be transformed into the frequency domain and divided into third octaves.

3.3 *ISO 2631-5:2004. Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 5: Method for Evaluation of Vibration Containing Multiple Shocks*

This standard describes a method applicable to WBV exposure containing multiple shocks primarily affecting the spine. This situation commonly occurs in vibrations transmitted to individuals who are seated and the vibrations are transmitted through the surface of the seats. Unlike other standards, this is the only one that provides a dose–effect relationship when assessing individuals exposed to vibrations.

Determining the acceleration dose of the spine involves: (1) calculating the response of the spine; (2) determining the number of peaks and their magnitude; and (3) calculating the acceleration dose by applying the dose model derived from the Palmgren–Miner's fatigue theory (Fig. 1).

In the x- and y-axes, the spinal response is approximately linear and represented by a single degree of freedom (SDOF) lumped-parameter model. In the z-direction, the

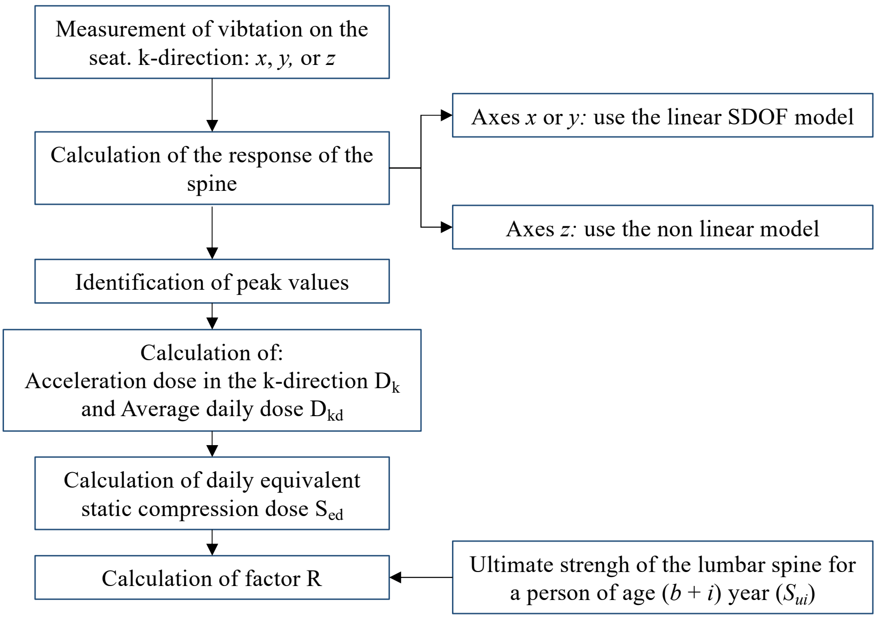

Fig. 1 Flowchart for acceleration dose calculation ISO2631-5:2004. *Source* Adapted from ISO2631-5:2004

spinal response is non-linear and represented by a recurrent neural network model. Subsequently, the peak values are identified. A peak is defined here as the maximum absolute value of the acceleration response between two consecutive zero crossings. For the x- and y-directions, peaks in positive and negative directions should be counted. For the z-direction, only positive peaks should be counted (compression of the spine is of primary interest for exposure severity). With these data, acceleration dose Dk is calculated. For assessment of health effects, it is useful to determine the average daily dose (Dkd), in meters per second squared, to which an individual will be exposed.

Exposure to multiple shocks causes transient pressure changes in the vertebrae that, over time, can have adverse effects on health as a result of material fatigue processes. For the assessment of the effects on health, the standard defines the calculation of the parameter of equivalent static compressive stress (S_e) in MPa. This model uses the Palmgren–Miner's biomechanical model approximation, in which it is assumed that there is a linear relationship between the part of the compressive stress resulting from the input shocks and the maximum acceleration response of the spine.

The daily equivalent static compression dose, S_{ed}, is the calculated S_e parameter value for the acceleration dose (daily dose D_{kd}). The R factor is calculated from S_{ed}. For its calculation it is necessary to know the ultimate strength of the lumbar spine for a person of age $(b + i)$ years (S_{ui}), b is the age at which the exposure starts and *i denotes the year counter*. It can be defined for use in the assessment of adverse health effects related to human response acceleration dose. R takes into account the increase in the age of the individuals exposed and the duration of exposure.

The standard provides limits for the R factor that allow assessing exposure:

- R < 0.8 → the probability of adverse effects on individuals' health is low.
- R > 1.2 → the probability of adverse effects on individuals' health is high.

On the other hand, it also provides limits for the S_{ed} parameter:

- S_{ed} < 0.5 MPa → the probability of adverse effects on individuals' health is low.
- S_{ed} > 0.8 MPa → the probability of adverse effects on individuals' health is high.

3.4 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 2631-5:2018 maintains the objective of its previous version, i.e., providing a method for quantifying the vibrations that contain multiple shocks relating to health, considering that the exposure occurs when the workers are seated. This standard specifies that the methods can be used to assess the risk of chronic damage derived from exposure to multiple shocks in scenarios such as driving military vehicles, construction vehicles or heavy off-road vehicles, among others. The methods described in the standard are based on the estimated biomechanical response of the bony vertebral plates in individuals with good physical condition and that do not exhibit pathologies in their spines.

Unlike the 2004 version, this ISO standard defines two assessment methods to be used depending on the exposure regime. Exposure regimes can be differentiated as follows:

- *Severe exposure conditions*: This type of exposure is typical of military vehicles that travel off-road, high-speed boats, etc. These conditions may contain periods of free fall, in which acceleration in the 'z' axis predominates, and exposed individuals may lose contact with the seating surface. The assessment of this type of exposure uses the severe method and assumes zero acceleration in the directions of the 'x' and 'y' axes in the process of calculating the compressive forces in the spine. Requirements for acceleration signal measurement differ from those established in ISO 2631-1.
- *Less severe exposure conditions*: Unlike the previous case, WBV exposure conditions do not contain periods of free fall and the individuals do not lose contact with the seat surface during the entire exposure period. This type of exposure is more likely to occur in the industrial setting, including heavy vehicles, tractors, construction and earthmoving machinery, and travelling on uneven surfaces (off-road, bumpy roads, etc.). Exposures are assessed with the least severe method. The measurement requirements are the same as those described in part 1 of ISO 2631 for non-time-weighted acceleration measurements.

Therefore, the application of the assessment methods defined in the standard should consider, in the first place, the type of exposure regime. In this process, two conditions should be assessed, namely: (1) whether the exposure contains periods of free fall or loss of contact with the seat surface; and (2) whether the signal contains peaks above 9.81 ms^{-2}. If the two or one of the conditions is satisfied, the method of severe conditions should be applied. Otherwise, the less severe conditions method should be applied. Figure 2 illustrates a diagram for selecting the method applying the requirements established in the standard.

This method uses as input, at least, the acceleration measured on the three axes of the seating surface. However, unlike the previous version, it can also include in the assessment the measurement of the acceleration that is transmitted through the back of the seat, the feet (through the floor of the cabin), and the hands. These acceleration time series are used to calculate the compression force between the vertebrae considering transfer functions of a biomechanical model.

The transfer functions of the biomechanical model depend on the posture, body mass, and body mass index of the individuals exposed to WBV. Therefore, based on the measured acceleration, the exposure conditions, and the drivers' characteristics, the model calculates through transfer functions the response of the spine in terms of compression force. The maximum compression forces obtained in this process are used to calculate the compression dose.

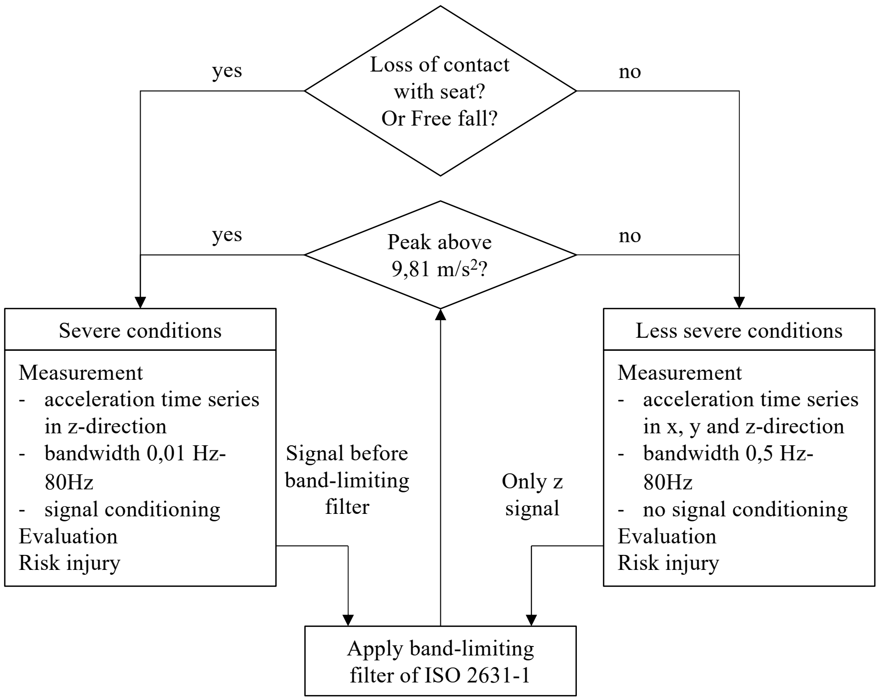

Fig. 2 Flowchart for the application of the models used in this document. *Source* Adapted from ISO2631-5:2018

The standard specifies that if only the acceleration transmitted to the drivers through the seats is available, this value is also used as the acceleration transmitted through the backrest. On the other hand, the value of the acceleration transmitted through the hands and the ground of the cabin should be omitted. In addition, given that the model needs to include the history of exposure to vibrations throughout the drivers working lives, the standard proposes that, if these data are not available, a typical exposure of four hours per day should be assumed as well as that the individuals were exposed from the age of 20–65 years, for a total of 240 days per year. In addition, the position of the drivers during the exposures should be considered, for which the standard provides groups of positions, from which one should be selected in order to include it in the model.

Once the input variables are defined, the model estimates the internal lumbar forces in the spine from transfer functions derived from finite element models of the seated human body. These finite element models present posture variations based on the anatomy of seated and upright individuals, considering the impact of different magnitudes of accelerations. The models have been validated from a large number of measurements of the apparent mass and transfer functions of the different parts of the human body. They were used to calculate the transfer functions of the accelerations for the different classes of acceleration magnitude considering the four points of contact between man and machine (seat surface, backrest, feet and hands).

From the transfer functions and the Fourier transform of the time series of the acceleration measured at the points of contact of the drivers with the machine, the model calculates the vertebral forces for each point of contact and direction of the excitation in the frequency domain. The sum of the excitations transmitted from each point and direction gives rise to compression and shear forces between the vertebrae as a consequence of the combined excitation. Subsequently, the compression-decompression forces are transferred to the time domain by applying the inverse Fourier transform. This procedure gives rise to time-dependent compression-decompression forces C_{dyn} (N).

The sum of the peak compressive forces $C_{dyn,i}$ (N) occurring in the vertebral disc (area B) (mm^2) for each exposure is defined as compressive (S^A). These three magnitudes are determined separately for each level of the vertebral disc. The maximum compression forces are negative values defined as a maximum value of the additional compression force between two consecutive mean value crossings.

The area of each vertebral level has been selected from the data published in the scientific literature (Wilder et al. 1988) and is included in the model provided by the standard. The mean values of B for the vertebral level T12/L1 is 1460 mm^2, L1/L2 1 is 520 mm^2, L2/L3 is 1580 mm^2, L3/L4 is 1590 mm^2, L4/L5 is 1600 mm^2, and L5/S1 is 1550 mm^2.

The standard has followed a conservative criterion in the selection of the sixth power in the calculation of S^A in order to estimate the adverse effects on health.

Experimental data show that the value of the Palmgren–Miner's exponent vary depending on the biological tissue and the methodology used in the tests, and could range from 5 to 14 for cortical bone and up to 20 for cartilage. Due to the consideration of the sixth power in the SA calculation process, peak values of compressive force that are considerably lower (by a factor of three or more) with respect to the maximum peak do not contribute significantly to the compression dose.

Like the previous version of the standard, the estimation of the effects of WBV exposure on health requires the determination of the equivalent daily compression dose $S_d{}^A$ (MPa). In this case, the calculation should be performed for each level of the spine considering the nth exposures throughout the day. Considering the values of $S_d{}^A$ obtained from the daily exposure patterns, it is possible to calculate the risk factor (R^A) for each vertebral level (from T12/L1 to L5/S1) for the exposure history of individuals throughout their working lives. The R^A factor can be used to assess whether the dose value $S_d{}^A$ can cause long-term adverse health effects. In the calculation process, the year in which the exposure began and the duration of the exposure with respect to the age of the exposed individuals are considered for obtaining a constant exposure pattern per day in all years from the beginning to the end of the exposure. If instead of considering daily exposure to be the same on all days of the year that the individuals are exposed to WBV, exposure patterns are considered to vary over the years, and this condition should be included in the calculation of the R^A factor. The standard specifies the following values to consider the adverse effects on workers' health:

- $R^A < 0.8$ indicates a low probability of adverse health effects.
- $R^A > 1.2$ indicates a high probability of adverse health effects.

It should be noted that obtaining a value of RA = 1 does not indicate that the probability of failure is certain. This factor indicates that the dynamic load due to mechanical shock has reached the same order of magnitude as the maximum (static) resistance that the vertebra is capable of resist.

4 Discussion

The analyses of Directive 2002/44/EC and ISO2631-1:2008, ISO2631-5:2004, and ISO2631-5:2018 indicated that although they all assess the effects on health, their considerations are different. One of the most important differences is the type of assessment, i.e., long or short term. To carry out the WBV assessment in the short term, ISO 2631-1:2008 and Directive 2002/44/EC define the indicators A(8) and VDV, the latter being more sensitive to peak values. ISO 2631-5 2004 and ISO 2631-5 2018 define two calculation methods for the daily equivalent compressive dose $S_d{}^A$. This means that the value of R is based on the results obtained from different methods. Table 1 shows the most important differences between the three standards.

Different studies have shown (de la Hoz-Torres et al., 2021a, 2021b, 2022; Eger et al., 2008) how the VDV method is the most restrictive. In addition, the studies found fact that the methods provided different assessments of the same exposures

Table 1 Summary of differences between the analysed standards

	ISO 2631-1:1997 and Directive 2002/44/EC	ISO 2631-5:2004	ISO 2631-5:218
Method	A(8) VDV	S_{ed} R	$S_d{}^A$ R^A
Assessment of health effects	✓	✓	✓
Defines the methods referenced in the Directive 2002/44/CE	✓	×	×
Assessment of the effects of long-term exposure	×	✓	✓
Consider the posture and anthropometric characteristics	×	×	✓
Consider the transmission to the spinal column	×	✓	✓
Consider vertebral levels	×	×	✓
Consider other accelerations in addition to that transmitted through the seat	×	×	✓

and that the consideration of drivers' anthropometric characteristics influences the risk assessment.

In this context, it is worth noting that the possibility of assessing the cumulative effect of WBV exposure over the years is essential to ensure that activities are safe, since it is possible to predict whether the worker's health will be compromised. However, Directive 2002/44/EC only provide methods for daily assessment of WBV exposure, which may cause an exposure to be considered safe when in the long term the cumulative effects may cause adverse effects on the worker's health.

5 Conclusions

MSDs exhibit high prevalence among occupational populations as well as high economic and social impact. WBV exposure is related to the onset of MSDs and degeneration of the lumbar spine. International standards have focused on their assessment. In this sense, Directive 2002/44/EC, ISO 2631-1, and ISO 2631-5 describe models for assessing exposure to WBV. In the present study, the assessment methods described have been compared, as well as the values they define for the protection of the health of workers exposed to WBV. It was observed that Directive 2002/44/EC did not indicate that long-term exposure should be taken into consideration.

On the other hand, the new version of ISO 2631-5:2018 includes important factors for the assessments, such as considering the posture and anthropometric characteristics and the vertebral levels of the individuals affected, as well as other accelerations in addition to those transmitted through the seats. This fact makes the assessments more precise, providing personalized assessment of long-term WBV exposure, determining the effects on the exposed individuals and the way of working.

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Ergonomics and Biomechanics

A Fuzzy Logic-Based Selection Approach to Select Suitable Industry 4.0 Tools for Ergonomic Risk Mitigation: Application to the Portuguese Wine Sector

António A. Freitas, Tânia M. Lima, and Pedro D. Gaspar

Abstract Industry 4.0 (I4.0) reveals a special relevance for the Portuguese industry as it represents a major opportunity to overcome the main competitive barriers. On the other hand, organizational expansion frequently leads to an increase in work-related accidents, resulting in needless increases in financial expenses. For this reason, the integration of I4.0 tools is a recommended way to gain benefits, including improvements both in productivity and occupational risk mitigation. This work proposes a fuzzy logic approach in a decision-making method for the selection of suitable I4.0 tools for minimizing ergonomic risks. The method is based on the results of an ergonomic risk assessment performed from the point of view of energy expenditure during task execution, which has already been characterized and studied by several authors. As a result, ergonomic risk assessment allows the estimation of ergonomic load related to productive process activities. The results obtained from the I4.0 tool selection method provided viable solutions both operationally and in terms of minimizing ergonomic risks, strongly suggesting the implementation of autonomous systems, namely automated integrated systems, and autonomous robots, and also suggesting the incorporation of other I4.0 tools in tasks that require specific human intervention, such as cobots, exoskeletons, and lifting systems.

Keywords Risk assessment · Selection method · Decision support · Metabolic energy · Manufacturing processes

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1 Introduction

The intense environment of competitiveness induces changes in the concepts of business management. This fact forces companies to identify and apply strategies to make the most efficient use of their manufacturing resources. To provide sustainability, companies started to establish strategies based on price, quality, productivity, quick response, environmental management, product diversity, and flexibility, starting to use these strategies as competitive weapons (Bahadir and Satoglu 2012).

According to data from INE (2021), the wine sector is included in the ranking of the five most economically representative subclasses in Portugal, representing an annual turnover of more than two million euros. On the other hand, the wine industry belongs to the processing industry, which presents a higher number of severe and fatal accidents, according to ACT (2021), next to the construction sector.

In the specific case of the wine industry, considering the high sensitivity of wines in terms of quality and food safety, one of the most significant aspects of the winemaking process is the cleaning and maintenance of equipment, machinery, and installations. These procedures, combined with the operations of vinification, racking, storage, and bottling, involve several substantial risks, including ergonomic risks (Youakim 2006; Eurisko 2011; Checchi and Casazza 2012; Anaya-Aguilar et al. 2018).

Thus, to mitigate the occupational risks, it is crucial to evolve and proceed with the automation of the wine sector, while also taking advantage of the opportunity to improve production processes. Therefore, for this reason, the implementation of Industry 4.0 (I4.0) not only ensures higher productivity via the integration of digital production systems with analysis and communication of all data created in an intelligent environment, but it also reduces ergonomic hazards inherent in manufacturing processes (Markova et al. 2019). Organizations are starting to measure the positive impact on the responsiveness, autonomy, and flexibility of manufacturing facilities. New generations of interconnected and autonomous equipment, such as cobots (collaborative robots), are increasingly emerging (Beetz et al. 2015).

As a way to solve problems related to the selection of robotic solutions, including I4.0 tools, decision support tools based on the Fuzzy Logic methodology are often used. In this context, several authors contributed by developing methodologies based on Fuzzy Logic approaches, as Sahu et al. (2015), which proposed the introduction of some qualitative parameters for the selection of the best mobile robotic solutions through the use of a step-by-step procedure for evaluating mobile robots, allowing the determination of the robot's proximity according to its capacity, and Wilms et al. (2019), which proposed a decision support method for application in the selection of specific robotic systems for implementation in the tool and die manufacturing industry, providing the establishment and assessment of economic feasibility and efficiency.

On the other hand, Nasrollahi et al. (2020) suggested a methodology to solve the problem of adequate selection of industrial robots using two appropriate methods for multicriteria decision making (MCDM), a fuzzy logic-based method and the PROMETHEE method, using the criteria of weighting and classification of decision alternatives, respectively. The method provided the capability for solving complex multi-attribute decision problems, incorporating quantitative and qualitative factors.

Despite the fact that many authors contributed to the development of several decision support tools following many methodologies, there is a lack of decision support methods for solving problems related to the selection and organization of I4.0 tools from the perspective of ergonomic risks (Weckenborg and Spengler 2019).

Thus, this work aimed to contribute to filling this gap in the literature by proposing a decision support method, based on a Fuzzy Logic model, to select suitable I4.0 tools to apply in the wine industry, considering the occupational risk component, allowing the mitigation of occupational risks allied to a higher level of operational process efficiency.

To achieve this purpose, this study encompasses two main aspects:

- The characterization of production activities in the wine sector, in terms of metabolic energy expenditure during task execution, based on the results of several works that have already studied and characterized different types of tasks, which, by analogy, can be transposed to this work;
- The development of a decision support method, centred on a Fuzzy Logic approach, to select suitable I4.0 tools to support the activities that presented higher values of metabolic energy expenditure.

2 Material and Methods

The methodology applied in this work was based on four phases, wherein the first phase consisted of an ergonomic risk assessment substantiated on the expenditure of metabolic energy that occurs during the execution of the several tasks within each work area. Once energy expenditure is used as a measure of human ergonomic load (Weckenborg and Spengler 2019), according to (Battini et al. 2017), the estimation of ergonomic risks based on energy expenditure allows to describe the three main ergonomic dimensions during physical work: level, repetitiveness, and duration. Thus, excessive energy expenditure, which is related to the repetitiveness of work, is associated with metabolic stress, fatigue, and discomfort. In addition, workers frequently alter the muscle request patterns to compensate for fatigue from repetitive work, leading to inadequate postures.

Although the most common method is indirect calorimetry with measurement of oxygen consumption, in this work the ergonomic risk assessment was made by the estimation of the energy spent on the various tasks that are part of the production processes, which was based on several activities already characterized and studied by several authors from the point of view of energy expenditure (Ainsworth et al. 2011; Ainsworth et al. 1993, 2000).

The second phase involved the selection of work activities that present a higher potential impact on increasing the ergonomic risks (with METs above 5.8), as determined by the risk assessment performed.

In the third phase, I4.0 tools that can contribute to minimizing ergonomic risks were selected, based on the nature of each type of activity.

Considering the selected work activities in the previous step, the fourth phase consisted of the development of a fuzzy logic method as a decision support method in the selection of suitable I4.0 tools for minimizing ergonomic risks.

Development of the Fuzzy Logic Method

The I4.0 Tool Selection Method, based on fuzzy logic to minimize ergonomic risks, was created through the Toolbox Fuzzy Logic of MatLab software version R2021a, relying on the use and interaction of five modules: The Fuzzy Logic Designer, The Membership Function Editor, The Rule Editor, The Rule Viewer, and The Surface Viewer.

Through the Fuzzy Logic Designer module, the method's design was created based on a structure composed of seven variables, seven rules, and seven possible outputs (Fig. 1).

Through the Membership Function Editor, seven input variables were created, according to the operational requirements of the selected activities:

1. Horizontal mobility;
2. Vertical mobility;
3. Capacity for cargo transport;
4. Work rate and pace;
5. Support for the lower limbs;
6. Support for upper limbs;
7. Importance of human intervention.

The seven variables were created according to the ergonomic risk assessment carried out, representing the highest impact in increasing the ergonomic load. The first three variables are related to the mobility along the manufacturing facilities, including access to other levels (e.g., stainless-steel vats), while the remaining ones are related to the execution of tasks that do not involve displacement to other locations. The seventh variable is related to the need for human intervention in very specific tasks for which automation would not be adequate.

For each variable, three membership functions with Gaussian distribution were created, which correspond to three attributes: reduced, low, average, and good, with an exception in the case of the variable relevance of human intervention, which is based on two attributes: relevant and not relevant.

The output variable was created with seven attributes, which correspond to the most appropriate I4.0 tools for minimizing ergonomic risks.

It should be noted that the output variables were built on a scale from 0 to 60, while the others were comprised on a scale between 0 and 20.

The rules created, which are shown below, are based on the possible interactions between the variables according to the nature of the activities/tasks and the potential applicability of each I4.0 tool.

Rule 1—Selection of systems integration and automation (SIA):

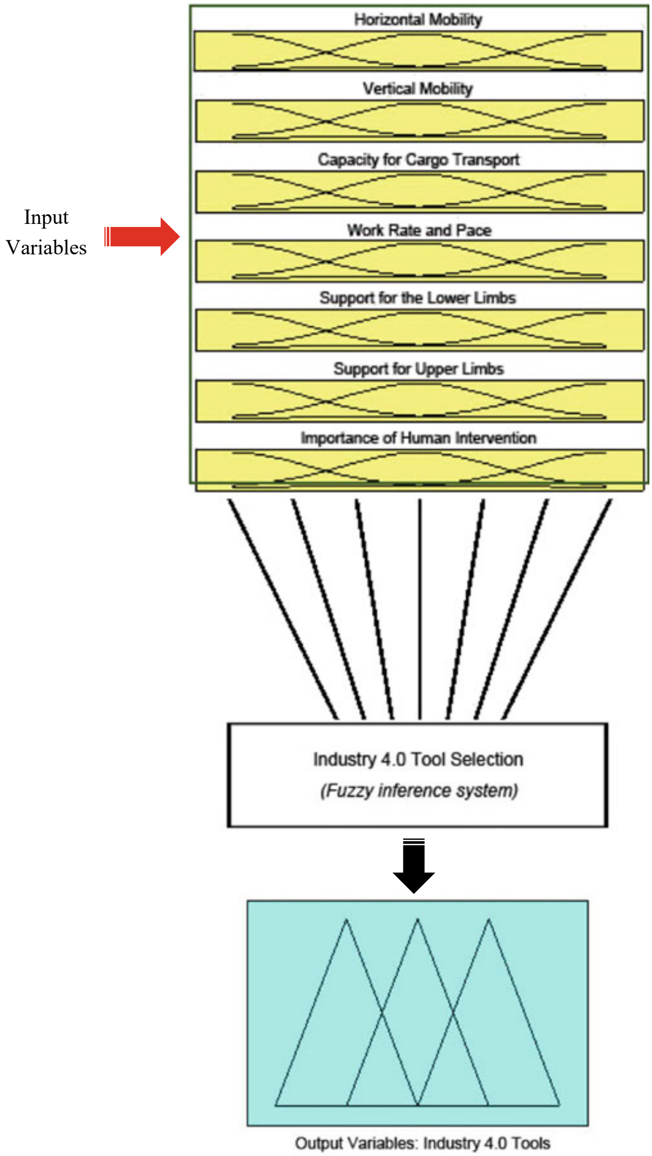

Fig. 1 Structure of the I4.0 tool selection method

- Horizontal mobility (at the same level): Good;
- Vertical mobility (between different levels): Good;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Not considered;

- Upper limb support: Not considered;
- Relevance of human intervention: Not relevant.

Rule 2—Selection of the autonomous robot (AR):

- Horizontal mobility (at the same level): Good;
- Vertical mobility (between different levels): Medium;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Not considered;
- Upper limb support: Not considered;
- Relevance of human intervention: Not relevant.

Note Since human presence is not relevant for the execution of the task, support for upper and lower limbs was not considered in rules 1 and 2.

Rule 3—Selection of the collaborative robot or cobot (CR):

- Horizontal mobility (at the same level): Reduced;
- Vertical mobility (between different levels): Medium;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Not considered;
- Upper limb support: Not considered;
- Relevance of human intervention: Relevant.

Note Although human presence is relevant for the execution of the task in question, support for upper and lower limbs was not considered in this rule, as it is a non-wearable system.

Rule 4—Selection of the exoskeleton with full-body support (EFBS):

- Horizontal mobility (at the same level): Good;
- Vertical mobility (between different levels): Good;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Good;
- Upper limb support: Good;
- Relevance of human intervention: Relevant.

Rule 5—Selection of the exoskeleton with upper limb support (EULS):

- Horizontal mobility (at the same level): Reduced;
- Vertical mobility (between different levels): Good;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Reduced;
- Upper limb support: Good;
- Relevance of human intervention: Relevant.

Rule 6—Selection of the exoskeleton with lower limb support (ELLS):

- Horizontal mobility (at the same level): Good;
- Vertical mobility (between different levels): Good;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Good;
- Upper limb support: Reduced;
- Relevance of human intervention: Relevant.

Rule 7—Selection of the lifting system (LS):

- Horizontal mobility (at the same level): Low;
- Vertical mobility (between different levels): Good;
- Cargo carrying capacity: Good;
- Work speed/pace: Good;
- Lower limb support: Good;
- Upper limb support: Reduced;
- Relevance of human intervention: Relevant.

The created rules were based on two perspectives: (1) the improvement in operational efficiency with the implementation of I4.0 tools and (2) ergonomic load mitigation. Thus, regarding the operational efficiency improvement, the rules were created to obtain the highest efficiency from the I4.0 tools. That includes a good mobility (horizontal and vertical) with a high cargo capacity and fast work speed and pace, whereas the ergonomic load mitigation is related to the lower and upper limb support, which must be higher depending on the effort required from the operator during the execution of the task.

Regarding the relevance of human intervention, this aspect is related to the specificity of the task. That is, due to its nature, if the task requires human intervention, the relevance will be "Relevant", else it will be "Not relevant".

With respect to the seven possible outputs or I4.0 tools suggestions, the most autonomous tools, as SIA and AR, are based on the irrelevance of human intervention, as they are tasks that can be performed on a large scale, and on the need for high performance in terms of horizontal and vertical mobility, with high load capacity and fast work speed/pace. The suggestions of exoskeletons, CR or LS depend entirely on the relevance of the human intervention, varying on the area of the human body that needs more support. It is noteworthy that the specific suggestion of CR is based on its application on static tasks (low mobility required) that must be done in large scale with the human presence.

3 Results

The results obtained are described in the next three subsections, according to the order of implementation established.

3.1 Ergonomic Risk Assessment and Selection of Higher-Risk Tasks

After the ergonomic risk assessment, the tasks with the highest impact on the increase of ergonomic risks (with METs higher than 5.8) were selected and related to the respective main activities.

As a result, Table 1 shows a synthesis of the most physically demanding tasks (with METs greater than 5.8) and their respective activities, taking into consideration the ergonomic risk factors, the type of effort, the relevance of human presence, and the type of displacement required.

3.2 Industry 4.0 Tools Selection to Reduce Ergonomic Risks

The I4.0 tools that can contribute to minimizing ergonomic risks, considering the nature of each type of activity, were selected, and the results are shown below.

- Lifting system (LS): consists of a simple lifting system that, although it can be operated by the user, has safety sensors (Industry 2021);
- Exoskeletons: are wearable devices that can assist and increase the wearer's muscular power. (Yan et al. 2021). Exoskeletons can provide lower limb support (ELLS), upper limb support (EULS), and full-body support (EFBS);
- Collaborative robots, or Cobots (CR): are intended to direct human–robot interaction within a shared space, or where humans and robots are nearby (Malik and Bilberg 2017);
- Autonomous robots (AR): This robotic technology employs sensory-motor capabilities to interact autonomously in an open environment (Jayaratne et al. 2021);
- Systems integration and automation (SIA): consists of an automated system that allows the monitoring of processes by obtaining data from different types of probes and sensors, liquid and solid flow meters, and video cameras, acting on the processes through several types of mechanisms, such as electro valves (Winegrid 2021).

3.3 Industry 4.0 Tool Selection Method

The main characteristics, which correspond to the variables used in the method, were evaluated, and the selection method was used to obtain the most appropriate tool for each activity based on the nature of the associated tasks, as illustrated in Fig. 2 for the activity of receiving and unloading grapes.

Table 1 Metabolic energies spent on activities during the production process

Activities	Physically demanding tasks (MET > 5.8)	Estimation of metabolic energy expenditure[1]	
		MET	kcal/min
1. Grape's reception and unloading	1.1. Containers' unloading/dumping	5.9	7.4
	1.2. Access to the vehicles' cargo boxes	8.8	11.0
2. Reception hopper verification, maintenance, and cleaning	2.1. Access to the reception hopper and perform the verification, maintenance, and cleaning	7.5	9.4
3. Grape selection/sorting	3.1. Boxes handling of rejected grapes	6.5	8.1
4. Destemming/crushing	4.1. Stem removal (manual load handling)	8.0	10.0
5. Destemming/crushing/extracting system check/maintenance/cleaning	5.1. Access to the access the system and perform the maintenance/cleaning	7.5	9.4
6. Sulphitation	6.1. Access to the top of fermentation vats	5.8	7.3
7. Must clarification	7.1. Transport of filter materials	6.9	8.6
	7.2. Removal of filtration residues	8.0	10.0
	7.3. Wine transfer operations	8.0	10.0
	7.4. Access to the top of fermentation vats	5.8	7.3
8. Must preparation	8.1. Cleaning and preparation of fermentation vats	8.0	10.0
	8.2. Access to the top of fermentation vats	5.8	7.3
9. Control of Alcoholic Fermentation	9.1. Access to the top of fermentation vats	5.8	7.3
10. Maceration Verification/Monitoring	10.1. Access to the top of fermentation vats	5.8	7.3

(continued)

[1] The estimation was obtained by comparison with tasks already studied by Ainsworth et al. (1993); Ainsworth et al. (2000); and Ainsworth et al. (2011).

Table 1 (continued)

Activities	Physically demanding tasks (MET > 5.8)	Estimation of metabolic energy expenditure	
		MET	kcal/min
11. Control of Malolactic Fermentation (white wines))	11.1. Wine transfer operations	8.0	10.0
	11.2. Access to the top of fermentation vats	5.8	7.3
12. Racking/Transfer	12.1. Cleaning and preparation of fermentation vats	8.0	10.0
	12.2. Access to the top of fermentation vats	5.8	7.3
13. Depletion/Pressing	13.1. Access to the top of vats	5.8	7.3
	13.2. Wine transfer operations	8.0	10.0
14. Presses check/maintenance/clean	14.1. Access to the top of presses	5.8	7.3
15. Control of Malolactic Fermentation (red wines)	15.1. Wine transfer operations	8.0	10.0
	15.2. Access to the top of fermentation vats	5.8	7.3
16. Fortification (addition of wine alcohol)	16.1. Wine transfer operations	8.0	10.0
	16.2. Access to the top of vats	5.8	7.3
17. Oenological adjustments	17.1. Wine transfer operations	8.0	10.0
	17.2. Access to the top of vats	5.8	7.3
18. Preparation of base lots	18.1. Wine transfer operations	8.0	10.0
	18.2. Access to the top of vats	5.8	7.3
19. Stabilization/Clarification	19.1. Stabilization/clarification material handling	8.0	10.0
	19.2. Access to the top of vats	5.8	7.3
20. Filtration	20.1. Transport of materials for filtering	8.0	10.0
	20.2. Removal of filtration residues	8.0	10.0
	20.3. Wine transfer operations	8.0	10.0
	20.4. Access to the top of vats	5.8	7.3
21. Wooden barrels preparation	21.1. Wooden barrels preparation	7.0	8.8
22. Storage/Stage (wooden barrels)	22.1. Storage/stacking of wooden barrels	7.5	9.4
	22.2. Wine transfer operations	8.0	10.0

(continued)

Table 1 (continued)

Activities	Physically demanding tasks (MET > 5.8)	Estimation of metabolic energy expenditure	
		MET	kcal/min
	22.3. Access to the top of vats	5.8	7.3
	22.4. Access to the higher levels of barrels rows	5.8	7.3
	22.5. Unstacking of wooden barrels	7.5	9.4
23. Storage/Stage (stainless vats)	23.1. Cleaning/preparation of stainless-steel vats	8.0	10.0
	23.2. Wine transfer operations	8.0	10.0
	23.3. Access to the top of vats	5.8	7.3
24. Estufagem or Wine Heating (Production of Madeira wine)	24.1. Cleaning/preparation of stainless-steel vats	8.0	10.0
	24.2. Wine transfer operations	8.0	10.0
	24.3. Access to the top of vats	5.8	7.3
25. Blending	25.1. Cleaning/preparation of stainless-steel vats	8.0	10.0
	25.2. Wine transfer operations	8.0	10.0
	25.3. Access to the top of vats	5.8	7.3
26. Final adjustments	26.1. Oenological adjuvants and additives transport	8.0	10.0
	26.2. Wine transfer operations	8.0	10.0
	26.3. Access to the top of vats	5.8	7.3
27. Reception of packaging materials	27.1. Verification Process	5.8	7.3
28. Bottle rinsing	28.1. Cleaning/preparation of the rinsing system	8.0	10.0
	28.2. Access to the bottling system module	7.5	9.4
29. Filling	29.1. Cleaning/preparation of the filling system	8.0	10.0
	29.2. Access to the bottling system module	7.5	9.4
30. Corking or sealing	30.1. Cleaning/preparation of the filling system	8.0	10.0
	30.2. Access to the bottling system module	7.5	9.4
31. Capping	31.1. Cleaning/preparation of the capping system	8.0	10.0
	31.2. Access to the bottling system module	7.5	9.4

(continued)

Table 1 (continued)

Activities	Physically demanding tasks (MET > 5.8)	Estimation of metabolic energy expenditure	
		MET	kcal/min
32. Labelling and lot number printing	32.1. Cleaning/preparation of the systems	8.0	10.0
	32.2. Access to the bottling system modules	7.5	9.4
33. Boxing	33.1. Cleaning/preparation of the boxing system	8,0	10.0
	33.2. Access to the bottling system module	7.5	9.4
34. Closing and printing information on the boxes	34.1. Cleaning/preparation of the systems	8.0	10.0
	34.2. Access to the bottling system modules	7.5	9.4
35. Palletizing	35.1. Packaging of finished product boxes on pallets	8.0	10.0
36. Storage	36.1. Storage of finished product boxes	8.0	10.0
37. Dispatch/Shipping	37.1. Pallet check	7.5	9.4

Through Fig. 2, it is possible to observe that the tool suggested as the most adequate, taking into account the specified parameters, is the autonomous robot (AR).

Similarly, the method was applied to the remaining activities, and the results obtained are shown in Table 2.

Overall, according to Table 3, the most suggested I4.0 tool types were mainly automated integrated systems, autonomous robots and, lifting systems.

4 Discussion

The ergonomic evaluation based on the estimation of the metabolic energy expenditure during the execution of tasks shows that the activities that represent higher ergonomic risks are: the reception and unloading of grapes; clarification of musts, due to the contribution of the filtration process that provides a higher level of ergonomic risk; the filtrations; the storage and ageing of wines in wooden barrels, as it includes intense manual load handling; the storage and ageing of wines in stainless steel vats, with the main contributions being the cleaning of the vats, and the wine transfer operations; and the blending operation, for the same reasons.

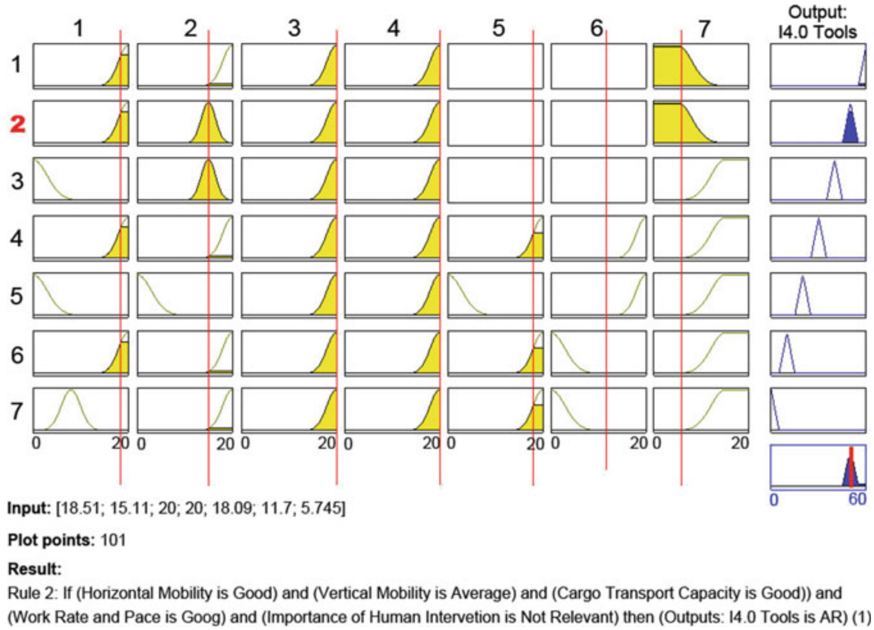

Fig. 2 Obtained results after applying the I4.0 tool selection method to the reception and unloading of the grapes

As for the choice of I4.0 tools suitable for minimizing ergonomic risks, the method used, based on fuzzy logic, allowed the selection of the most appropriate tools for each task from among several alternatives, according to the main requirements of the selected activities, namely in terms of:

- Horizontal mobility;
- Vertical mobility;
- Cargo transport capacity;
- Speed/pace of work;
- Support for lower limbs;
- Support for upper limbs;
- Relevance of human intervention.

Thus, the results obtained lead to a strong tendency to recommend more autonomous systems, namely automated integrated systems and autonomous robots, most of which are suggested for activities related to winemaking, stabilization, clarification, filtering, and storage/stage.

Compared to the works of several authors related to the decision-making process for the selection of industrial robotic solutions to improve the production capacity, it is verified that the main selection criteria focus essentially on the load capacity, lifting capacity, repeatability, velocity ratio, and degree of freedom (Fu et al. 2019; Suszynski and Rogalewicz 2020; Rashid et al. 2021), and additionally, the cost is

Table 2 Results obtained for each activity after applying the method based on fuzzy logic

Activities	Assessment of the main features							I4.0 tools
	1	2	3	4	5	6	7	
1. Grape's reception and unloading	18	15	20	20	18	12	5	RA
2. Reception hopper check/maintenance/cleaning	17	18	19	20	19	5	17	ELLS
3. Grape selection/sorting	18	15	18	20	5	19	5	RA
4. Destemming/crushing	19	15	20	20	5	20	5	RA
5. Destemming/crushing/extracting system check/maintenance/cleaning	17	19	20	20	19	19	17	EFBS
6. Sulphitation	19	19	19	19	5	5	5	IAS
7. Must clarification	19	15	19	20	5	5	5	AR
8. Must preparation	19	19	19	20	19	19	17	EFBS
9. Control of Alcoholic Fermentation	19	19	19	19	5	5	5	SIA
10. Maceration Verification/Monitoring	19	19	19	19	5	5	5	SIA
11. Control of Malolactic Fermentation (white wines)	19	19	19	19	5	5	5	SIA
12. Racking/Transfer	19	15	19	19	5	5	5	AR
13. Depletion/Pressing	19	19	19	19	5	5	5	SIA
14. Presses check/maintenance/cleaning	17	19	20	20	19	19	17	EFBS
15. Control of Malolactic Fermentation (red wines)	19	19	19	19	5	5	5	SIA
16. Fortification (addition of wine alcohol)	19	19	19	19	5	5	5	SIA
17. Oenological adjustments	19	15	19	20	5	5	5	AR
18. Preparation of base lots	19	19	19	19	5	5	5	SIA
19. Stabilization/Clarification	19	19	20	20	5	5	5	SIA
20. Filtration	19	15	19	20	5	5	5	AR
21. Wooden barrels preparation	5	15	19	20	5	19	17	CR
22. Storage/Stage (wooden barrels)	19	19	20	20	5	5	5	SIA
23. Storage/Stage (stainless-steel vats)	19	19	20	20	5	5	5	SIA
24. Estufagem or Wine Heating (Production of Madeira wine)	19	19	20	20	5	5	5	SIA
25. Blending	19	19	20	20	17	17	17	EFBS
26. Final adjustments	19	15	19	20	5	5	5	AR
27. Reception of packaging materials (Dry goods)	8	19	17	20	17	5	19	LS
28. Bottle rinsing	8	19	17	20	19	5	19	LS
29. Filling	8	19	17	20	19	5	19	LS
30. Corking or sealing	8	19	17	20	19	5	19	LS
31. Capping	8	19	17	20	19	5	19	LS

(continued)

Table 2 (continued)

Activities	Assessment of the main features							I4.0 tools
	1	2	3	4	5	6	7	
32. Labelling and lot number printing	8	19	17	20	19	5	19	LS
33. Boxing	8	19	17	20	19	5	19	LS
34. Closing and printing information on the boxes	8	19	17	20	19	5	19	LS
35. Palletizing	17	15	19	20	5	5	5	AR
36. Storage	19	19	20	20	5	5	5	SIA
37. Dispatch/Shipping	8	19	17	20	19	5	19	LS

Table 3 Summary of solutions found to minimize ergonomic risks in selected work activities

Suggested industry 4.0 tools for implementation	Number of activities covered by the solutions
Systems integration and automation (SIA)	13
Autonomous robots (AR)	9
Lifting system (LS)	9
Exoskeletons with full body support (EFBS)	4
Collaborative Robots or Cobots (CRC)	1
Exoskeletons with lower limb support (ELLS)	1

often taken into account (Zhao et al. 2021). To reach a high-level of standard for these criteria, the selection usually falls on the most autonomous solutions with high speed ratio (Nasrollahi et al. 2020).

For the activity of wooden barrel preparation that requires the interaction of human–robot working in parallel or in collaboration, the collaborative robot was suggested. According to Weckenborg and Spengler (2019), when the ergonomic environment gets more challenging, i.e., higher energy expenditure is required for manual task execution, fewer workers and more cobots are used, which, according to the obtained results, is exactly what should happen in the reorganization of this task. Thus, the repetitive and complex tasks can be assigned to the cobot, whereas the cognitive tasks with human added value are assigned to operators (Laouenan et al. 2022).

The exoskeletons with full body support were suggested for the tasks of verification, maintenance, and cleaning of the destemming/crushing/extracting system and the presses, as well as for the must preparation and blending operations. As stated by Fox et al. (2020), the full-body support exoskeleton provides many positive effects, such as the reduction of strain from lifting and weight support of heavy loads. Thus, this type of exoskeleton can provide complete assistance in the activities of walking, standing, carrying, and handling tasks (Bai et al. 2022), which correspond to the activities included in the referred tasks.

Regarding the tasks of verification, maintenance, and cleaning of the reception hopper, which imply the need for flat walking and uphill walking among other activities, the exoskeleton with lower limb support was the suggested I4.0 tool. According to Gordon et al. (2018), flat walking and uphill walking are benefited by the assistance of ELLSs. It has been verified by Jin et al. (2018), that in the case of inclined walking, the metabolic cost is higher than in the case of level walking.

For the bottling line operations (from 27 to 34), including verification activities and light maintenance operations, which may only involve very short displacements, it was suggested the implementation of lifting systems, which provide the exclusive effects of elevation and load carrying, being close to the effect of the exoskeleton with full body support.

5 Limitations

The current research was mostly based on a literature review, both in terms of theoretical foundations and concerning practical application. For this reason, the study's main limitations are related to the estimation of data based on previous works by several authors, particularly about the survey and assessment of occupational risks, as well as the compilation of operations that integrate the various production processes, and these data need to be updated and confirmed in terms of practical applicability.

6 Conclusions

The ergonomic risk assessment method based on the expenditure of metabolic energy, although carried out indirectly, allowed the achievement of objective and reproducible results when applied to the assessment of ergonomic risks in the production processes of the wine sector. In this way, the method provided the necessary objectivity, enabling the application of the I4.0 tool selection method, whose implementation contributes to the reduction of risks of this nature.

Regarding the solutions suggested after the I4.0 tool selection method, there was a strong tendency to recommend more autonomous systems, namely automated integrated systems and autonomous robots. This suggestion provides a way of rationalizing resources, minimizing operator errors, and increasing the potential for operational efficiency by optimizing the criteria of load capacity, lifting capacity, repeatability, velocity ratio, and degree of freedom. So, a substantial improvement in the quality of finished products is consequently achieved.

The remaining I4.0 tools, LS, EFBS, CRC and ELLS, were suggested for the execution of tasks that require human intervention but that can integrate the highest possible level of automation in order to provide the necessary support to the human operator, enabling this way the reduction of metabolic energy expenditure by the operator.

All the solutions suggested after applying the decision support method allow the mitigation of ergonomic load by reducing the metabolic energy expenditure, thereby minimizing the ergonomic risks.

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Ergonomics and Machine Learning: Wearable Sensors in the Prevention of Work-Related Musculoskeletal Disorders

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Abstract One of the biggest challenges of the labor world is to ensure the health and well-being of the workers. Preventing work-related musculoskeletal disorders (WRMSDs) is increasingly relevant across all sectors. In recent studies, there has been a growing application of machine learning and sensory technology to develop strategies for ergonomic risk detection and prevention of WRMSDs in the short and long term. The use of wearable sensors allows real-time monitoring of workers' postures, and has proven to be an asset for ergonomic studies due to its high accuracy. In addition to preventive applications, machine learning can increase workers' productivity and safety. Despite being an area that shows great potential, it still has some limitations and opportunities for development. This literature review was carried out in a structured and systematic way based on the defined inclusion criteria and keywords chosen. Fifteen articles published between 2017 and 2022 were analyzed. This paper aims to study the current state of the use of the application of wearable sensors in Ergonomics and identify the challenges that this technology faces in the future.

Keywords Machine learning · Ergonomics · Wearable sensors · WRMSDs

1 Introduction

Ergonomics is the scientific discipline dedicated to understanding the interactions between humans and other elements and applies theory, principles, data and methods to optimize human well-being and overall system performance (Stefana et al. 2021; International Ergonomics Association 2015). Although there are several methods and rules for identifying and assessing ergonomic risks workers may be exposed to during their work activities, these are based on self-assessment or visual observation.

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Although they are quick and direct to assess, they are not always the most accurate. The need to research and develop alternative methods of automatic assessment based on the use of cameras or sensors placed at strategic points on the body Inertial Measurement Units (IMU) began to exist (Olivas-Padilla et al. 2021).

In this way, machine learning techniques help prevent WRMSDs, as recent reviews have described the usefulness of these techniques to address research questions that assist in identifying and assessing risk factors (Chan et al. 2022).

Wearable sensors correspond to emerging technology and are an excellent proposition to support human activities and improve quality of life (Stefana et al. 2021). Large electronic companies such as Apple, Microsoft, and Huawei have launched their wearable devices. These devices have wearable sensors as key components, which currently receive great focus in research studies (Cheng et al. 2021).

Using this type of sensor in a work environment can generate some controversy. However, there has been a great interest in developing this area as it can lead to promising results.

This article aims to study the current state of the application of wearable sensors in Ergonomics, through a literature review of several scientific articles that address this type of device applied to the prevention of WRMSDs and identify the challenges that this technology faces in the future.

2 State of the Art

According to the latest research by International Data Corporation, the global markets for devices that integrate wearable sensors are worth about $578 million today. It is estimated that the global market size will reach about $1.968 billion by 2026 (Cheng et al. 2021).

Wearable devices can take many forms and are very different in their applications, which leads to various research and reviews of their use in various domains. These types of sensors are used in Ergonomics to increase work efficiency, improve workers' well-being, and reduce the risk of WRMSDs (Stefana et al. 2021).

2.1 Wearable Sensors

A wearable device is essentially a tiny device with a large capacity for motion capture, as well as for processing, storage, and communication, being "any electronic device or product designed to provide a specific service that can be used by the user". In the context of Ergonomics, they have capabilities such as: measuring physiological and psychophysiological parameters, assessing human performance, monitoring motion, and performing motion analysis in a manufacturing context (Stefana et al. 2021).

Such capabilities justify the increased interest in using these devices, in this case wearable sensors, regarding motion and risk assessment of WRMSDs (Zhao and

Obonyo 2021). These sensors allow engineers to efficiently collect data for assessing of physical and mental workload (Horváthová et al. 2019).

The increased use of sensors, particularly IMU sensors, is due to their low cost, low complexity and use in various studies. It is also possible to find examples where sensors embedded in cell phones are used in the literature. These are advantageous because they are low cost, intuitive to use, can be controlled remotely, and have low costs associated with maintenance and use (Nath et al. 2018; Huang et al. 2020).

2.2 Wearable Sensors in Ergonomics

Wearable sensors (IMU) combined with machine learning models have been increasingly studied in the context of workers' posture and movement detection of workers. However, there is the need to validate the ergonomic risk of the postures detected and the capacity of continuous recognition of new postures (incremental learning), being considered as a risk factor in a situation in the workplace that is directly related to a health hazard (Nath et al. 2018).

The primary function of these sensors applied in Ergonomics is to detect and recognize inadequate postures, for ergonomic evaluation as a strategy for monitoring and preventing WRMSDs. The risks of WRMSDs are directly related to the repetitive adoption of inadequate postures, excessive effort, and muscle fatigue. As such, ergonomic rules were used to recognize postures and to determine model accuracy, and sensor output was used to measure joint motion stability, body load, and proper postures. The classification of occupational tasks of manual handling of loads allowed for ergonomic exposure assessment, and is a strategy for preventing WRMSDs (Petz et al. 2021).

In the literature consulted, Prevention through Design (PtD) is addressed as an initiative taken by the National Institute for Occupational Safety and Health (NIOSH), which encompasses a series of efforts to anticipate and design for ergonomic risks in environments, work methods, operations, processes, equipment, tools, products, new technologies, and the organization of work (Nath et al. 2017; Zhao and Obonyo 2021).

Workers' self-assessment to assess risk factors of WRMSDs has proven to be an unobjective method, especially when workers have little knowledge about them. Alternatively, assessment methods such as the Ovako Working posture Analysing System (OWAS), Posture Activity Tools and Handling (PATH), Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) have emerged. Although these methods represent an improvement over self-assessment, they still require observation by Ergonomics experts and the use of some measuring instruments. In recent years, there has been a technological development aimed at supporting or even replacing the observation of experts in the field. An example of this advance is the application of sensors to increase the precision in the results (Huang et al. 2020).

In the area of occupational ergonomics, wearable sensors, as well as other motion capture systems, can be used to collect information about body movements throughout physical exertion, which in turn can be studied to improve the health of workers. For example, the use of wearable sensors and the analysis of collected data can contribute to pre-assessing heavy work, assigning tasks taking into account physical requirements, checking the practicability of shifts, and also scheduling ergonomic intervention depending on the severity and level of exposure to a given risk (Donisi et al. 2021).

Postural ergonomic risk monitoring can be done through direct or indirect methods. The direct way of monitoring involves methods such as self-assessment questionnaires (e.g., Borg scale) and observational methods that include work by a specialized technician who evaluates the operator's posture and movements (OWAS, NIOSH, RULA, Occupational Repetitive Actions (OCRA), REBA). They use data from sensors that are attached to the body (accelerometers, gyroscopes, magnetometers, electromyography and echocardiography) (Manghisi et al. 2020).

2.3 Wearable Sensors Limitations

Despite the technological advancement, it is important to note that there are still limitations and that the success of the implementation of wearable devices is dependent on major challenge (Khakurel et al. 2018).

One of the limitations is related to the reading accuracy of this type of sensor, which depends a lot on the care taken in their calibration, resulting in significant differences in predicting the values read only with minor changes in the calibration of these devices.

The use of wearable sensors can also cause some discomfort to workers because they are rigid electronic devices attached to clothing or skin (Chander et al. 2020).

The application of technological devices involves collecting personal information from workers (Oyekan et al. 2021). The processing and storage of the data raises four relevant questions: How will the data be collected and for what purpose will it be used? Who has the skills and capabilities to analyze, interpret quantified data and provide feedback to employees? Who owns the data? And finally, What security measures will be taken to protect it? Such uncertainty may compromise the acceptance and use of wearable technology in the workplace and affect the relationship between employees and employer (Khakurel et al. 2018). In addition, data collection can make workers feel that their assembly efficiency is being monitored and can reduce the acceptance of the developed system (Oyekan et al. 2021).

The application of the model must comply with General Data Protection Regulation (GDPR), and several principles must be ensured: the protection of personal data, the ability to analyze or remove data about them, and also, anonymity, and the data must be deleted after that period (Bortolini et al. 2020). However, it is still not enough to answer all the problems that arising from collecting, processing and storing information.

Other, even more, specific limitations are related to wearable sensors embedded in smartphones. These include being impossible to ensure that they will be placed precisely in the same place of the body at different analysis times and due to individuals' different physiological characteristics of individuals. For example, the solution may be to use sensors that cannot be influenced by the placement location (Nath et al. 2018).

Finally, it should be noted that there are still significant gaps in research related to the application of machine learning to the prevention of WRMSDs, especially in the areas of intervention and implementation (Chan et al. 2022).

3 Methodology

Once the topic "Ergonomics and Machine Learning" was chosen, a comprehensive search for several articles was started to clarify and define the approach of the review article to be developed (Snyder 2019). Thus, it was decided to develop the article about this sub-theme by verifying a significant number of articles related to the application of wearable sensors in Ergonomics.

The collection of articles started by considering inclusion criteria and the choice of keywords. The inclusion criteria were:

- articles published in scientific journals and written in English;
- articles published in the last five years (2017–2021), since the topic has undergone constant evolution and it was intended to have the most up-to-date review possible;
- articles that address solutions to physical Ergonomics;
- articles that propose some wearable sensors.

This research was carried out in a structured and systematic way using the scientific journal platforms "Science Direct" and "MDPI" and also the academic database Scopus, to obtain a broader search. The keywords used in the search engine were "Machine Learning" AND "Ergonomics", "Machine Learning" AND "Wearable Sensors".

The relevance of each article was evaluated and then processed with the development of the review article. In a first step, only the title and abstract of several articles found were analyzed to understand if they were related to the topic. Some of the articles that did not match the defined inclusion criteria were identified and rejected, and others because access to the full article was not allowed.

After this screening, the 21 articles that met the defined inclusion criteria were read entirely so that from then on, they could be used in the preparation of the review article.

The flow diagram in Fig. 1 summarizes the main steps of the methodology adopted to prepare of the review article.

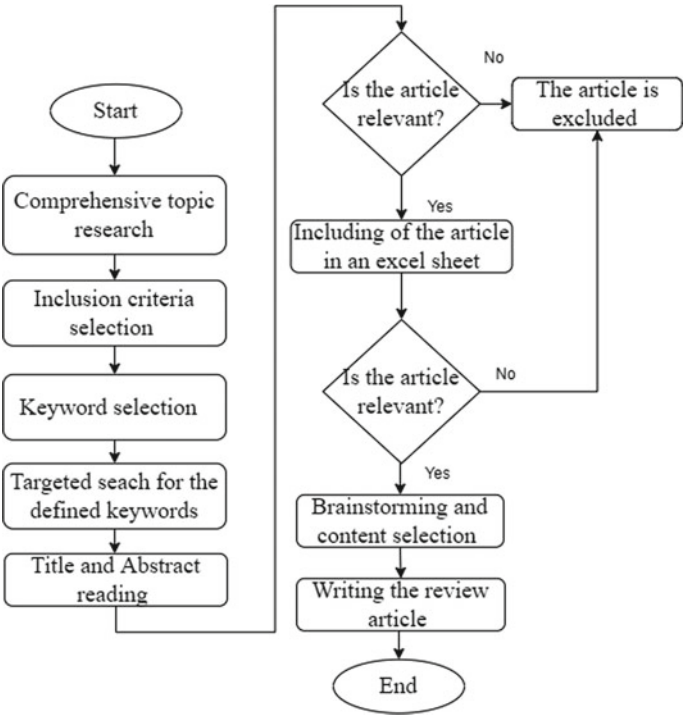

Fig. 1 Flow diagram of the methodology followed for the elaboration of the article. Adapted from Neves et al. (2019)

4 Analysis and Discussion of Results

After the selection process, an analysis of the type of article was performed. About 71% of the articles consulted were scientific articles. The six review articles analyzed contributed only to understanding and analyzing the topic and elaborating state of the art. No books or conference papers were consulted.

In order to identify the different types of sensors and technologies used for the detection and evaluation of ergonomic risks, only the 15 research articles contributed to the construction of Table 1. This table makes it possible to find some characteristics of the selected articles, namely the type of sensor used in each study, their application area and the type of movement/posture recognition models/software.

Most articles use IMU System-based wearable sensors to collect data that will later be used as input by machine learning models/software. Wearable inertial sensors are electromechanical devices typically composed of a combination of accelerometers, gyroscopes, and magnetometers that directly measure linear acceleration, rotational speed, and the path of an object in space (Zhao et al. 2021).

With the worldwide spread of smartphones and mobile devices comes the possibility of using small sensors that collect motion data, and components for storing it.

Table 1 Characteristics of the wearable sensors used in ergonomic studies

Sensor	Body application area	Software or model	Addressed ergonomic methods	Results	References
8 Wearable Sensors (shirt)	Neck, shoulder, forearms, arms and lumbar vertebrae	Long Short-Term Memory Model (LSTM)	–	Motion detection accuracy of over 80%	Petz et al. (2021)
Wearable Sensors (IMU System)	Full body, arm, wrist, legs and hip	CLN Model (CNN + LSTM)	–	–	Zhao and Obonyo (2021)
Wearable Sensors (IMU System) + Pressure sensors (helmet and insole)	Head and foot	ANN—Artificial Neronal Networks	–	95% recognition rate	Zhang et al. (2022)
Opal System by APDM Inc. (IMU System)	Dorsal	Machine learning tools: Random Forest, Decision Tree, Gradient Boost, AdaBoost, k-Nearest Neighbour, Naive Bayes, Multilayer Perceptron	–	Best algorithm—Gradient Boost 95% accuracy 94% sensitivity 96% in specificity	Donisi et al. (2021)
Integration of IMU sensors (RGB—color and deep sensor) with cameras (Kinect v.2™)	Full body	MAS—hardware (Motion Analysis System) MOCAP—software (Motion Capture)	–	–	Bortolini et al. (2020)
Sensor Microsoft Kinect ® V2	Full body	ErgoSentinel Software	RULA	–	Manghisi et al. (2020)
CAPTIV sensors + cameras	Full body (Neck, hip, arm, forearm, knee, ankle and foot)	–	–	Legislation maximum: 32 BPM (30–39 years) Maximum recorded: 85 BPM woman, 92 BPM man	Horváthová et al. (2019)

(continued)

Table 1 (continued)

Sensor	Body application area	Software or model	Addressed ergonomic methods	Results	References
Smartphone sensors (Acceleration, depth and bending) IMU sensor class—accelerometer and gyroscope (2 smartphones: arm and waist)	Arm and waist	–	RULA REBA	–	Nath et al. (2017)
Smartphone Sensors (Google Nexus 5X and Google Nexus)	Arm and waist	–	–	90.2% accuracy	Nath et al. (2018)
Wearable Inertial Sensors	Arms, torso and wrist	ActiLife Software, Expectation–Maximization Algorithms (EM), Software SAS, Software WEKA 3.8.0	–	–	Zhao et al. (2021)
BioMed (IMU System)	Full body	Gesture Operational Model	–	–	Olivas-Padilla et al. (2021)
Xens MVN Link Sensors (IMU System)	Full body	–	REBA RULA	88.3% accuracy for RULA and 91.7% for REBA	Huang et al. (2020)
MetaMotion C Sensors (IMU System)	Head, right arm, chest, right thigh and calf	CLN Model (CNN + LSTM)	OWAS MHT	–	Barkallah et al. (2017)
SRS (soft-robotic-stretch) (IMU System)	Foot, ankle	–	–	–	Chander et al. (2020)
Wearable sensors	–	–	–	–	Ranavolo et al. (2020)

These types of equipment can be incorporated into clothing, such as suits (Biomed) (Olivas-Padilla et al. 2021) and shirts (Petz et al. 2021), or placed directly on the body in strategic locations, as long as they do not disturb the activity (Chander et al. 2020; Donisi et al. 2021). The study can be performed by using of wearable sensors embedded in cell phones (Nath et al. 2017, 2018). However, the use of the cell phone has also allowed proximity to the worker by informing them in the case of improper postures (Zhao et al. 2021).

These sensors are responsible for storing a large amount of information, however without, software or algorithms capable of analyzing it, the information would be irrelevant (Khakurel et al. 2018).

The articles analyzed demonstrated various machine learning algorithms and methods used. Some of them only aim at applying technology to draw conclusions. Operator performance is usually evaluated, with productivity and ergonomic risk being quantified using some Key Performance Indicator (KPI's) (Bortolini et al. 2020). Other software proposes alternative or improved models (Barkallah et al. 2017; Manghisi et al. 2020), and a comparison of algorithms could still be found (Donisi et al. 2021).

The most common ergonomic rules mentioned were: RULA and REBA for the analysis of postures and joint angles, OWAS to measure the risk of inappropriate postures, and the time to adopt them (provides recommendations for action to correct the inappropriate postures with different degrees of urgency), Occupational Safety and Health Administration (OSHA) to measure the risk levels of WRMSDs in the work environment. Other developed studies also consider Maximum Holding Time (MHT), which allows the identification of postures held for a long time and is integrated with OWAS. Furthermore, this application served to evaluate the Convolutional Long Short-Term Memory (CLN) model and conclude that Deep Neural Network (DNN) models can be applied in posture recognition and ergonomic evaluations to minimize WRMSDs risks (Donisi et al. 2021).

In addition to industrial applications, the construction field was also a prominent area in the sample analyzed. Also, there has been an increased interest in the use of wearable sensors, in the construction area concerning the motion and risk assessment of WRMSDs (Zhao and Obonyo 2021). However, the interest may be because that workers in this area perform intensive manual tasks that can lead to WRMSDs due to their overexposure to improper postures (Zhao et al. 2021).

The graph in Fig. 2 presents the distribution by year of publication of the scientific articles over the time interval considered (last five years).

After analyzing the graph, it is possible to conclude that 2020 and 2021 have the highest number of publications included in this article. Thus, it is possible to confirm the information previously mentioned and referenced: the study and development of new technologies using wearable sensors for the detection of risk factors and prevention of WRMSDs s has raised great interest.

Finally, the results demonstrate that they align with what has been said in the literature. These studies showed a wide variety of sensors, software, and modes of operation and demonstrate the importance of wearable sensors in preventing WRMSDs.

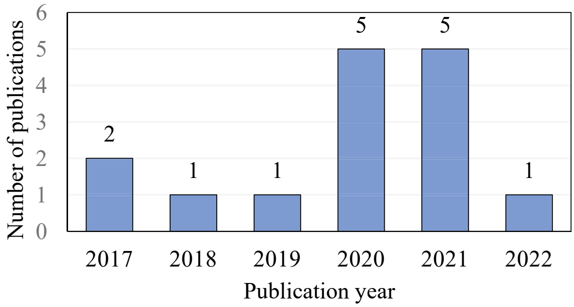

Fig. 2 Distribution of consulted publications over the time interval considered

5 Conclusion

Wearable sensors applied in Ergonomics allow continuous monitoring of human performance with ease, in real time. However, machine learning applications comes in a way to make ergonomic assessment more accurate compared to traditional methods, which use only observation and/or self-assessment. Furthermore, the use of technologies to perform ergonomic evaluations of risks factors leads to the need to revise the International Standards for human ergonomics. In the literature consulted, the types of wearable sensors that were used the most for scientific studies were inertial sensors. It was also found that a wide variety of software and models allow the reading and interpretation of the data collected by the sensors. Despite the growing interest in using of this type of sensor, there are numerous limitations. First the collection, processing and security of data is a highly complex process, and despite the existence of legislation that tries to address this issue, it is still under discussion. In addition, issues related to the comfort of using the sensors and their accuracy mean that there is still a long road full of challenges to be overcome. In the future, it is suggested that the works published in the machine learning area allow access to the collected data and the developed code in order to facilitate new studies in this area.

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Towards the Digital Transformation of Inspection Tasks in Aircraft Manufacturing Through a Human-Centric Design

Ana Colim, Rosana Alexandre, André Cardoso, Débora Pereira, Pedro Lima, Mariana Silva, and Sacha Mould

Abstract In aircraft manufacturing, the inspection workers are often exposed to risk factors (e.g. straining postures). Knowing the lack of ergonomics studies focused on this context, this chapter presents an ergonomic assessment conducted during the design phase of a new device to be used by the inspectors of metallic parts of airplanes. This device will consist of a portable artificial vision system intended to capture and process images of defects. This study intended to provide requirements for its appropriate human-centric design. Workers' postures were assessed by the Rapid Upper Limb Assessment (RULA) method after motion capture (with inertial sensors), which indicated a musculoskeletal risk that must be mitigated soon. Furthermore, a survey was conducted in which workers provided their perceptions of the work conditions. The level of required attention was the most negative factor pointed out. Anthropometric data were also collected and specific guidelines were provided to design the handle of the device. Finally, the workers participated in a usability test of the digital interface prototype of the new device, which proved itself intuitive and efficient to use and in line with the workers' needs. The current study emphasizes the relevance of the participatory ergonomic approach during digital transformations of workstations.

Keywords Aerospace manufacturing industry · Ergonomics and human factors · Postural analysis · Usability · Cognitive workload

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1 Introduction

In the aerospace manufacturing industry, workers are frequently exposed to biomechanical risk factors, especially in the final stages of the production processes, being essential for the adoption of a human-centric design of workstations and tools (Beuß et al. 2019). The use of manual tools/devices is very common in these industrial contexts, and it is crucial to assess their suitability for the tasks and their users. Scientific literature shows that the prolonged use of handheld tools can cause discomfort and physical fatigue during work, especially for the hand-wrist musculoskeletal system (Adeleye et al. 2020; Çakmak and Ergül 2018; Veisi et al. 2019). During manufacturing tasks, workers may be exposed to different biomechanical risk factors, such as the adoption of straining postures (e.g. extension/flexion and/or lateral deviation of the wrist), excessive muscular efforts, mechanical compression of soft tissues due to the handles' design not respecting the hand anatomical structure (Çakmak & Ergül 2018). In addition to increasing the risk of work-related musculoskeletal disorders (Garg et al. 2017), this muscle fatigue can affect workers' job satisfaction and performance (Garg et al. 2017; Pheasant 2003), being a critical factor in demanding tasks in terms of manual dexterity and required attention.

The scientific literature demonstrates the research gap in this domain, in which there is the need for ergonomic studies about biomechanical constraints in aircraft production lines (Arkhipov et al. 2018). Additionally, the manual devices used to support industrial tasks (in this case, the inspection) must be designed to optimize the entire process in terms of effectiveness and efficiency.

Along with biomechanical risk factors, inspection workers also undergo cognitive overload since it involves information-intensive processes (Abbas et al. 2020). In this domain, the reduction of the number of manipulated accessories and the digitalization of the process are essential requirements to optimize the production flow and the inspection precision, as well as to reduce the cognitive workload and task completion time (Wang and Dunston 2006).

Digitalization of the working process, using human-centric design stands out in the paradigm of Industry 5.0. This industrial paradigm places the human being at the centre of the industrial process (Nahavandi 2019). In this sense, the changes made within the digitalization of the workstations must be developed respecting an ergonomic participatory approach, with the active involvement of the workers (Guimarães et al. 2015; Nahavandi 2019).

This study corresponds to the first phase of a research project that intends to develop a digital device to support the quality inspection tasks of metallic surfaces of airplane structural parts. This equipment will consist of a portable artificial vision system capable of capturing and processing images, as well as supporting the inspection reports creation. Up to now, in the aerospace company where the current research is developed, the described tasks associated with this inspection are performed through a traditional and time-consuming procedure, using different manual tools. Therefore, an ergonomic approach was developed to (1) assess the main risk factors during the inspection process, and (2) test the usability of a digital interface prototype for the new device. With this assessment, we intend to do a data-driven definition of ergonomics requirements for future equipment, respecting a human-centric design.

2 Materials and Methods

The current study focused on inspection tasks of metallic surfaces of airplanes' structural parts, in an aircraft manufacturing industrial site. These inspection tasks, summarized in Table 1, are performed by two workers in each work cycle. A group of 5 workers voluntarily participated in the study and signed an informed consent term in agreement with the Declaration of Helsinki.

As mentioned previously, the current study is in the scope of the design phase of a digital device powered by artificial vision. This equipment will be capable of: (1) taking images from indications under UV and visible lights (replacing the use of a cellphone camera); (2) performing image processing to measure defects dimensions (replacing the use of a ruler and a magnifying glass); (3) ensuring good usability in terms of graphical user interface (UI) and handling, (4) automatically generate digital reports with the inspection results.

Regarding the tasks that will be transformed by the future inspection equipment (Tasks 2 and 3), the actual postures adopted by the workers were assessed (Fig. 1). For this assessment, an upper-body MVN motion capture system (XSens technologies) composed of 11 Inertial Motion Units—IMU (XSens MTw2 trackers with a 3D accelerometer, 3D gyroscope, and 3D magnetometer) was used to record the kinematics data. The IMU were fixed respecting the manufacturer guidelines and calibrated in the standing N-pose through a walking trial (Colim et al. 2021; Schepers et al. 2018). The raw sampling frequency was 1000 Hz and the output was 60 Hz. For data gathering and processing the XSens MVN software (version 2019.2.1) was

Table 1 Work sequence of each inspection cycle

Tasks' description	Time (min)	Activities				Additional information
1. Inspection with UV light (Fig. 1a)	20					Visual inspection with no lighting (black scenario)
2. Assess each defect with visible light (Fig. 1b)	10/each defect					Visual inspection with a magnifying glass (10x)
3. Identification of the defect type and photograph caption (Fig. 1c)	20/each defect					A ruler is used to measure the defect size, and a cellphone camera is used to acquire the image

Legend: - operation; - carry; - wait/temporary storage; - control

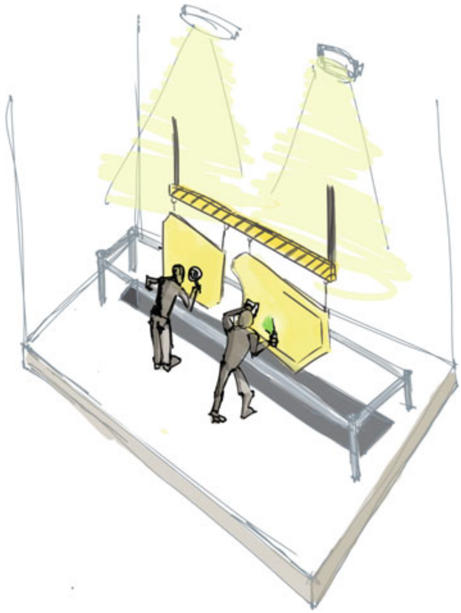

Fig. 1 Representation of the postures adopted during the inspection tasks

used. Considering the data recorded (joint angles measured with the IMU), to assess the musculoskeletal risk associated with the mentioned tasks, for each posture the Rapid Upper Limb Assessment (RULA) score (McAtamney and Corlett 1993) was determined.

In addition, a questionnaire was applied to the inspection workers ($n = 5$). Beyond the collection of demographic data, this questionnaire was divided into two main parts, to analyse the workers' perceptions of: (1) the work conditions, and (2) the usability of a prototype interface for the future digital device.

Regarding the questionnaire, the items about ergonomic conditions were based on the Ergonomic Workplace Analysis (EWA) method (Ahonen 1989), foreseeing a comprehensive assessment of the inspection workstation, across 13 topics, namely: (1) workspace; (2) general physical activity; (3) work postures and movements; (4) risk of accident; (5) work content; (6) restrictiveness; (7) workers' communication; (8) decision-making; (9) work repetitiveness; (10) level of required attention; (11) lighting; (12) thermal conditions; and (13) noise. These topics were assessed by a scale with a four-level rating scale: "very bad" (4 points); "bad" (3 points); "good" (2 points); "very good" (1 point). Moreover, the workers' perceptions about cognitive workload were also measured using the NASA Task Load Index (NASA-TLX) method (Hart 2006). This method allows the assessment of mental demand, physical demand, temporal demand, effort, performance, and frustration level, the outcomes of which are quantified on a 100-point scale.

Regarding the usability of the device's interface, a prototype was developed on Figma (version 108.1.0, https://www.figma.com/). The goal was to understand and evaluate the functionality of the device interface. For this, elements such as (1) navigation, (2) information architecture, and (3) language (if the proper task terminology was perceptible or confusing), rather than the visual appearance, were tested. The main idea was to identify: (1) critical points to accomplish the specific tasks, and (2) workers' expectations, opinions, needs, and perceptions about it.

The usability test session comprised three parts: (1) introduction, (2) task performance, and (3) post-test comprising the questionnaire. Participants were asked to introduce information regarding the metallic piece in inspection and perform the necessary steps for capturing the defect and send it to the report. This was done in a smartphone Android (6.18 in.), whose screen would have approximate dimensions to the final solution.

The questionnaire's part focused on the usability test was composed of six open questions about workers' experience interacting with the prototype and also questions of the System Usability Scale (SUS), which evaluates the perceived ease of use of a digital product, and is characterized by the dimensions of effectiveness, efficiency and satisfaction. The SUS is a 10-item scale, each evaluated on a 5-point Likert scale (Brooke 2020). Then, it is computed as a global score that can range from 0 to 100, being 68 as the first value indicating that the system's usability is good, as slightly above the average (Bangor et al. 2009).

Finally, to define physical requirements to design the handle of the future device, right-hand anthropometric data were collected, namely: index finger length, handbreadth (across thumb), and maximum grip diameter. A correction of 25 mm was added, related to gloves thickness (Pheasant 2003). These data were collected using a RealMet institute small anthropometer.

For all the data collected, a descriptive statistical analysis was performed, except for the SUS results, considering the mean as a measure of central tendency and the standard deviation as a measure of the values' dispersion.

3 Results

The sample of 3 male and 2 female workers (mean age = 35.4 ± 8.0 years old), of the inspection workstation, have an average work experience of 7.0 (± 1.6) years and are all right-handed. The future equipment will be handled by the right hand and the mean values of the measured anthropometric data are: (1) index finger length of 88 (± 6) mm; (2) handbreadth of 118 (± 4) mm; and (3) maximum grip diameter of 75 (± 6) mm.

Regarding the postural assessment during Tasks 2 and 3 (Table 2) of the current work situation, the RULA scores indicate that investigation and changes are required soon, foreseeing the reduction of musculoskeletal risk exposure.

Concerning the ergonomic assessment, based on the workers' perceptions, the EWA results are presented in Fig. 2 and the NASA TLX results in Fig. 3.

Table 2 Summary of the RULA assessment based on the joint angles measured by the IMU

Task	Group A (Right upper arm, forearm and wrist)	Group B (Neck, trunk and legs)	RULA score	Main postural risk factors
2. Assess each defect with visible light	4	8	6	Arm flexion ~76º with abduction; wrist extension ~28º with lateral deviation; neck extension with lateral rotation and deviation; trunk flexion ~37º with lateral deviation
3. Identify the defect type and photograph	4	5	5	Arm flexion ~48º with abduction; wrist extension ~20º with lateral deviation; neck extension ~20º

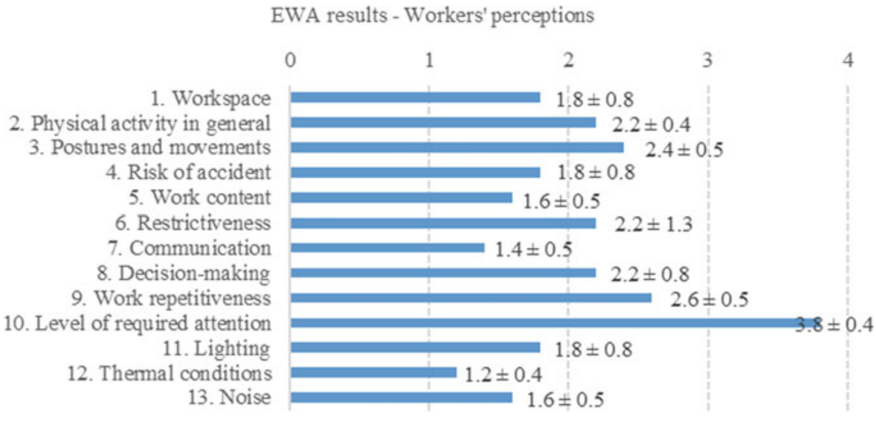

Fig. 2 EWA results for the inspection workstation (according to the workers' perceptions)

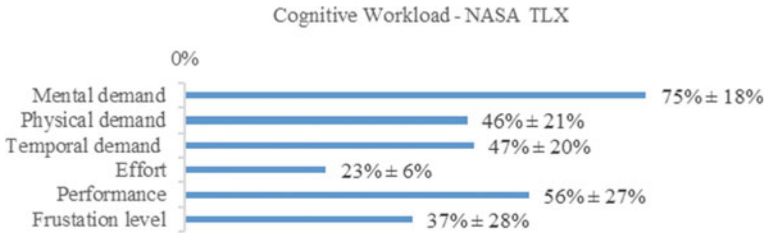

Fig. 3 NASA TLX results, considering the workload perceived by the workers

For the interface prototype of the digital device, the user experience was considered good, with a total score of 81 points, meaning that, in general, the prototype satisfies the workers' needs and few changes need to be incorporated into the subsequent design. Overall participants reported that the UI of the new equipment improves the process of inspection.

4 Discussion

4.1 Ergonomic Assessment: Work Conditions and Interface Usability

During the inspection tasks that were assessed (the existing work situation without the new device), the workers handled different manual tools, namely: an inspection lamp with UV and visible light on the left hand; and on the right hand a magnifying glass, a ruler, and a cellphone to photograph (in an alternating manner). The tasks' visual demands and the manual tools that are used require straining postures, mainly, of the upper body. According to the RULA assessment, the workers are exposed to a musculoskeletal risk that should be mitigated soon. The adoption of straining postures was also pointed out by the workers as a negative factor, due to the geometry and location of defects on the inspected pieces. The need for manual tool handling is also a relevant constraint mentioned by them. Therefore, these results support the need for a new inspection device integrating different functions and, consequently, eliminating these different handheld tools. In this domain, ergonomics requirements, presented in the subsequent subchapter, have to be defined in the design phase to contribute to the postural correction [as recommended for any manual tools design (Adeleye et al. 2020; Çakmak & Ergül 2018; Veisi et al. 2019)].

Regarding the work conditions, the workers highlight the level of required attention as the worst factor (as evidenced in Fig. 2), followed by work repetitiveness. This is in line with NASA-TLX results, which demonstrated that mental demand is the factor that most contributes to experienced workload in these inspection tasks.

These findings are in agreement with the researchers' initial expectations, reinforcing the need for solutions that could support and help the inspection workers. Therefore, the new equipment will be designed with capabilities that facilitate images' capture and processing, with digital support for the defects' measurement and identification, as well as for the digital reports' creation. It should be emphasized that these specifications meet the expectations and needs reported by the workers.

However, with the introduction of this novel device, the human–machine interaction must be investigated, to close the machine specifications/functions and the workers' capabilities/needs, achieving a human-centric design (Ávila-Gutiérrez et al. 2021). For this purpose, in addition to the previously described assessment, the usability of a prototype digital interface was also evaluated. With the data collected through the usability testing sessions (video recordings, think-aloud technique, questionnaire responses, and annotations), it was possible to obtain both qualitative and quantitative data. The findings showed that during the usability test, all participants reported confusion, especially with two screens. The main complaints were related to the incomplete amount of information that these screens displayed and also with their layout. However, there were no readability problems or problems with the size of the buttons, one of our first concerns. The participants also mentioned that the interaction flow of the new device is straightforward, fast, and easy, as we could see from their comments: "*it is more practical and fast*" (Worker 1) and "*ease for defect recording*" (Worker 4).

4.2 Requirements Definition for the Digital Inspection Equipment

Considering the ergonomic assessment here presented, several requirements for the design of the digital equipment were defined. These requirements will lead to the design and prototyping of the new device (to be tested with the workers). For this human-centric design, the main requirements for the physical characteristics of the equipment (CCOHS 2015) are the following:

1. the new device should weigh up to 0.4 kg as it is a tool that requires some precision (such as stability when capturing the images); if this weight is exceeded, the handle design must include a counterweight at the location of the grip in relation to the device's center of mass (not exceeding the total weight of 2 kg). Ideally, the device's center of mass should be aligned with the center of the hand holding it;
2. the handle type must remain as a power grip in which the hand involves the entire grip; for that, the handle diameter shall not exceed 40 mm (respecting the maximum grip diameter of the inspection workers);
3. the design of the handle shape must avoid deviations of the hand-wrist system (this must be aligned with the forearm); the handle may be curved to avoid these postures during the tasks' performance (as occurred in the actual conditions). This handle may need to include a physical protrusion on the extremity to prevent the device from slipping/sliding during use;
4. the handle must avoid compression of the hand's soft tissues, respecting its anatomy; a length between 125 and 145 mm is recommended (considering the anthropometric data of handbreadth with the gloves' correction);
5. the button position to activate focus and image capture must be set taking into account the reach of the index finger.

Concerning the equipment's UI, based on the usability test results and also from the analysis of the entire project development team, some improvement points were devised, namely concerning the navigation and information architecture, as follows:

1. The addition of a pop-up with alert messages concerning the time left to the end of the inspection;
2. The addition of a new screen in which the inspector can insert information about the defect position and measurements;
3. Reappraise the inclusion/defect selection screen to make it easier to understand;
4. Reappraise the batch selection screen to comply with the changes that came from technical needs.

As one can see, usability tests are most effective when used during product development and not just when the product is ready (Norman 2013). The next step is to improve the UI with visual design elements (e.g. typography, system icons, and color) and test it again to verify if it aligns with the workers' needs and improves the overall experience.

4.3 Future Work

The next steps of this study are: (1) the improvement of the design (according to the feedback from the workers in the usability test) and layout of the UI; (2) the integration of the proposed physical requirements in the new equipment to fulfill the workers' needs and re-assess prototypes; (3) the assessment of the final solution.

Finally, it should be noted that the involvement of workers will be crucial throughout the process so that the design of the inspection system will be adaptive, including the real needs of the workers' tasks and capabilities. This participatory ergonomic approach (Guimarães et al. 2015) is expected to achieve a successful implementation of this digital device in the real work context, contributing to the improvement of the inspection process.

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Next Generation Automobile Haptic Seat: In Inclusive Way

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Abstract Autonomous Vehicles will change the present driving paradigm and the car will be considered a 3rd living space, contributing to the social inclusion of the visually impaired. This study aimed to develop a haptic seat to alert and inform passengers about certain situations on the road and define the perceived minimum, optimal and uncomfortable vibrational values to be considered when designing guidelines for the development of haptic devices. An instrumented car seat with 10 actuators was developed, and an experiment was designed and applied to 39 participants, to determine the Ascending Minimum Threshold (AMT); Descending Minimum Threshold (DMT); Optimal Vibration (OV) and Discomfort (D), and study the relationship of these variables with gender, anthropometric characteristics, and age. Software for data collection was also developed. This research found significant differences between men and women, regarding the MAT (female: 24%, male: 26%), OV (female: 34%, male: 40%), and D (female: 47%, male: 60%), concluding that women showed greater sensitivity to haptic stimulation. Anthropometric measures and age also showed a correlation with the variables mentioned above. Therefore,

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this study suggests that differences between gender, anthropometric measures, and age of users, should be considered when designing haptic devices for car seats.

Keywords Haptic seat · Human · Machine interfaces · Haptic perception · Autonomous vehicles · Assistive technology

1 Introduction

Autonomous Vehicles (AVs) will change the present driving paradigm, and the car will also be considered a 3rd living space due to the possibility of their passengers undertaking activities during commutes (such as reading, online meetings, or watching a movie) that were not possible to perform while driving.

Recent studies estimate that 1.3 billion people have some kind of visual impairment worldwide, 36 million are blind and 216 million have moderate to severe visual impairment. Although it has been suggested that the majority of visual impairment is avoidable, other factors such as the aging of the population might considerably increase the number of blinds and moderately or severely vision impaired up to 115 and 588 million people, respectively, by 2050 (Leo et al. 2020). This growing population may encounter several difficulties in their activities of daily living since we operate in highly visual contexts. Difficulty and fear of independent travel are one of the greatest disabling consequences of blindness. With time, this may cause fear of going out, leading to social problems such as isolation, anxiety, and depression (Ribeiro et al. 2015; Senra et al. 2015).

To ease these circumstances, in recent years, a variety of assistive devices have been proposed, such as refreshable Braille displays, screen readers, audiobooks, or smartphones with voiceover/talkback functions. In this context, technologies with haptic feedback have received increasing attention in the last years, since touch stimuli do not block or distort the sounds coming from the environment, which represent an essential input for blind users (Kim and Harders 2020).

Haptic interfaces in the seat have been mainly targeted at conveying spatial information, warning signals, and coded information. Due to the efficacy of using the driver's back as a receptor of spatial information, tactile applications in augmented seats have been greatly focused on providing navigational information (Van Erp and Van Veen 2001; Hogema et al. 2009; Fitch et al. 2007; Hwang et al. 2012; Breitschaft et al. 2019; SCHROTH Safety Products 2020; Ji et al. (2011); Sorgini et al. (2018)).

During this project, the representativeness of individuals with visual impairment, as well as the need to integrate this group with the future transport reality were considered. The aim of this study was to develop a haptic seat capable of alert and informing passengers about certain situations on the road and understand the perceived minimum, optimal and uncomfortable vibrational values, so that this information can be replicated to the visually impaired and constitute guidelines for creating these types of devices.

2 Materials and Methods

2.1 Research Steps

This study was divided into four steps: (I) Definition of the problem, (II) Development of the Haptic Car Seat, (III) Software development; (IV) Experimental procedure and data collection and (V) Data analysis.

2.2 Participants

During this experiment, the team recruited 39 test subjects, 20 males and 19 females, within the age range of 22 to 57 years old. Before the experiment, participants who had coats were asked to remove them, so that they would not interfere negatively with the results. Each participant signed a consent form agreeing to take part in the experiment. Participants were then asked to sit on the SAV seat, and the shoulder height sitting and the buttock popliteal length (seat depth) were recorded in order to evaluate the correlation between the anthropometric measures of the test subjects and the dependent variables under study. These measures were chosen as they represent the part of the human body that is in contact with the car seat. Participants' sex, age, height, and body mass were also collected.

2.3 Haptic Seat Development

For the experimental preparation a standard seat was used. The vehicle seat consists of seat pan and back support as illustrated in Fig. 1. It is also shown the locations where the vibration actuators were installed, underneath the seat's leader. A total of 10 actuators (motors) were installed throughout the whole seat contact area to produce the vibrations.

All the motors were from Vybronics, model JQ24-35F580C (see left side of Fig. 2), of type ERM, with a rated voltage of 5.0 VDC, rated current of 150 mA, 12.8 G@100 g (RMS), and a frequency range of 0–42.5 Hz (or 0 to 2550 RPM). To prevent contact with the eccentric mass, a 3D printed shield was used (see Fig. 2—right).

A total of ten motors were used, controlled using a multi-driver board for ERM and LRA from Texas Instruments (model DRV2605LEVM-MD), in turn controlled by a Raspberry Pi 4, as illustrated in Fig. 3. One of these boards can control up to eight motors, hence, two boards were used: one to control six of the motors (B1—upper left, B2—upper right, B3—upper center, B4—lower center, B5—bottom left, and B6—bottom right, and another to control the remaining four (S1—distal left, S2—distal right, S3—proximal left, and S4—proximal right).

Fig. 1 Seat with the locations where the vibration actuators were installed (on the left), and the final setup (on the right)

Fig. 2 The motor from Vybronics, model JQ24-35F580C (on the left), and the 3D printed shield used to prevent contact with the eccentric mass

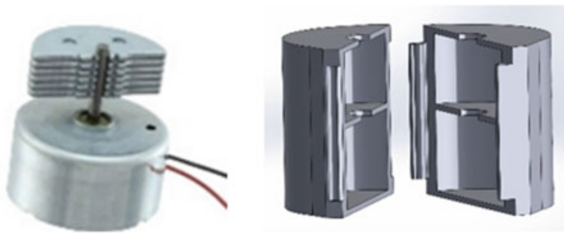
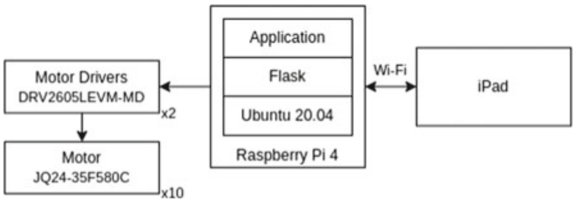


Fig. 3 Haptic Seat's simplified hardware and software architecture



To measure the surface vibrations and thus have a real amplitude and frequency map of the produced vibrations (see Fig. 4), each actuator was fitted with an accelerometer on top of the seat leader, right above the installed actuator.

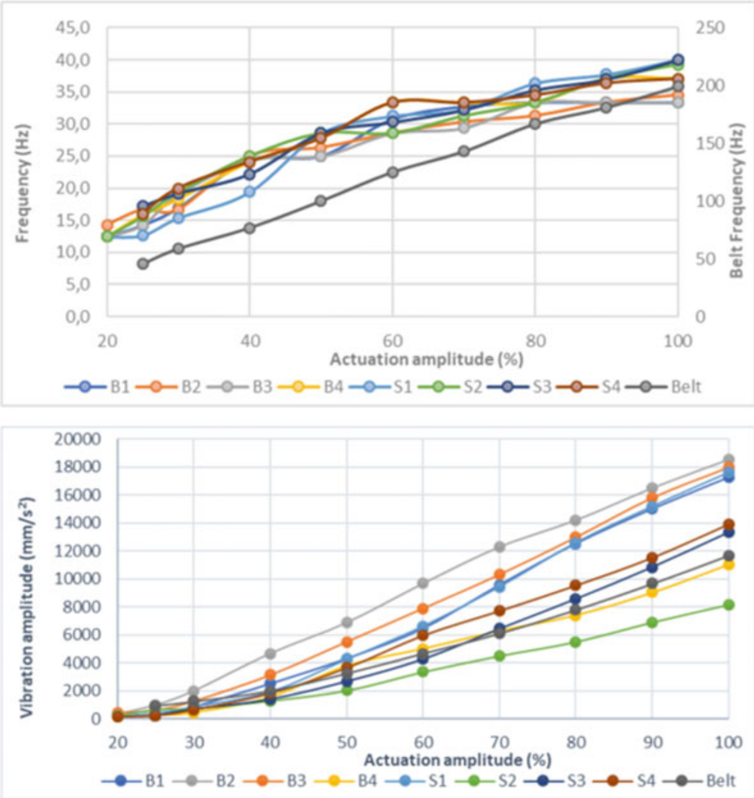


Fig. 4 Vibration frequency and vibration amplitude as a function of the actuation amplitude (0–5 VDC)

2.4 *Software Development*

A graphical user interface was developed, to run on an Apple iPad Pro, for the vibration intensities evaluation (see Fig. 5). This evaluation consisted in the identification of: (i) the moment when the subject began to perceive the vibration, in a scenario that started with a low intensity but which was gradually increased (Ascending Minimum Threshold or AMT); (ii) the moment when the subject stopped perceiving the vibration, in a scenario that started with a high intensity but which was gradually decreased (Descending Minimum Threshold or DMT); (iii) the most comfortable vibration intensity to receive a warning (Optimal Vibration or OV); and (iv) the vibration intensity considered uncomfortable (Discomfort or D).

As illustrated in Fig. 2, the iPad's web browser was used to access a web page hosted by a Flask web server running on the Raspberry Pi 4. As the subject interacted with the web page, the motors were controlled based on the current scenario. Inputs from the subject throughout the evaluation were saved for later analysis.

Fig. 5 Graphical user interface developed for the vibration intensities evaluation

2.5 Experimental Procedure and Data Collection

As shown in Fig. 1 on the right, an experimental setup was developed in which the participant, wearing light clothes, sat on the car seat and evaluated the haptic stimuli. In this way, the steps taken in data collection are presented: 1—Recruitment of individuals of both sexes aged 18–65 years without comorbidities (Diabetes Mellitus, neurological diseases, or injuries) that could influence haptic sensitivity; 2—Signing the consent form to participate in the study (19 women and 20 men were recruited who agreed to participate voluntarily in the study); 3—Measurement of anthropometric data (Body Mass, Height, Acromion-Seat Distance, Gluteo-Popliteum Distance); A one-minute training phase, comprising a set of 4 vibrations with different intensities (15%, 20%, 15%, 20%) presented in random order were delivered by all 10 actuators (4 on the pan and 6 on the back) to the participant, which was instructed to acknowledge vibration by saying "yes" whenever a stimulus was perceived.

In the experimental phase, 10 actuators (4 on the pan and 6 on the back) were active at the same time for each stimuli presentation.

2.5.1 Minimum Threshold

Method of limits: for this first part of the experiment, vibration intensity was varied manually by the experimenter to determine minimum thresholds. This procedure will include two tasks (A and B) as presented in Table 1.

During the performance of Task A, and starting from 15%, the experimenter increases the vibration intensity at intervals of 1% until the test subject identifies orally that had recognized the vibration. Then the experimenter repeats this process five times. During the performance of task B, and starting from 30%, the experimenter decreases the vibration intensity at intervals of 1% until the test subject communicates that he/she no longer feels the vibration. The process was repeated five times. After

Table 1 Task for determining the minimum vibration threshold

Task A. (5 trials)	The vibration intensity is increased from 15% until the participant responds "detected," by pressing a key. This procedure is repeated five times
Task B. (5 trials)	Then, starting from the standard stimulus, intensity is decreased until the participant responds "not detected". This procedure is repeated five times

the above-mentioned 10 trials (five trials for task A and five for task B), the average point was considered as the absolute minimum threshold of vibration intensity.

2.5.2 Optimal Vibration Intensity

The participant was introduced to a tablet interface where vibration intensity could be self-regulated through a slider (see Fig. 5). Then, the experimenter asked the participant the following question: "Which vibration intensity would be the most appropriate to alert a passenger that he/she must prepare to leave the vehicle, considering that he/she is close to the destination?". The participant manually regulated the intensity of the haptic actuators and whenever he/she felt that an optimal vibration intensity was delivered, the confirm button was pressed on the tablet. The slider returned to the starting position and the participant repeated the procedure five times. No time constraints were applied.

2.5.3 Maximum Comfort Threshold

Using the previous setup, the participant was introduced to the maximum comfort threshold determination task. The experimenter triggered the task with the question: "Which vibration intensity will you describe as the maximum intensity you consider comfortable? Please adjust the slider to the vibration that you find comfortable and from which it becomes uncomfortable."

Again, the participant manually regulated the intensity of the haptic actuators and confirmed a vibration intensity through a button on the tablet. The slider returned to the starting position and the participant repeated the procedure five times.

3 Results

Thirty-nine test subjects, 20 males and 19 females, within the age range of 22–57 years old participated in this experiment. The responses obtained are related to the percentage of electrical voltage (from 0 to 5 V) applied to the motor that produces the vibration in the car seat. Results were analyzed for the minimum ascending threshold, the minimum descending threshold, the optimal vibration intensity, and the maximum threshold (discomfort). Anthropometric and socio-demographic characteristics were also considered (see Table 2).

Data related to the minimum and maximum threshold as well as optimal vibration sensation did not show a normal distribution (Kolmogorov–Smirnov/Shapiro–Wilk, $p \leq 0.05$). Therefore, a non-parametric comparison test (Mann Whitney U Test) was performed in order to verify the differences between men and women for the variables Ascending Minimum Threshold, Descending Minimum Threshold, Optimal Vibration, and Discomfort. For the evaluated group, it was found that there was a

Table 2 Minimum Thresholds (Ascending: AMT; Descending: DMT), Optimal vibration—OV, Discomfort—D, Anthropometric and Socio-demographic characteristics

Gender		AMT (%)	DMT (%)	OV (%)	D (%)	A[a] (years)	S[a] (cm)	BM[a] (kg)	ASD[a] (cm)	GPD[a] (cm)	BMI[a] (kg/m^2)
	Average	23.7	16.4	35.5	48.4	38.0	161.9	57.4	50.8	45.5	21.9
Female	Median	24.0	17.0	34.0	47.0	36.0	161.0	56.0	51.0	44.0	20.8
n:19	IR[a]	7.0	9.0	29.0	47.0	31.0	23.0	7.0	7.0	13.0	10.9
Male	Average	25.2	17.2	41.8	65.3	29.5	178.2	77.1	55.4	46.3	24.2
n: 20	Median	26.0	18.0	40.0	60.5	27.5	180.0	78.0	47.0	47.0	23.8
	IR	4.0	9.0	30.0	60.0	25.0	27.0	50.0	14.0	10.0	15.12

[a]Interquartile Range (IR); Age (A); Stature(S); Body Mass (BM); Acromion Seat Distance (ASD); Gluteo Popliteum Distance (GPD); Body Mass Index (BMI)

difference in the following variables: Ascending Minimum Threshold ($p = 0.005$), Optimal Vibration ($p = 0.01$), and Discomfort ($p = 0.001$). It was also noticed that the female group showed greater sensitivity to haptic stimuli in general.

Using Spearman's non-parametric correlation test, it was possible to identify in females a strong inverse relationship between the acromion-seat distance and the indication of optimal vibration (Cc: −0.700; $p = 0.001$) and moderate correlation for discomfort (Cc: −0.528; $p = 0.02$). Therefore, the greater this measure, the lower the percentage value of vibrations by the car seat. For males, there was a moderate positive correlation between height and the minimum ascending threshold (Cc: 0.577, $p = 0.015$), therefore, the higher the male individual, the higher the percentage value of vibration to start being noticed.

We also sought to understand the relationship between anthropometric data and haptic sensitivity, in which, for both genders, stature was shown to be the variable that exerted the greatest influence, with emphasis on the ascending minimum threshold ($p = 0.001$) and descending minimum threshold ($p = 0.034$).

This analysis demonstrated that there was a tendency for the influence of body mass on the sensitivity of the vibration produced by the car seat in an ascending way ($p = 0.058$). However, a larger number of participants would be needed to identify the impact of this measure on vibratory sensitivity.

4 Discussion

Some studies have been carried out with the use of vibration in car seats in order to alert the driver to dangerous situations (Telpaz et al. 2015; Chang et al. 2011). However, there is little recent information about the haptic perception of individuals who are seated on these benches (Morioka and Griffin 2008; Yong et al. 2011). The present study generated information related to this perception, with the objective of presenting a sensory output for individuals with visual impairments, a group of people who make up a high percentage of the world population (Leo et al. 2020).

Overall, the results obtained from this study seem to reveal important data regarding the perception of a haptic stimulus. Starting with the significant differences found between men and women, when evaluating Minimum Threshold, Optimal Vibration, and Discomfort. The study allowed to find that the female group showed greater sensitivity to haptic stimuli when studying the variables above mentioned. These results converge with the observed findings in haptic appreciation between gender demonstrated by Weinstein (1968). According to this author, women were significantly more sensitive than men to pressure sensitivity.

Regarding optimal vibration, the results of this study pointed to a variation between men and women of 34% to 40% respectively. When translating to motor action frequency in Hz (Fig. 4), it was noticed that these values varied between approximately 20 and 25 Hz. These values are in line with those proposed by Yong et al. (2011) who demonstrated an optimal motor actuation frequency of approximately 26–34 Hz). Morioka and Griffin (2008) demonstrated that below 80 Hz of motor vibration, there is a more effective tactile appreciation on the surface of the body in contact with the seat than on the hands and feet.

Another finding of this study is related to the anthropometric proportion of the evaluated individuals, and it was possible to identify in females a strong inverse relationship between the acromion-seat distance and the indication of optimal vibration (Cc: −0.700; $p = 0.001$). Therefore, the greater this measure, the lower the percentage value of vibrations by the car seat. In contrast, for males, it was found a moderate positive correlation between height and the minimum ascending threshold (Cc: 0.577, $p = 0.015$), thus, the higher the male individual, the higher the threshold. These results seem to be aligned with the findings of Weinstein (1968) who concluded that males and females may show significantly opposite sensitivities for the same body parts.

This study contributes to the incremental knowledge of haptic perception, aiming to improve users' experience inside autonomous and non-autonomous vehicles. An important accessibility component was included in this study to support users with different types of visual impairments. In the end, the results of this project contribute to the definition of guidelines for the development of assistive technologies to be included in the context of autonomous and non-autonomous cars.

5 Conclusions

The goal of this study was to develop assistive technology to be applied in the context of the 3rd living space that could contribute to the social inclusion of the visually impaired but that at the same time could be used by all users. Following accessibility and inclusive design guidelines, and using multimodal solutions, a haptic seat was developed to determine the minimum and maximum threshold for perceived vibration, and the optimal vibration intensity that should be used in the warning "arrival approach" to be given by the seat to the passenger of the SAV.

Regarding gender, significant differences were found between men and women, regarding the Minimum Ascending Threshold (female: 24%, male: 26%), Optimal Vibration (female: 34%, male: 40%), and Discomfort (female: 47%, male: 60%). Also in the evaluated group, women showed greater sensitivity to haptic stimulation.

Regarding the anthropometric issues of the evaluated group, the greater the distance between the acromion and the bench surface, in the female group, the lower the vibratory percentage to reach optimal vibration and the sensation of discomfort. For men, the taller they are, the higher the percentage value of vibration starting to be noticed.

There was also a tendency towards a negative correlation between the age of the women and the vibration intensity that generated discomfort.

Therefore, this study points to issues to be observed in the construction of haptic stimulation devices installed in car seats, namely: the sensory differences between gender, the change in the perception of the stimulus as a function of the anthropometric characteristic, and the need to assess the age of users of this technology. As suggestions for future works, a study should be conducted in a real environment and with visually impaired participants. Moreover, a study should be conducted to understand the subjective evaluation of the vibration rhythms according to urgency and pleasantness, as well as the perception of the dynamic vibration applied in the seat.

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How Can BPM Combined with Ergonomic Assessment Contribute to Improve Working Conditions? A Mixed Approach Applied to a Practical Case

Diana Pinheiro, Paula Carneiro, and Leonor Teixeira

Abstract This document presents a practical case in a company, where the Business Process Management/Business Process Model and Notation to map the processes is combined with ergonomic evaluation methods—Nordic Musculoskeletal Questionnaire, analyzing the ergonomic conditions of the workers. The objective is to demonstrate that this combination is beneficial and allows tracing a resolution path, enhancing the solution. The methodology used first was Business Process Management/Business Process Model and Notation and then the Nordic Musculoskeletal Questionnaire, presenting the results of both throughout the work. It was concluded that this work showed the usefulness of using Business Process Management/Business Process Model and Notation to model processes, discovering non-value-added activities and later the use of Nordic Musculoskeletal Questionnaire in order to evaluate the identified problems, which in this case are related to Human Factors and Ergonomics.

Keywords Human Factors and Ergonomics (HFE) · Manual Material Handling (MMH) · Business Process Management · Nordic Musculoskeletal Questionnaire (NMQ)

1 Introduction

Human Factors and Ergonomics (HF/E) is a topic that reveals its extreme importance since despite the growth of technologies and information systems, the human factor

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will continue to be present in the context of in the context of work and organizations (Kadir et al. 2019).

For this reason, the concern with this topic and research in this area, bring the most varied advantages. Productivity is every company's objective—and by taking care of HF/E it is possible not only to increase productivity but also to reduce the probability of injuries at work and associated costs (Brito et al. 2020). Therefore, when integrating into the company's manufacturing environment, a problem was identified related to the weight that suppliers are subject to when handling the components of transport used, whether pallet trucks or logistic trains, to the production lines, causing work accidents or long-term illnesses, such as work-related musculoskeletal disorders (WMSDs), compromising the ergonomic conditions of employees. This is one of the major gaps regarding HF/E issues—the lack of concern for manual material handling issues (Kim et al. 2021; Muller et al. 2020; Skals et al. 2021; Yang et al. 2020).

This study, conducted in a practical context, aims to verify how Business Process Management (BPM) can help to identify areas of intervention in the work context, in order to assist in ergonomic evaluations. About this topic, there are no known studies in the literature that address this question, i.e., that combine the understanding of processes through BPM and Business Process Model and Notation (BPMN) with ergonomics evaluation. Only a master's dissertation was found (Polderdijk 2017) with the same line of thought as this paper, which is to take advantage of BPMN to help identify areas of action within the work process. It relates BPMN with the assessment of risk human's factors, through the development of an extension to BPMN that allows the use of notation oriented to this assessment, allowing to analyze the physical risks and visualize the results of the model. It also demonstrates that, for experienced BPMN users, the need for a new notation does not bring huge benefits, since they already have the sensitivity to recognize the existence of physical risks analyzing only the BPMN without the extension. However, for beginners, it proved to be quite useful and easy to understand. Thus, to achieve a solution to this problem, BPM and its phases were used as a methodology to identify areas of intervention, allowing a holistic view of the process, and subsequently to apply methods of evaluating the WMSDs in the areas of intervention.

Resuming, it is necessary to make a distinction of the objectives: the main focus of this study is to evidence the relevance of the knowledge of the processes through the BPM in the ergonomic aspects (in this case, in the ergonomic evaluations), and also demonstrate how BPM, BPMN, and ergonomics can be positively connected to each other.

On the other hand, and in the industrial environment, this study aims to redefine the weights that employees should handle without compromising production and ergonomic conditions.

2 Human Factors and Ergonomics

Human Factors and Ergonomics (HF/E) is an area of study focused on "improving the quality of human life, compatibility, effectiveness, safety, ease of performance and well-being", regardless of their role in the organization (Reiman et al. 2021). Ergonomics "is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system" (International Ergonomics Association 2022). Considering the (International Ergonomics Association 2022), the results of working in this area are, usually, diverse, as: (i) improving the conditions in which a function is performed; (ii) create a balance between the worker's capabilities, whether anatomical, physiological or cognitive, and the demands of the task; and also, (iii) to optimize the coexistence between man, machine and the work environment.

Some studies refer that, "regardless of increasing automation trends in the industry, this will still include humans, hence some sort of human–computer/machine interaction" (Kadir et al. 2019) and as such, it is imperative to be concerned with their ergonomic conditions. Although some companies still look at ergonomics as a cost rather than an opportunity for improvement and investment, it is notable that ergonomic analysis has a very significant impact on the organizations, standing out: increased productivity; decrease in work injuries, as unnecessary movements can be identified and eliminated; cost reduction and non-productive times (Brito et al. 2020; Colim et al. 2021; Kadir et al. 2019; Vinoth Kumar et al. 2021).

The concern and application of techniques and improvements related to HF/E is transversal to all organizations and sectors, such as Automotive, Food, Aerospace, Textile, Metallurgical Industry and Manufacturing (Vinoth Kumar et al. 2021). In the industry, one of the biggest gaps regarding HF/E issues is the manual material handling (MMH), which contributes to pain and WMSDs. At issue are the lives of workers with associated disabilities that prevent them from doing certain normal daily activities, this is because, "there is a clear relationship between musculoskeletal disorders and physical load" (Kim et al. 2021; Muller et al. 2020; Skals et al. 2021; Yang et al. 2020).

2.1 Work-Related Musculoskeletal Disorders (WMSDs)

One of the major concerns of ergonomics is WMSDs, which are impairments of the musculoskeletal system, mainly caused by the performance of work tasks and the environment in which the work is performed (Govaerts et al. 2021). WMSDs refers to a "set of inflammatory and degenerative diseases that affect the locomotor system, i.e. muscles, tendons, bones, cartilage, ligaments or nerves and when provoked or aggravated by work, or by the circumstances in which it develops" (EU-OSHA 2021; Govaerts et al. 2021).

There is a high prevalence of WMSDs in workers throughout their working life, which limit the production flow of a shop floor, leading to lost productivity, since, good ergonomics can reduce the physical wear of the employee and, thus, optimize the production flow, directly influencing the productivity of companies, which is the main focus in an organization (Beuß et al. 2019; Denadai et al. 2021; Oyekan et al. 2021).

WMSDs have become a serious health problem in developing and developed countries with significant impact on individuals and the economy across the world (Rathore et al. 2020). With the back and spine being the most common musculoskeletal injuries, affecting more than a quarter of adults each year (Oyekan et al. 2021). Also, Govaerts et al. (2021) concluded that in the secondary industries of twenty-first century Europe, the general lumbar region, shoulder/neck, neck, shoulder, lower back and wrist were the most prevalent with mean values of 60%, 54%, 51%, 50%, 47%, and 42%, respectively.

2.2 WMSDs Risk Assessment Methods

The implementation of intervention actions to reduce exposure to risk factors related to WMSDs is the most used prevention strategy. As such, to implement certain intervention actions, situations and occurrences must be evaluated (Kee 2021).

There are several assessment approaches, from checklists and self-assessments facilitating the collection of information on the Gemba, to observational methods, which allow the assessment of the posture of various body segments and critical factors of physical exposure, through risk classifications, based on scores and direct measurement methods. Among the various assessment methods, observational techniques have been used more frequently as they are cheap, easy to use, flexible and do not interfere with workers' tasks or the work being performed (Kee 2021).

Ergonomic assessment tools are used to discover the level of risk in the work environment and then create a solution to overcome such problems (Rajendran et al. 2021).

Within the category of checklists and self-assessments is the Nordic Musculoskeletal Questionnaire (NMQ), according to Crawford (2007), is a standardized questionnaire methodology that allows the evaluation of lumbar, neck, shoulder and general complaints, facilitating the comparison of results between studies.

As the name implies, it is a general forced-choice questionnaire, identifying areas of the body that cause musculoskeletal problems. The filling is aided by a body map to indicate the locations of symptoms being neck, shoulders, upper back, elbows, lumbar region, wrist/hands, hips/thighs, knees, and ankles/feet. Respondents are questioned and through the NMQ it is possible to assess symptoms such as pain, discomfort, or numbness for 9 body segments; symptom intensity on a scale, usually with 4 levels (mild, moderate, intense, and unbearable) in the last 12 months; the presence of symptoms in the last 7 days and the absence of the worker in the last 12 months.

The NMQ has been applied to a wide range of areas to assess musculoskeletal problems, such as drivers, industry (Andriani et al. 2021; Denadai et al. 2021; Macdonald and Waclawski 2006), health (Carneiro et al. 2017, 2019), agriculture (Dianat et al. 2020; Grzywiński et al. 2016), among others (Crawford 2007).

3 Business Process Management

Business Process Management (BPM) helps the management and transformation of operations in the manufacturing environment, and it can be considered, in essence, an idea of management (Czvetkó et al. 2022; Reijers 2021).

It is evident that organizations achieve their goals and success when they pay more attention to their business processes. A business process can cover the most varied departments and as such, the management of a business process is not trivial, making it impossible to impose universal implementation rules to be followed. However, there is a general principle associated with BPM: understanding the activities of a business process, the people involved in these activities, the information that is being exchanged and processed, and the technologies involved (Dumas et al. 2018; Reijers 2021).

The phases considered in the BPM lifecycle are: process identification, process discovery, process analysis, process redesign, process implementation and process monitoring and controlling (Czvetkó et al. 2022). Additionally, BPM is supported in and a language universally accepted, i.e. the Business Process Model and Notation (BPMN 2.0) that emerged as a strong candidate, emphasized by its acceptance as an ISO standard", able to minimize the discrepancy between what actually happens and what is supposed to happen (Corradini et al. 2022; Geiger et al. 2018). This language offers some advantages, highlighting its characteristics, being a graphical, simple and standardized language, capable of unifying the way the different entities involved see process models (Salvadorinho and Teixeira 2021).

4 Materials and Methods

Since BPM are associated with an easy understanding and simplicity, the methodology followed in this study was based on the use of the BPM life cycle, (Dumas et al. 2018), combined with ergonomic assessment techniques, more specifically the NMQ (see Fig. 1). This method is quick to apply, requires few resources and its stakeholders are employees who are in the field subject to problems and therefore, it is the result of the evaluation of those who deal daily with the difficulties.

In the first phase of this cycle, i.e., in the Process Identification, the focus was to identify the process to be improved, where it was verified through Gemba walks and conversations with employees, that they are exposed to excessive weight when handling components (boxes with material with weights between 20 and 30 kg,

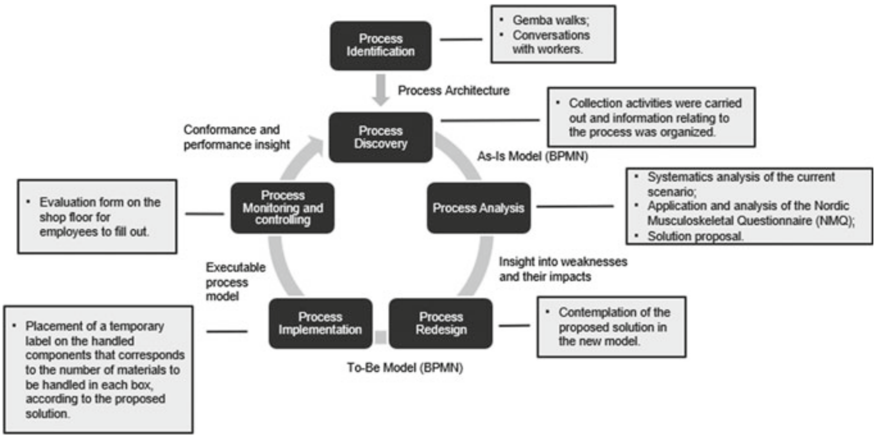

Fig. 1 Business Process Management (BPM) life cycle with the respective action in each phase [adapted from (Dumas et al. 2018)]

sometimes exceeding 30 kg). Subsequently, in Process Discovery, collection activities were carried out and were organized. From that, the AS-IS model was built using the BPMN 2.0, the current state was documented, just as it is—the entire process from the customer's order to the finished product warehouse. In the Process Analysis, a systematic analysis of the current scenario was carried out, based on all the information collected. Activities with non-value-added activities were detected and they can be solved simultaneously with the main problem identified in the first phase. Still in the Process Analysis phase and considering that part of the problem in the process lay in ergonomic issues, the NMQ (whose sample size was 14, see Table 1) was applied, and an analysis of the musculoskeletal symptoms was performed based on the responses obtained.

Finally, a solution proposal was created supported in the results of questionnaire and based on Portuguese legislation, reducing the load handled by employees (with a maximum weight of 15 kg). The future intention is to further reduce this burden, however, this decrease must be progressive so that the change can be followed in a gradual and controlled way, since the acceptance of change in the environment and in the process is one of the great challenges in a company. The next phase is the Process Redesign that "goes hand in hand" with the previous phase. The most promising change options, which correspond to the proposed solution of the Process Analysis phase, are contemplated in the TO-BE model. Advancing in the phases of the BPM cycle, arrives the penultimate phase, which is the Process Implementation,

Table 1 NMQ sample data

N	Gender		Average age	Maximum of ages	Minimum of ages
14	Female: 79%	Male: 21%	34 years old	52 years old	24 years old

where the transition from the conceptual model to the implementation itself is made, where it started by placing a temporary label on the manipulated components that corresponds to the number of components to be handled in a box, according to the recommended weight (15 kg). Finally, the Process Monitoring and Controlling is carried out on the factory floor with the help of an evaluation form for employees fill out.

So far, phase one of the problem has been presented, which corresponds to the application of the BPM cycle only once. However, it is intended to apply a phase two that is based on the reduction of the 15 kg imposed, and it would be done by repeating all this BPM cycle again.

5 Results and Discussion

5.1 The Process and Its Main Waste in Terms of Work Conditions

The BPM cycle is associated with the knowledge and construction of models that portray the identified problems, in a process-oriented perspective, using the BPMN 2.0. As mentioned, this approach was used in this study to evaluate the activities that compose the process and consequently the working conditions as well as associated sources of waste. As such, from the Process Discovery phase results the AS-IS model (Fig. 2) which maps the current process from the time orders are placed by the customer until the final product goes to the finished product warehouse.

In general, the model is read as follows: Orders are placed by the customer and received by the planning department. Later, they open a production order (PO) in the enterprise resource planning (ERP) system and forwards it to the warehouse, releasing it to the manufacturing execution system (MES).

Through the MES, the warehouse accesses the PO, checking the stock of components—if stock available, production begins; otherwise, the material failures are noted, and another PO is checked. Assuming there are components, the line starts to produce, and the line suppliers start supplying the line.

Throughout the day, the line suppliers circulate between the lines and the warehouses, in order to replenish the lack of material. It is at this stage that the problem under analysis arises: excess weight in the boxes that the suppliers handle for the production line—excess weight that can cause work accidents (which has already happened in the company), musculoskeletal injuries or waste of time because they need to call someone to help pick up the boxes, and usually, they call someone from the line, interrupting the production flow of the same.

The process ends with the finished product going to the finished product warehouse.

Based on an analysis of the value added to each process activity, some activities were identified with non-value-added and, consequently with negative impact on

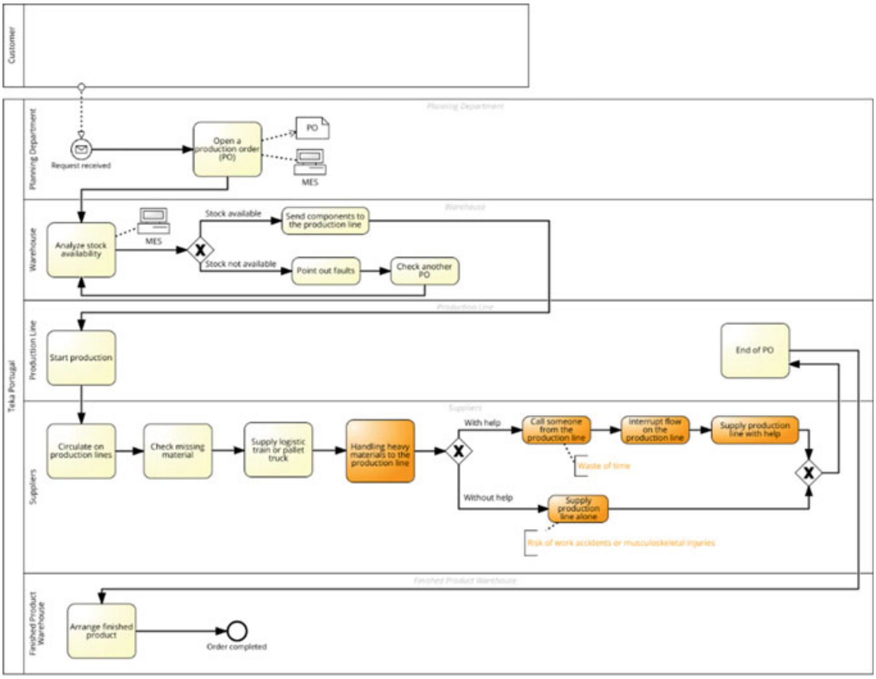

Fig. 2 AS-IS model

ergonomic conditions: (i) handle heavy materials for the production line; (ii) call someone from the production line to help, interrupting the production flow, causing considerable waste of time (about eight minutes on each production line per day); (iii) fueling yourself, with a high risk of work accidents or the appearance of long-term illnesses, such as WMSDs. Thus, the process was redesigned without these activities (TO-BE model), implying a reduction of the loads so that it could be carried out unaided and with some safety.

Once these are eliminated, there is a safe flow of material handling, without compromising production or the ergonomic conditions of the workers.

5.2 Assessment of Ergonomic Issues Based on NMQ

In this section, the results of the application of the NMQ will be presented, only to the employees responsible for supply, since this is the area where problems related to working conditions occur and, therefore, it is the focus of evaluation.

Analyzing Fig. 2, the body regions with the highest percentage of complaints in the last 12 months are: Shoulders and Lumbar Region (86%), Knees/Legs (71%) and

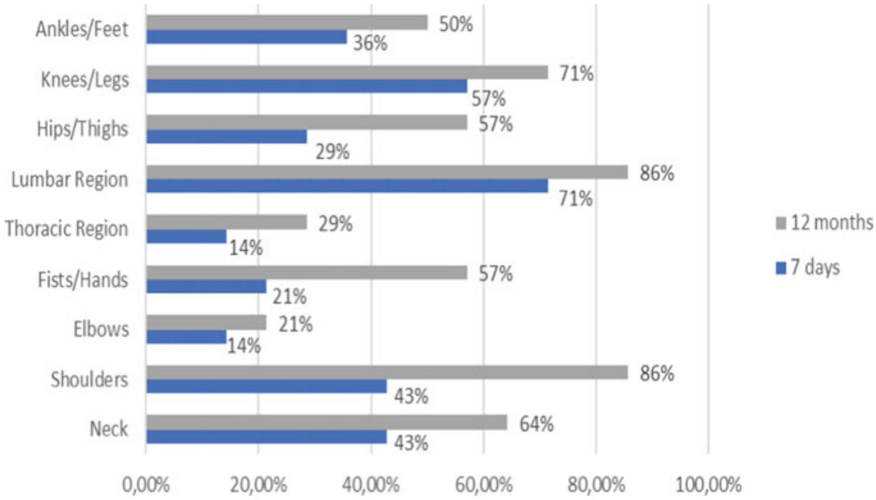

Fig. 3 Percentage of employees who had problems in the last 7 days and 12 months, by body region

Neck (64%). In relation to the last 7 days, with a significantly higher value, is the Lumbar Region (71%), followed by Knees/Legs (57%), Shoulders and Neck (43%).

This questionnaire also assessed whether during the last 12 months employees had to avoid normal daily activities (such as work, housework, or hobbies) because of problems in different regions of the body. 71% of employees said they had to avoid normal daily activities, 50% due to problems in the Lumbar Region and 36% found the same in the Knee/Legs, Hips/Thighs and Shoulders area. The results are shown in Fig. 3.

The collaborators evaluated the intensity of the problems in the last 12 months, by region of the body according to the scale shown in Fig. 4. They report suffering from pain, discomfort or numbness in all regions of the body.

The region of the body where pain, discomfort or maximum numbness has a higher percentage is the Lumbar Region, felt by 12 workers, where 29% classified it as maximum, 36% as intense, 14% as moderate and 7% as light. Soon after, the Ankles/Feet, the Hips/Thighs and the Neck. Regarding Ankles/Feet, of the 7 respondents who reported pain, discomfort or numbness, 14% categorized it as maximum, 29% as severe, 7% as moderate. In the case of Hips/Thighs, of the 8 people who showed complaints, 14% labeled it as maximum, 21% as severe, 14% as moderate and 7% as mild.

Of the 9 people who showed warnings at the Neck level, 14% identified them as maximum, 21% as intense, 29% as moderate and 7% as mild.

Note that the Shoulders and Knees/Legs have the highest percentages of pain, discomfort or numbness at the intense level. As such, for Knees/Legs, with around 10 employees reporting discontent, 7% labeled this as maximum, 43% as intense, 21% as moderate.

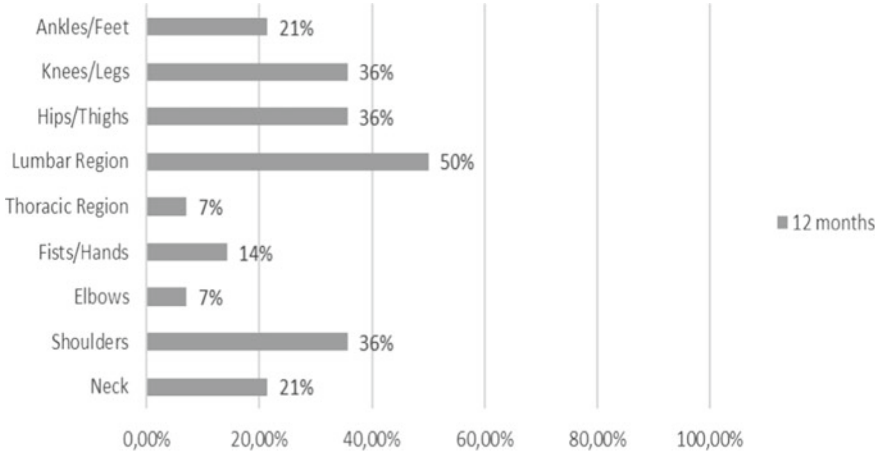

Fig. 4 Percentage of employees who avoided their normal activities because of problems in the last 12 months, by body region

Finally, in the Shoulders, 12 of the workers who felt it, 7% classified it as maximum, 36% as intense, 29% as moderate and 7% as mild (Fig. 5).

According to the results obtained in the NMQ, the importance of ergonomic issues in a company is evident, being these transversals to the most varied areas as the literature review supports (Vinoth Kumar et al. 2021). The NMQ show a clear displeasure and the most varied complaints in relation to pain, discomfort or body numbness, and these results cannot be ignored and even there is an urgent need to

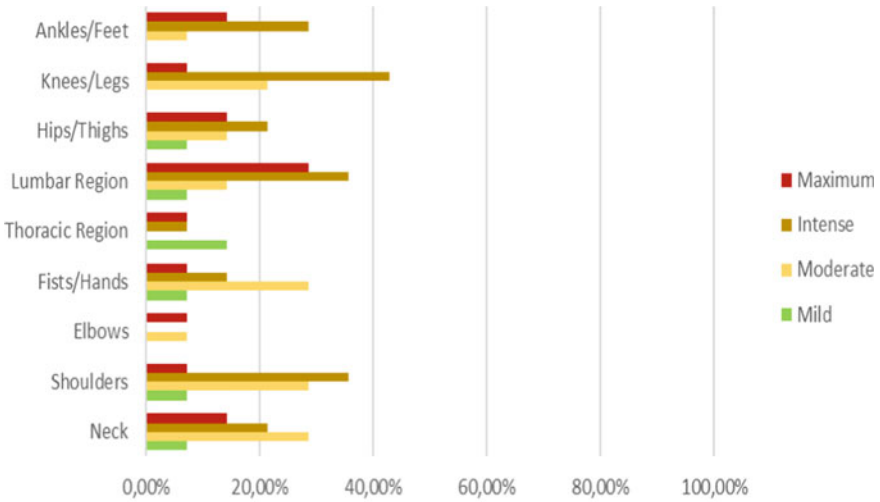

Fig. 5 Intensity of the problem, reported by employees in the last 12 months, by body region

act to reduce these percentages or, in the best of hypotheses, leave to have any kind of complains.

It should be noted that these results are in agreement with other investigations already carried out by Govaerts et al. (2021), in which, effectively, the most affected regions are the lumbar region and the shoulders.

However, to answer the question of the title of this document—the entire process so far was built by BPM and its phases, which were guidelines to know what to do in each phase and which methods to apply in each one. The simplicity of this tool and easy understanding, also defended by the literature (Geiger et al. 2018; Salvadorinho and Teixeira 2021), allowed to find and develop the problem in an intuitive way, making it possible to reach the conclusion of the need for an ergonomic evaluation (in this case, the NMQ) much faster.

Therefore, the relevance of knowledge of the processes through BPM is highlighted, allowing to know the actors and relate them to each other. The modeling achieved through BPMN enhanced the understanding of the problem, since it is a universal and clear language. In addition, it is concluded that since BPM combined with BPMN has these valences, it is possible to assume, based on the case study, that it can also be combined with ergonomic evaluations, reproducing the intended results—which are based on the understanding of the ergonomic processes.

Finally, as mentioned in methodology, a second phase is still intended to be implemented, which will be based on the reduction of the 15 kg already defined and for that, the method adopted will be to apply the BPM cycle continuously, combined with BPMN and more ergonomics evaluations, adjusting the process until reaching the point where ergonomically the desired safety is achieved, and work processes will not be compromised.

6 Conclusions

This presented the results of a study that aimed to solve an ergonomic problem, identified with a process-oriented approach. For that, tools from two different areas—BPM and ergonomic assessment based on NMQ—were used. The process-oriented approach allowed to map the process under analysis, identify the non-value-added activities as well as the problems associated with ergonomics. The NMQ-based assessment allowed to deepen the characteristics of the problem in terms of ergonomic assessment. Thus, in addition to the process maps with the details associated to the activities that most contribute to the problem, it was concluded through NMQ complaints such as:

- All collaborators demonstrated some type of problems in the various regions of the body;
- The body regions with the highest percentage of complaints in the last 12 months are: Shoulders and Lumbar Region;

- Approximately 80% of employees stated that they had to avoid normal daily activities;
- At least one worker rated their pain as maximal in at least one region of the body.

This study also concluded that a process approach prior to ergonomic intervention can help identify and quantify the problems and their impact on work with clear practical contributions for the organization under study. From the point of view of theoretical contributions, this work advances knowledge in an area where there is little work developed, particularly in terms of harnessing techniques and tools from different areas—process and ergonomics—in order to be more effective in the proposed solution.

The limitations include: the small size of the sample, however, the consistency of the results is evident since all workers show some type of problem in NMQ and the time required to apply the full BPM cycle. So, as future work it will be to complete the cycle, then make a new evaluation, until a stable solution is reached from the point of view of the working conditions and the ergonomic condition of the worker. And by doing this, it is created better working conditions for employees and increase in productivity is potentiated, since productivity and ergonomic conditions are directly linked.

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The Importance of Small Details in Ergonomic Risk: Influence of Casters' Characteristics on the Force Exerted in Pulling and Pushing Tasks

Tiago Afonso, Paula Carneiro, Anabela C. Alves, and Sílvia Barros

Abstract The importance of ergonomics in the workplace of organizations resulting from changes in the scenario of production of goods and services in recent decades has brought great challenges for them, in reconciling productivity and workers' well-being. This article is the result of research carried out in a company that produces metallic parts for automobiles. This research included an ergonomic study of manual handling and movements of loads through containers inserted in rolling bases. The study showed that the casters' characteristics of the rolling bases had an impact on the strength used to pull or push the loads. It is also intended to show with this article that in a Lean environment, even what seems to be a small detail, its analysis can be important if it contributes to the reduction of human effort.

Keywords Ergonomics · Lean thinking · Manual handling of loads · Rolling bases · Casters

1 Introduction

Ergonomics is a scientific discipline that studies Human interactions with other elements of the system, with the aim of improving human well-being and the system's overall performance (IEA 2021). The conditions in which tasks are carried out, as well as their characteristics and demands, can lead to Work-related musculoskeletal

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disorders (WMSD) over time. The main WMSD risk factors are repetitive tasks, tasks involving the application of force, and the adoption of awkward postures (Barroso et al. 2006).

Thus, there is a need to achieve a balance between eliminating production process wastes and ensuring the best working conditions for the employees. In this way, efficient ways to improve jobs can be demonstrated, aiming at the well-being of employees, and providing overall performance within organizations (Mattos et al. 2016).

Currently, due to the importance of the strategic and financial point of view, the increase in productivity aroused widespread interest from the part of organizations in ergonomics, anthropometrics, and studies about manual handling of loads (Silveira and Salustiano 2012).

According to Resnick and Zanotti (1998), workstations can be designed to maximize performance and minimize costs considering both the level of ergonomics and productivity. On the other hand, jobs with a low ergonomic level can generate high absenteeism due to musculoskeletal problems, especially in older employees (Battini et al. 2017).

According to some authors, namely, Arezes et al. (2015) and Vicente et al. (2016), Lean Production aims to create value and reduce waste through different tools and specific diagnostic techniques and process improvement. Those must be associated with the improvement of working conditions and safety of employees (Brito et al. 2019; Alves et al. 2019). Within the scope of Lean Production, there are three main areas of intervention where improvements can be found, namely, in the identification of waste (Muda), variability (Mura) and overload (Muri) (Imai 1986). Muri, or overload is a root cause of waste that could be reduced with the improvement of ergonomic and safety conditions. Hence, there is increased importance in reducing the effort of operators.

One of the aspects of Muri is the excessive effort of operators and this being considered one of the root causes of Muda, it is possible to affirm that the reduction of waste must be associated with the improvement of workers' conditions and safety (Vicente et al. 2016).

Thus, the objective is to "doing more with less", eliminating waste to reduce costs and increase productivity, which is one of the current goals pursued by companies. "Less" means less materials, less resources, less inventories, and less human effort. To reduce human effort, first, it is important to assess the conditions of workers (Eira et al. 2015).

Companies must implement the Lean philosophy promoting better ergonomic conditions. Thus, mura and muri should be the focus and concern of companies so that people have better working conditions for good performance and thus eliminate the symptoms of muda (Melo et al. 2020). In pandemic times, the synergies between all scientific areas makes more sense than ever (Afonso et al. 2021b).

Given this context, the present study was developed to explain the importance of ergonomic study in an analysis of pushing and pulling loads, placed on rolling bases, and to analyze one of the causes of the increase in the forces exerted, the mechanical movements of the incorporated casters on the rolling bases.

Their causes are highlighted, going to their detail (e.g. problems associated with casters), making it necessary to understand the problems of the of systems vision, in order to provide the best conditions for workers, always based on a lean vision, and constantly promoting continuous improvement within organizations.

This article is divided into five sections. The first section refers to the introduction. The second section presents the materials and methodology used in this article, associated. The third section presents an explanation of the study context associated with the case study. The fourth section presents the diagnosis and proposals for improvements associated with their associated results, associated with discussions of possible future improvements, in addition to the proposals presented in the article. Finally, the main conclusions are discussed in in the last section.

2 Material and Methods

The case study described in this article was developed in the context of an intra-logistic project for a company. The research methodology used was action research where the researcher started several cycles of action and research until implementing proposals. The five phases of the action research methodology followed were: (1) diagnosis and problem definition; (2) action planning; (3) implementation; (4) measure and evaluation and (5) specification of learning (O'Brien 1998).

To carry out the ergonomic study, dialogues, observations, document analysis, time study, work sampling, ergonomic analysis with the Sue Rodgers method (Rodgers 1992), risk assessment in manual material handling tasks (applying the NIOSH equation) and evaluation of posture (applying the OWAS methodology) were carried out to correctly define the problems occurred.

2.1 Context of the Study

In previous years, the company where the study was carried out tried to implement milkruns to improve the physical flow of materials in a specific stamping line. With this, the company intended to improve the internal value flow of this unit, implementing a just-in-time culture. This attempt was made as part of a continuous improvement project, based on the Lean philosophy and with the objective of reducing the waste associated with the supply and performance of the machines.

The company is a multinational company of metallic parts for the automobile industry. It is a company that works with "heavy" and long pieces, for example, stamped pieces. The company had a significant number of employees, and it was structured in several departments. The production department was structured in autonomous production units (APU).

In the APU, the milkrun placed empty containers (packaging), for production workers to place the pieces produced by the presses. They were then collected by the milkrun worker.

The critical situation occurred when the production worker filled a container with the parts produced by the machines, which are steel or aluminium, making the weight of the packages significant, weighing between 500 and 850 kg, which makes it difficult to manoeuvre when pushing and pulling the load. The packages were placed on a rolling base support, which could reach up to 1200 kg. In this case, a stacker was used to collect the container. This situation leads to problems not only at an ergonomic level, but also at the production and logistical level (Afonso et al. 2021c).

The objective of the milkrun worker's task was to collect the containers full of parts produced by the presses and leave the empty containers next to the machines, for the machine workers to place the pieces produced by the machines. In addition, machine workers who were carrying out their tasks must leave them to assist the milkrun worker in pushing/pulling the container on the milkrun carriages.

This situation entailed great risks of WMSD, increased cycle time of tasks performed both by machine operators and by the logistic train and a high rate of absenteeism, turnover and turnover due to the great difficulty of the task (Afonso et al. 2021a).

2.2 Problem Associated with Casters

One factor associated with the ergonomic risks was the pulling forces exerted by the workers of both the machines and the logistic workers. The level of effort the worker made when pulling/pushing the containers depended on the position of the casters. To understand the referred problem, it is essential to make an introduction about casters.

The industrial castor is a set of a wheel and support, associated with a fixing plate, incorporated into a base that allows it to support a fixed load (in kilograms). Casters can be swivel or non-swivel. There are several types of castors, depending on the weight of the loads and the type of loads that they themselves must support. There are several concepts to consider when rotating. These concepts range from the fixing bases, passing the diameter of the wheels of the casters, the total height of the wheel installed in the equipment, types of wheel support, types of bearings, wheel width, offset, etc. as demonstrated in Fig. 1 developed by the authors of this paper.

As for the key characteristics, there are ten to consider, as there are several essential requirements and needs presented by the organization. These ten key characteristics are: (1) Load capacity, (2) Total caster height, (3) Wheel diameter, (4) Temperature resistance, (5) Corrosion resistance, (6) Fixing base, (7) Bearing, (8) Yield by type of soil, (9) March noise, (10) Wear resistance.

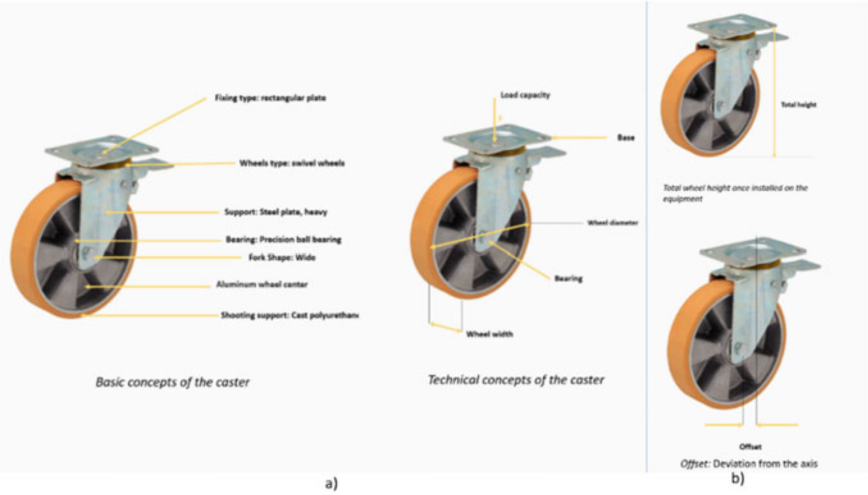


Fig. 1 **a** Basic and technical concepts of the rotation, **b** example of two key features of the study

2.3 Problem Observed in the Manual Loads Handling

The problem related to the mechanical development of castors (wheels), occurred when they were pushing because the wheel always took the direction in which it was turned (Fig. 2). The problem happens when the workers tried to perform this rotation, they must go through a certain time, in which the wheels rotate to be at 90°, between the starting point and the endpoint, and then these wheels pass 180° from the initial direction. What happens was that the workers pushed a load that was perpendicular to the effort that must be exerted and that was not designed to be performed in this way, due to the significant effort exerted. These discrepancies in forces, between the transition from the initial moment and the final moment, was the starting effort, or initial effort and the moving effort as shown in Fig. 2 designed by the authors of this paper.

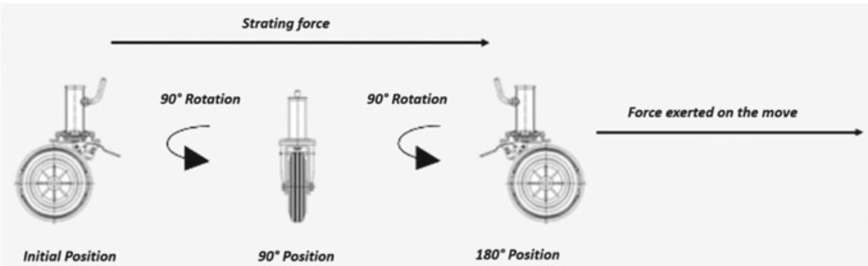


Fig. 2 Forces exerted during pushing and pulling containers on carriages

When two workers performed the movement, they could move the container inserted in the rolling base diagonally to minimize the starting effort when trying to turn the wheels. In this way, it becomes more comfortable at the beginning of the effort, moves to one side, and then rotates, to form an arc, and in this way to avoid an effort significant start-up.

Regarding the position of the wheels, they would perform a slow rotation and be oriented in the direction of effort, by the weight of the container. The movement becomes easier, starting with a lateral pushing movement and then directing to the appropriate place, than trying to overcome by force the friction of the four wheels. As they were swivel wheels, the wheel with adequate support did not offer facilities to place the wheels in the correct positions, since they were positioned in the direction of pushing or pulling, and thus allocated the loads as desired.

Thus, the study of casters was made to understand the difference between the initial effort and the displacement effort, in three meters, as represented in Fig. 3. By measuring with a dynamometer, it was found that, on average, the difference between the value of the initial force (or start) and the value of the force in motion was about 53% when the container inserted into the rolling base was pushed by a single worker, and it was 62% in the case of two workers. On the other hand, when the container inserted into the rolling base was pulled by a single worker, the moving force value was about 53% when the container inserted into the rolling base was pushed by a single worker, and it was 60%, in the case of two workers.

This problem was associated with the coating of the actual castor wheels inserted in the rolling bases, which is explained in the next section. One of the factors to consider was the fact that the floor of the factory under study was of an epoxy type, a floor with rigid monolithic coatings with a two-component polymer composition hardener and epoxy resin.

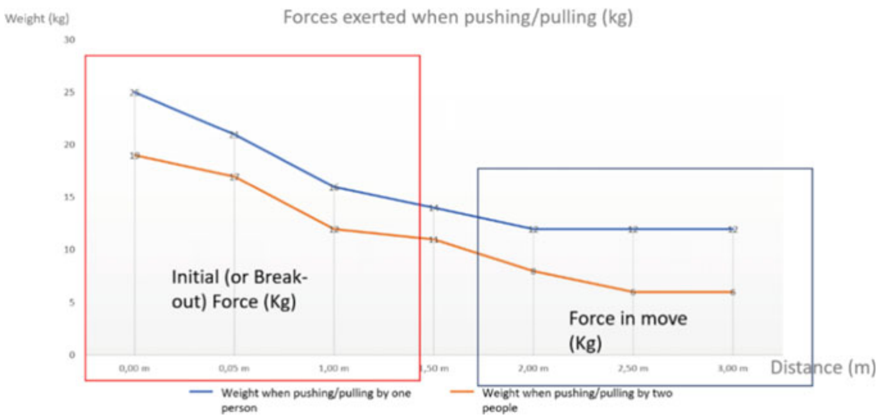


Fig. 3 Example of a graph of the study of forces when pushing/pulling

3 Proposal for Improvements and Results

The case study described in this article was developed in the context of an intralogistic project for a company. The research methodology used was action research where the researcher started several cycles of action and research until implementing proposals. The five phases of the action research methodology followed were: (1) diagnosis and problem definition; (2) action planning; (3) implementation; (4) measure and evaluation and (5) specification of learning (O'Brien 1998).

In this section, it is addressed the proposals for improvements associated with the ergonomic problems encountered. The researcher studied other coatings on castor wheels and rolling bases configurations. A discussion is followed about others improvement proposals.

3.1 Other Coatings on Casters Wheels

The problem related to the impact of the rotation of the casters (wheels), inserted in the rolling bases, it became necessary to verify the coating material of the wheels, which were made of polyurethane. To decide which coatings were available, the choice was based on a study carried out by a supplier, on the initial resistance to advancement of the different types of wheels. Through this study, it was found that the types of wheels that allowed less initial starting effort, in relation to polyurethane wheels, were cast iron and polyamide wheels. However, the rolling resistance was about 50% of the initial drag resistance. Thus, the study will be based on cast iron and polyamide castors, compared to polyurethane castors.

A survey was also carried out on the most suitable wheels for the study, where three types of wheels stood out. With the implementation of different types of wheels, polyurethane, cast iron and polyamide, the polyurethane wheels that already existed in the organization's current rolling bases and which will be the basis for comparison between the other types (polyamide and cast iron), were implemented in a mobile base with the existing configuration.

In this way, the impact, at an ergonomic level, of the implementation of each type of wheel through the dynamometer was studied, to analyse the starting forces (initial forces) and the forces in movement (maintenance forces), when pushing/pulling the containers under study with different casters in the following configuration of rolling bases.

However, after the implementation of the different types of wheels, throughout the study, it appeared that there were problems regarding the impact on the work environment. When carrying out movements with the containers, incorporating polyamide wheels and cast-iron wheels, there was rapid and significant wear of the factory floor, which was an epoxy floor. These still used the floor covering and coat of paint. This fact could lead the company to have significant costs over time, with the maintenance of the shop floor of the APU under study.

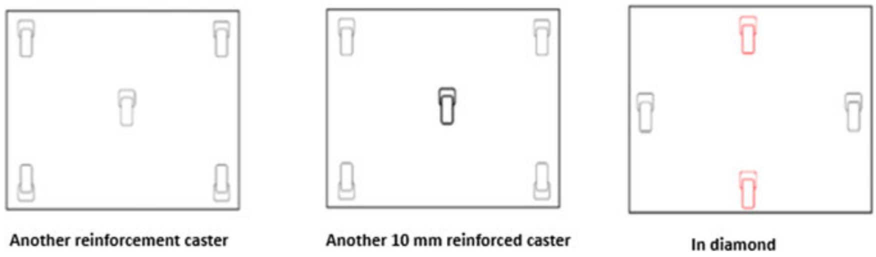


Fig. 4 The different rolling bed configurations under study

3.2 Study of Rolling Base Configurations

The problem related to the mechanical development of castors (wheels), In addition to the study associated with the castors, a study of the arrangement/configuration of the castors on the rolling bases was carried out, being the representations of Fig. 4 examples of such representations. In this case, the rolling bases were designed either with a reinforcement of casters similar to the current ones in the middle or with a reinforcement of castors in the middle but with a wheel with a 10 mm reinforcement, be it a rolling base with a so-called "diamond" configuration, with four wheels, two fixed wheels and two unidirectional swivels.

These configuration alternatives were tested and analysed to find the most suitable alternative in relation to the current configuration. This test and analysis included the study of the impacts of these implementations on the forces exerted when pushing/pulling, to improve the working conditions of logistics and production workers.

A force graph was drawn up with the aid of a dynamometer that allowed analysing of the impact of the position of these casters on these rolling bases. Throughout the study, the traction and movement forces were measured when pushing/pulling containers for three meters, and these were analysed through a graph (Fig. 3) after each analysis. Table 1 shows the movements carried out as a function of the configurations, observations, and impacts (results) of these improvement proposals. These rolling base configuration studies were carried out with containers placed, with two specific parts, in two different containers. In the large containers, parts considered large were inserted and in the small containers, parts considered small/medium were inserted. This analysis of the forces exerted when pushing/pulling these containers was also performed using a dynamometer.

The results of the breakout forces exerted as a function of the configuration of the alternative rolling bases were also analysed, in relation to the current configuration with the other tested configurations (Table 2).

Through the analyses performed for each rolling base configuration (Tables 1 and 2), it was concluded that none of the configurations were adequate to reduce ergonomic risk and reduce friction. The diamond configuration makes it possible to reduce the start-up effort, however, it did not improve the movements made in the

Table 1 Analysis of different rolling base configurations

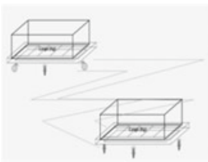
Configuration	Movement made	Observation	Impact/results
Configuration with one more reinforcement casters		Diagonal movement in order to place the containers towards the milkrun carriages	In order for these wheels to turn, an initial force greater than the force exerted in the existing configuration must be exerted so that the wheels are now 90° between the start point and the end point, and then pass these wheels 180° of the initial sense. Therefore, this configuration increases the existing ergonomic risks
Configuration with one more caster with 10 mm reinforcement		Diagonal movement in order to place the containers towards the milkrun carriages	In this configuration, the rolling base was never supported with all the wheels, and the same problem occurred as in the previous configuration, that is, it provides an increase in starting forces
"Diamond" configuration		In this case, it was not possible to carry out the usual diagonal movement, due to the placement of the two fixed wheels, making it difficult to place the container in the desired direction	The "diamond" configuration provides a reduced ergonomic risk and less friction, despite not being acceptable forces. However it makes the driver's tasks more difficult. Train, therefore, becomes difficult to position towards the carriages or at the edge of the line, because the fixed wheels do not allow to walk from one side to the other in the desired way

Table 2 Results of starting (initial) forces between rolling bed configuration and other configurations

	Result of starting (initial) forces comparing current base configuration of bases with large containers with large parts	Result of starting (initial) forces comparing the current base configuration of bases with small containers with small and medium parts
Configuration with one more reinforcement rotation	↑ 23%	↑ 20%
Configuration with one more castor with 10 mm reinforcement	↑ 33%	↑ 30%
"Diamond" Configuration	↓ 28%	↓ 35%

allocation of containers in the logistic train carriages, leading to a possible increase in the cycle time of the route taken by the logistic operator. In this way, the best configuration was the existing configuration (current configuration), as the forces were smaller. Comparing the configurations with the allocation of one more castor, whether of the same size, or with a 10 mm reinforced caster, because it was relatively easier to maneuver and place in the desired direction. In this way, no proposed configurations eliminated the three problems mentioned and highlighted in the study, at the logistic, productive, and ergonomic level.

4 Discussion Among Other Proposals for Improvements

Regarding the unsuccessful results described in the last section, two more proposals were researched.

One was the implementation of a motorized tractor with a load capacity that can exceed 1000 kg and that facilitates the execution of the tasks of pulling/pushing containers inside the carriages. In this way, this possible solution would reduce the significant forces exerted at the beginning of the pull/push task.

Another possible proposal for improvement was the possible implementation of new technologies recognized for internal logistics within the organization, through the study and analysis of the most recent technological alternatives, associated with the context of Industry 4.0 for the transport and handling of cargo. From there, it was possible to carry out a project to insert AGV, AIV or MIR, with the aim of improving both the intralogistics processes of the APU under study and finding another alternative in cargo handling, in order to improve the work conditions for the production and logistics workers. A platform-type AGV was proposed that collects the full containers and another one that places the empty containers next to the machine (Afonso et al. 2021a, b, c).

5 Conclusion

This study proves that small details can become big problems representing real ergonomic risks for the workers. Manual handling of loads becomes a constant concern of industries because it could put in cause the appropriate and necessary conditions for their well-being and increased productivity.

In this study, ergonomic risks bring problems both in terms of the organization's internal logistics and terms of productivity. In order to improve the working conditions of both operators (production and logistics), several ergonomic improvements were presented, and ergonomic risk reductions were discussed.

Through the association of Lean Thinking and ergonomics, always based on continuous improvement, it was sought to find a balance between the needs of the organization in terms of production and the well-being of workers.

Through the results, it was realized that despite the attempts to improve, due to other factors (e.g., characteristics of the organization's shop floor) it was not possible to eliminate the problems encountered. This means that a new action-research cycle must start.

The success of a company does not depend on a linearity of actions, but on a constant concern and adaptation to the various possible changes, both in terms of technological resources and in terms of human resources present in an organization. The constant evolution in terms of technology in today's markets, globalization, competitiveness and business models have an impact on production capacity, product factors, innovation and the various other essentials for a company's activity. In this way, there are possibilities to incorporate a project for automation of internal logistics processes within organizations through the insertion of the AGV, which can provide improvements both at the logistical and productive level, as well as at the ergonomic level, reducing workers to carry manual handling of loads.

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Ergonomic Risk Assessment in an Energy, Mobility, and System Company

Ana Teresa Gabriel, Sofia Madaleno, Flavio Kanazawa, and Claudia Ollay

Abstract Work-related musculoskeletal disorders have emerged as one of the biggest health problems in modern society. Conscious of the negative impacts on workers and productivity, companies have gained awareness regarding this subject. This current paradigm has highlighted the importance of Ergonomics. Over the years, countless methods have been developed to analyze and assess many types of activity. The methods are beneficial in identifying the risk level and implementing the recommended ergonomic intervention measures to improve workers' well-being, health and safety conditions. This study was performed in a Portuguese company in the energy, mobility, and system sectors. It consisted of an ergonomic risk assessment in the workstation responsible for the final assembly of immersed type transformers. The multiple tasks performed by the workers were prioritized, and only the most critical tasks were assessed using the following evaluation methods: Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Mittal Guide, and Manual Handling Assessment Charts (MAC). Then, a comparative analysis was carried out. Results evidenced that the analyzed tasks are at the high/very high-risk level. Finally, considering the evaluation performed, ergonomic intervention measures were highly recommended to the company.

Keywords Ergonomics · WRMSD · Risk assessment · Ergonomic intervention

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1 Introduction

The prevalence of Work-related Musculoskeletal Disorders (WRMSDs) is one of today's most relevant occupational problems (EU-OSHA 2019).

WRMSDs often arise from prolonged exposure to a set of risk factors, isolated or combined, present in their working environment. They are one of the most common causes of absence from work in many industrial sectors (Bevan 2015).

Although WRMSDs can affect any part of the body, they have a higher incidence in the lumbar region, cervical region, and upper limbs (DGS 2008; Keyserling et al. 1993). The prevalence of WRMSDs in the upper body (upper limbs, trunk, and neck) is characteristic of manual assembly activities. Assembling activities are usually characterized by the practice of repetitive movements and by remaining in inadequate postures for extended periods (Wang et al. 2014).

WRMSDs significantly impact the injured workers, companies (e.g., productivity, production processes, competitiveness), and the country's economy (OIT 2019).

It is essential to respect ergonomic guidelines and perform a risk analysis regularly inside the company. It is crucial for the prevention and early identification of risk factors that can lead to the development of WRMSDs (Pimparel et al. 2022).

Several studies identify ergonomic interventions as key elements in modifying workstations and organizing processes using methods that make it possible to identify and assess the risk level to which workers are exposed. The wide variety of existing methods is beneficial as it has been proven that applying more than one methodology increases the credibility of results (Burgess-Limerick 2018; Afonso et al. 2022).

Selecting the most appropriate assessment methods can be quite challenging, complex, and time-consuming. The selection must respect the following criteria: type of tasks evaluated, resources/limitations, and evaluator preference (Dempsey et al. 2005; Russell et al. 2007). The last criterion varies from person to person, as it is conditioned by factors such as, for example, the subject's familiarity with a given methodology as well as their education or training in applying it.

The most common physical risk factors are repetitiveness, manual material handling, and awkward postures (Costa and Vieira 2010). Also, the intense work rhythm, static postures (standing or sitting), exposure to vibrations, inappropriate machines and tools, as well as work organization (shifts and breaks) can increase the risk of injury (Carayon and Smith 2000; Bridger 2008; Roquelaure et al. 2009). Due to the characteristics of each person, not all workers are exposed to the same risk level. However, it is important to recognize situations that constitute a higher risk. Thus, it is essential to encourage a culture of information and training to identify risk factors and quantify the risk. This information is crucial to delineate the most adequated strategies to mitigate the risk (Haines et al. 2002; Jaffar et al. 2011).

2 Methodology

The work started by defining the main objectives for the research. After that, numerous visits were made to all departments of the industrial unit to understand the production process. In addition, several periods of direct observation were carried out and the company's registers regarding work absences and work accidents were consulted. It helped identify the workstation where this risk analysis would be performed and characterize the respective work sample. The selected workstation was designed as the "Final assembly workstation". This workstation performs the last assembling steps of the production process of immersed type transformers.

Subsequently, more visits were carried out to the Final assembly workstation. Also, a sample characterization questionnaire was applied to the workers of the selected workstation, aiming to characterize the working sample and their general feedback about the work.

The questionnaire was carried out orally. A short speech was used throughout the questions to ensure their understanding by all involved. Fields were either short-answer or quick-select. Two main fields were included in the questionnaire. The first refers to the worker's demographic information (e.g., gender, age, weight, height, years in the company/workstation). The second field regards the worker's perceptions of his work. Here, questions about the intrinsic characteristics of the tasks (e.g., postures, strength, repetitiveness), the organization of work (e.g., schedule, shifts, overtime, training), and the working environment (temperature, lighting) were addressed.

Considering the information collected, the Final assembly workstation's working context was characterized, and the tasks performed were described carefully.

Then, informal interviews combined with the direct observation previously performed, video recording, and photographs helped prioritize tasks and decide the most critical. Finally, the risk assessment was performed on the most critical tasks only. Also, the time study technique was applied to clarify whether the critical tasks involved repetitive movements.

After a careful analysis, the information collected in the previous steps made it possible to select the risk assessment methods that best suited the critical tasks' characteristics and the existing limitations. Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Mittal Guide, and Manual Handling Assessment Charts (MAC) were selected and applied.

The information provided by the risk assessment methods was compared through their standardization to a single scale. This step allowed reaching a consensus on the risk level of the tasks considered.

Finally, ergonomic intervention measures were proposed to the company to be analyzed by the management department. They aim to improve working conditions and reduce the risk of WRMSDs in the "Final assembly workstation".

Table 1 Demographic characterization of the sample

	Age (years)	Height (m)	Weight (kg)	Years in the company	Years in the workstation
Average	40.83	1.77	79.67	17.20	16.20
Standard deviation	13.14	0.12	15.71	10.62	9.81

3 Results

The demographic characterization of the sample and the results obtained by the ergonomic assessment methods will be presented in the following subsections.

3.1 *Demographic Characterization of the Sample*

The work sample was characterized based on the data collected through the questionnaire. It includes six male workers allocated in the "Final assembly workstation". All workers belong to the company's permanent staff and perform the same tasks during the workday.

The main parameters collected (age, height, weight, and years in the company/workstation) are summarized in Table 1.

3.2 *Tasks Description*

The assembly process performed in the "Final assembly workstation" consists of three mains stages, designated as A, B, and C. First, stage A concerns the tasks of tightening the interior components of the immersive transformer (named as active part). Second, stage B is the self-quality control test. At last, stage C corresponds to fitting the active part inside a vat. Table 2 describes the three stages.

Although the final assembly of an immersed transformer includes 35 tasks, it was considered that most tasks do not represent a significant risk for workers. Therefore,

Table 2 Stages required to produce one immersive transformer

Stage	Description	Number of tasks	Number of tasks analyzed
A	Tightening the interior components (active part)	10	0
B	Quality control test	3	0
C	Accommodate the active part into the vat	22	8

the risk assessment was performed on the most critical tasks, henceforward called critical tasks. The prioritization process involved direct observation of the factory floor and workers' feedback. Eight tasks were pointed out as critical (henceforward designated by T1, T2, T3, T4, T5, T6, T7, and T8). All of them are performed during stage C. In general, tasks of stage C require more strength while awkward postures are sustained to assess the vat interior.

3.3 Selection of Ergonomic Evaluation Methods

After identifying the critical tasks, each was even more observed and detailed described. Risk factors present in each task were enumerated, and adequate methods were chosen to assess the risk level. There was a concern to select more than one methodology for the same task since their comparison offers more credibility to the results. Therefore, the application and comparison of different methods validate the risk level obtained. This information is summarized in Table 3.

Mechanical compression at the distal limbs (hands and fingers) is caused by the use of manual tools. Methods that evaluated this risk factor effects in distal limbs associated with non-repetitive tasks were not identified in the literature. Although methods such as the Job Strain Index, Occupational Repetitive Actions (OCRA), and Hand Activity Level allow this analysis, they are only applicable to repetitive tasks, which is not the case in the present study.

Table 3 Description of the critical tasks and selected methods

Task	Description	Risk factors	Methods
T1	Screw tightening	Awkward postures Mechanical compression	RULA REBA
T2	Assembling and tightening of the active part inside the vat	Awkward postures Mechanical compression	RULA REBA
T3	Carry a platter	MMH	Mittal Guide MAC
T4	Assembling and tightening of the platter	MMH	Mittal Guide MAC
T5	Tightening of clamps of type BT	Awkward postures Mechanical compression	RULA REBA
T6	Stripping cables and crimping their terminals	Awkward postures Mechanical compression	RULA REBA
T7	Tightening nuts	Awkward postures Mechanical compression	RULA REBA
T8	Tightening of clamps of type AT	Awkward postures Mechanical compression	RULA REBA

3.4 Application of the Selected Ergonomic Evaluation Methods

The selected methods consider different input parameters. Also, they present the risk level at different scales and different classification processes. Thus, the results obtained were standardized to reach a consensus regarding the risk level.

RULA and REBA are assessment methods whose application is relatively similar. However, their risk level scales do not match. Therefore, the values obtained by each method were standardized for the same scale to compare them and identify the required action for each specific task. For this, the method used by Cunha was adopted (Cunha 2018). It is based on the Kong study (Kong et al. 2018). Results obtained by the two methods in tasks T1, T2, T5, T6, T7, and T8 are presented in Table 4.

Regarding tasks T3 and T4, to compare the results obtained by the Mital Guide and the MAC methods, it is also necessary to standardize their numerical scales. The method used by Simões was adopted (Simões 2015). It is based on the study by Pinder (2002). Table 5 presents the results obtained.

Table 4 Risk level of T1, T2, T5, T6, T7 and T8

Task	Methodology	Risk level (method scale)	Risk level (standardized scale)
T1	RULA	7	4
	REBA	11	4
T2	RULA	7	4
	REBA	9	3
T5	RULA	7	4
	REBA	9	3
T6	RULA	6	3
	REBA	5	2
T7	RULA	7	4
	REBA	10	3
T8	RULA	7	4
	REBA	10	3

Table 5 Risk level of T3 and T4

Task	Methodology	Risk level (methodology scale)	Risk level (standardized scale)
T3	Mittal Guide	0.73	1
	MAC	8.00	2
T4	Mittal Guide	1.25	3
	MAC	8.00	2

4 Discussion

The methodology adopted conducted to a detailed description of the production process as well as the tasks performed in the Final assembly workstation. This was crucial to identify the most critical tasks, the risk factors, and the adequate risk assessment methods.

RULA and REBA were selected to assess the risk level of awkward postures while Mittal Guide and MAC were used to the MMH tasks.

In general, there is a tendency for the RULA results to be higher than the REBA results. This information means that the risk level provided by RULA is higher. This tendency can be justified because the REBA evaluates the entire body, and the RULA gives greater importance to the upper limbs (Kee 2021). Results evidenced that the upper limbs can be more affected by the tasks T1, T2, T5, T6, T7, and T8 (the risk of developing WRMSDs in the upper limbs is higher than in the other parts of the body).

T1 was the only one that presented a unanimous result in both methods. It was classified as a very high-risk task. Therefore, it is consensual that this critical task is the one that presents a higher risk for any worker regarding the posture adopted. Thus, ergonomic intervention is required immediately.

T6 was the task with the lowest risk level. According to the RULA and REBA methods, the risk level is in the middle of medium and high. However, an ergonomic intervention is also recommended, even with less priority than the other critical tasks.

Although there is no agreement between RULA and REBA regarding the risk level associated with T2, T5, T7, and T8, it is highly recommended to perform an intervention and a deeper investigation of the possible causes that most contribute to the risk level obtained.

Regarding the MMH risk factor (T3 and T4), there was no agreement between the methods regarding the risk level of each critical task.

In task T3, the Mittal Guide presented a low risk while the MAC a medium risk level. For task T4, the same methods showed a high and a medium risk level, respectively.

Results suggest that T4 has a higher risk level when compared to task T3. For task T4, both methods point to the need for intervention and to eliminate (at least reduce) the risk. On the other hand, in task T3, the Mittal Guide indicates a low-risk level with no need for intervention, while the MAC recommends intervention.

The Mittal Guide considers more variables, one of which is the worker's anthropometric characteristics. As it is a more analytical methodology, it was assumed to present more accurate results (Pinder 2022).

On the other hand, MAC is a more subjective methodology that requires fewer input variables, which is reflected in a less precise analysis. Furthermore, it is necessary to consider that, in this methodology, the results obtained aim to prioritize the tasks with the highest score according to the parameters that contributed the most to the results. Despite the objective of both methods being the same (analyzing and evaluating the risk associated with MMC tasks), it was found that the Mittal Guide has more sensitivity in the evaluation (Pinder 2022).

The risk level provided by the Mittal Guide was privileged considering the referred characteristics of each methodology. Thus, we can conclude that task T4 needs an ergonomic intervention as soon as possible. For T1, no ergonomic intervention was proposed.

These results were presented to the company's managers together with suggestions of ergonomic intervention measures that may reduce the risk level and improve the working conditions. The measures proposed are very specific and related to the configuration of the workstation. General recommendations included providing education and training to the workers and improve the breaks (e.g., more breaks but shorter).

5 Conclusions

This study was developed over six months in a Portuguese company that acts in the energy, mobility, and system sectors. It focused on assessing the risk level of the tasks performed in the workstation where the final assembly of immersed transformers is performed.

Several visits to the factory floor were carried out. Direct observation, informal interviews, time study technique, and a questionnaire helped describe the tasks and select the critical ones. Eight tasks were identified as critical. Then, four ergonomic evaluation methods were applied to assess the risk level—RULA, REBA, Mittal Guide, and MAC. The combination and comparison of different methods contribute to validating the risk level.

The results obtained by the referred methods were carefully analyzed and compared. Overall, the study provided relevant data regarding the risk factors present in the workstation analyzed. As a result, modifications in the workstation were highly recommended to the company managers. They can be a key factor to the prevention of WRMSDs between workers.

Moreover, it is essential to mention that workers' quality of life directly affects their performance and the company's outputs. Ergonomics should be seen as a process of continuous improvement. Therefore, risk assessments should be integrated into the company's strategy and carried out more frequently. In addition, the authors suggested performing a similar analysis on the other workstations.

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Occupational Psychosociology and Human Factors

Stress and Associated Factors Among Nursing Workers in Pandemic Times

Carla Barros and Pilar Baylina

Abstract *Objective* This study aims to assess the impact of psychosocial risk factors on nurses' stress. *Background* The overall impact of COVID-19 on healthcare workers, nursing workers especially, led to an emotionally exhausting daily work activity, making them prone to occupational hazards, namely psychosocial ones. *Method* A cross-sectional study was developed with 284 nurses from public and private hospitals in Portugal. The Depression, Anxiety and Stress Scale (DASS-21) was used to assess mental health, and psychosocial risks were assessed through the Health and Work Survey (INSAT). *Results* Results showed a strong exposure to psychosocial risks. Work pace and intensity, work relationships and emotional demands stood out with higher global average percentages. However, it is worth noting that nurses still showed great joy and pleasure in performing their work activities. *Conclusion* A support network in the work environment needs to be promoted to prevent nurses' emotional stress and promote their psychological well-being during the present global health crisis. *Application* Therefore, research in this area is essential to understand the psychosocial risks that affect nursing workers and assess the less visible work-health relationships.

Keywords COVID-19 · Psychosocial risks · Mental health · Nursing workers

1 Introduction

The overall impact of COVID-19 affected health systems and increased the physical and emotional stress on healthcare professionals (Backes et al. 2021; Pereira et al. 2020). Due to the nature of work activity, and the exceptional characteristics of social and emotional demands, experienced in a pandemic, healthcare workers, especially

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nurses', are more likely to be at risk (Neres et al. 2021; Shaukat et al. 2020; Vizheh et al. 2020). Nursing workers are one of the most vulnerable professional groups, manifesting physical and psychological disorders, aggravated by the increased of work overload, social isolation, and interactions with patients.

The pandemic has actually shifted the focus to studies that measure the impact of psychosocial risks on healthcare professionals' mental health and well-being (Barros 2017; Barros et al. 2019; Leka et al. 2015; Baylina et al. 2018; Moreno Martínez et al. 2022; Salvador et al. 2021).

Nurses are exposed to a large and variable category of psychosocial risks, including increased workloads, time pressure, difficulties in communication and work organization, high emotional demands, lack of support from staff and management, insufficient social relationships, and ethical and social conflicts at work Akkus et al. 2021; Del Pozo-Herce et al. 2021; Franklin and Gkiouleka 2021; Sampaio et al. 2021).

Therefore, it is imperative to identify and assess psychosocial risk factors that may influence the health and well-being of healthcare workers. This study aims to assess the impact of psychosocial risk factors on nurses' stress in pandemic times.

2 Material and Methods

This cross-sectional study was developed with healthcare professionals from public and private hospitals in Portugal's north and center regions to assess the impact of psychosocial risk factors on nurses' mental health, particularly in anxiety, depression and stress. Data collected from 284 nurses took place between May and June 2021. Each healthcare professional received an envelope with the instruments used in the study protocol, which were later returned in a closed envelope after its completion. All ethical procedures of an anonymous, confidential, and voluntary questionnaire submission were followed.

The Depression, Anxiety and Stress Scale (DASS-21) (Lovibond and Lovibond 1995; Antony et al. 1998) was used to assess mental health. The DASS-21 consists of three subscales of 7 items, totaling 21. The anxiety subscale encompasses items related to situational anxiety and subjective experiences of anxiety and fear. The depression subscale contains items that describe dysphoria, discouragement, devaluation, low self-esteem, anhedonia, and apathy symptoms. The stress subscale includes items that focus on symptoms such as difficulty to relax, impatience and irritability, as well as low tolerance to frustration and disappointment. This 4-point Likert-type scale (0 = does not apply to me; 3 = applies to me a lot or most of the time) assesses the negative emotional states experienced for anxiety, depression, and stress. The Portuguese version (Pais-Ribeiro et al. 2004) was used, showing good internal consistency and convergent and discriminant legitimacy, with a three-factor hierarchical structure (anxiety, depression, and stress). This scale is widely used in several contexts, particularly with healthcare workers (Luo et al. 2020; Moreira et al. 2020).

The psychosocial risks were assessed through the Health and Work Survey—INSAT. The INSAT Survey (Barros et al. 2017) is a self-completion questionnaire that evaluates the relationships between working conditions, risk factors, and health problems. It is made up of seven axes that mainly include relative Likert scales: (I) Work; (II) Working conditions and risk factors; (III) Life conditions outside of work; (IV) Training and work; (V) Health and work; (VI) My health and my work; and (VII) My health and my well-being. For this study's purpose, the chosen scale integrated the following psychosocial risk factors at work: work pace and intensity; lack of autonomy; work relationships with co-workers; employment relationships with the organization; emotional demands; ethical and value conflicts; and job characteristics. INSAT has been used in several health-related studies before (Barros et al. 2019; Correia et al. 2021).

Data were analyzed with the support of the IBM SPSS statistical program for Windows, version 2 8.0 (SPSS Inc.: Chicago, IL, USA). The adopted significance level was $p \leq .05$. Frequency and percentage analyses were performed on the demographic characteristics of the participants (nominal variables from the INSAT questionnaire). Afterward, all psychosocial factors were transformed into nominal variables (no—0, yes—1) to analyze the associations between risk factors and DASS-21. Then, a Bivariate analysis was performed using point-biserial correlation to identify the psychosocial factors related to the dependent variables, particularly anxiety, depression and stress. Subsequently, a multiple linear regression (*Backward* method) was used only with the statistically significant associations to identify the models that best explained the relationship between psychosocial factors and anxiety, depression, and stress dimensions. The study's regression equations satisfied all hypotheses, and the results of the regression analyses were considered reliable.

The study protocol was approved by the Ethics Committee of Fernando Pessoa University (Ref. PI-112/20), respecting all the Declaration of Helsinki procedures.

3 Results

284 nurses working in public and private hospitals in Portugal's north and center regions participated in this study. The sample is mainly composed of 82.0% female and 18.0% male nurses aged between 21 and 64 years (M = 38.85; SD = 10.03). Of the 284 nurses who participated in this study, 55.7% were married or cohabiting, and 45.1% had no children. Professional experience ranges considerably from those who had worked for less than one year to those who had worked for 42 years (M = 13.49; SD = 9.63). Regarding the contract type, 90.1% of the participants work under permanent or open-ended contracts. 93.3% have full-time working hours, 64.8% work rotating shifts, and 51.1% work weekends.

The INSAT survey's descriptive analysis, described in Table 1, shows the frequency distribution of "yes" answers to psychosocial risk factors at work that have a significant impact on the nurses' professional practice. Results show a high exposure to psychosocial risks. Pace and intensity of work and emotional demands stand out as risk factors with higher overall mean percentages. However, it is worth noting that nurses still showed great joy and pleasure in performing their work activities.

The results of the DASS-21 are presented in Table 2 for the subscales of anxiety, depression and stress. It should be noted that higher average values were found in the stress. Subscale that translates into persistent states of tension and agitation, irritability, low tolerance to frustration, and difficulties in relaxing and calming down.

After the descriptive analysis, the inferential analysis was performed, starting with the Bivariate analysis to verify the statistically significant correlations between psychosocial factors and stress dimensions, respectively (Table 3). Only stress was used (high average values, 7.08) to the bivariate analysis. Stress translates the persistent states of tension and agitation, irritability, low tolerance to frustration, and difficulties in relaxing and calming down. The results shows that psychosocial work factors, such as work pace and intensity; work relationships; employment relationships; emotional demands have a positive and significant correlations with stress dimensions.

Afterwards, a multiple linear regression was performed only with the psychosocial work factors that showed statistically significant correlations to identify the predictive model of stress dimension based on the psychosocial factors (Table 4). The R-value found for stress dimension was statistically significant (Table 4).

The analysis of the beta values and respective *p*-values shows that cross-sectional psychosocial risks, predictors of stress, and psychosocial risks differ. No help from colleagues when solicited ($\beta = .138$; $p = .038$ for stress); Untrustworthy colleagues ($\beta = .204$; $p < .001$ for stress) are shown to be cross-sectional predictors for the manifestation of stress. Psychosocial risks related to emotional demands, particularly: hiding emotions ($\beta = .211$; $p < .001$ for stress); being afraid of suffering a work-related injury ($\beta = .109$; $p = .040$ for stress) are also equally significant predictors. Significant predictors were also found for the psychosocial risks related to work pace and intensity, such as frequent interruptions ($\beta = .115$; $p = .032$) for stress. The positive beta values corresponding to the significant predictors allow us to conclude that exposure to psychosocial risks is related to stress symptoms. The latter was also found to be related to a higher number of different psychosocial risks (related to increased workloads, social relationships, and emotional demands), thus being the dimension with the most worrying values.

Later on, the same was done for the job satisfaction and pleasure factors. The R-value found for being satisfied with the work performed was statistically significant (Table 5).

The analysis of the values found shows that pleasure and job satisfaction psychosocial factors can be protectors of mental health. Being satisfied with the work performed is a particularly protective factor against stress ($\beta = .117$; $p = .038$), with a higher average mental health value.

Table 1 Description of psychosocial work factors

Work pace and intensity	*% yes*
Working at an intense pace	94.4
Having to rely on the work of colleagues	82.9
Relying on direct orders from customers	76.1
Frequent interruptions	82.4
Hyper-solicitation	81.0
Work hours	*% yes*
Exceeding normal working hours	86.3
"Skipping" or shortening a meal or not taking the break at all because of work	82.7
Maintaining permanent availability	58.1
Work relationships	*% yes*
Needing help from colleagues and not having it	46.1
My opinion being disregarded for the service's functioning	44.4
Little recognition by management	47.5
Not having anyone I can trust	30.0
Being exposed to bullying	39.4
Employment relationships	*% yes*
I feel exploited most of the time	50.0
Being afraid of suffering a work-related injury	71.1
Lack of means to perform the work	50.7
The company disregards my well-being	63.0
Emotional demands	*% yes*
Confronted with public relations tense situations	94.7
Fear of verbal aggression	86.3
Being exposed to the difficulties and/or suffering of other people	94.7
Faking good mood and/or empathy	75.4
Hiding emotions	75.0
Ethical and value conflicts	*% yes*
Doing things, I disapprove of	64.8
My professional conscience is undermined	52.8
Lack of necessary means to perform a good job	57.7
Pleasure and satisfaction at work	*% yes*
Having the opportunity to do things that give me pleasure	90.4
Having the opportunity to develop professional skills	89.9
Being satisfied with the work performed	87.5
Being a valuable contribution to society	97.8
The performed work is valued and recognized	51.8
Having the feeling of a job well done	88.9

Table 2 Descriptive analysis of anxiety, depression and stress values from the DASS-21 scale

Variables	M (DP) min.-max	n (%)
Anxiety	4.12 (3.95) 0–15	284 (100%)
Depression	3.63 (3.81) 0–16	284 (100%)
Stress	7.08 (4.51) 0–21	284 (100%)

Table 3 Bivariate analysis of stress dimensions and psychosocial work factors

Psychosocial factors	Stress	
	R	*p*
Work pace and intensity		
Frequent interruptions	.187**	.002
Hyper-solicitation	.142*	.016
Work relationships		
No help from colleagues when solicited	.221**	<.001
Little recognition by management	.206**	<.001
Untrustworthy colleagues	.268**	<.001
Employment relationships		
I feel exploited most of the time	.120*	.045
Being afraid of suffering a work-related injury	.161**	.006
The company disregards my well-being	.190**	.001
Emotional demands		
Being exposed to the difficulties and/or suffering of other people		
Faking good mood and/or empathy	.196**	<.001
Hiding emotions	.216**	<.001

$^{*}p < .05$; $^{**}p < .01$

4 Discussion

Nursing is a physically and emotionally exhausting professional activity that has become more demanding with the pandemic, increasing the psychological vulnerability of these professionals. Results revealed that psychosocial risk factors at work are significantly present. Performing work activities became more exhausting and emotionally challenging due to the pace and intensity of work and high emotional demands. Working conditions worsened due to the interactions with seriously ill patients and consequent fear of being contaminated, associated with the lack of means and resources to perform quality work, which paved the way for the appearance of psychological health problems. Therefore, exposure to this set of psychosocial risks led to the aggravation of mental health disorders, as already mentioned in other

Table 4 Stress multiple linear regression predictive model—psychosocial work factors

Predictive models	Non-standard coeff.		Standar coeff.		I.C. to β (95%)		
	B	Standard error	β	t	*p*	Lower limit	Upper limit
Stress							
Constant	1.540	1.079		1.427	<.001	−.585	3.666
Frequent interruptions	1.283	.709	.115	1.808	.032	−.114	2.680
No help from colleagues when solicited	1.199	.574	.138	2.089	.038	.069	2.330
Untrustworthy colleagues	1.962	.579	.204	3.388	<.001	.822	3.103
Being afraid of suffering a work-related injury	1.058	.602	.109	1.756	.040	−.129	2.244
Hiding emotions	2.126	.633	.211	3.358	<.001	.879	3.373

* $p < .05$; ** $p < .01$

Table 5 Stress multiple linear regression predictive models—pleasure and job satisfaction factors

Predictive models	Non-standard coeff.		Standardized coeff.		I.C. to β (95%)		
	B	Standard error	B	*t*	*p*	Lower limit	Upper limit
Stress							
Constant	5.559	.780		7.122	<.001	4.022	7.096
Being satisfied with the work performed	1.593	.836	.117	1.906	.038	−.053	3.238

* $p < .05$; ** $p < .01$

studies with healthcare professionals (European Agency for Safety and Health at Work 2022; Miranda et al. 2020; Shaukat et al. 2020; Vizheh 2020).

In this study, symptoms associated with nurses' mental health were shown to be associated with anxiety, depression and stress symptoms. This situation has been reported in recent studies, which state that the COVID-19 pandemic has had a significant impact on these professionals' health: more than 90% of nursing professionals reported having symptoms of mental and emotional exhaustion, stress, fatigue, accompanied by anxiety and irritability (Del Pozo-Herce et al. 2021; Kang et al. 2020). Results indicate that stress was the symptom with the highest average scores, translated by persistent manifestations of irritability, agitation, and tension, consistent with studies developed in this pandemic period (Pedrozo-Pupo et al. 2020; Wang et al. 2020). In addition to the risk of infection and the lack of knowledge about the virus, the continuous shifts and the intense pace of work, accompanied by insufficient social support, increased the nurses' experienced levels of anxiety and stress (Ornell et al. 2020).

Results actually point to a consistency between psychosocial risks and stress symptoms. A set of psychosocial risks, mainly work pace and intensity, social relationships, and emotional demands, may predict the manifestation of psychological disorders. In fact, increased work pace and intensity, lack of work and working hours organization, accompanied by the lack of support and resources, aggravated during the pandemic, increased nurses' psychological vulnerability (Da Rosa et al. 2021; Duarte et al. 2021; Osório et al. 2021; Sampaio et al. 2021). However, the presence of pleasure and job satisfaction factors as protective role on mental health. Being satisfied with the work performed was specifically shown to be a protective factor against stress, meaning it can be a key element for preventing and protecting. During the COVID-19 pandemic, nurses actually found the best strategies to perform their duties in the best possible way, making them more aware of the importance of their profession and their own personal and professional fulfillment (Akkus et al. 2021; Buheji and Buhaid 2020).

5 Limitations

Although this research has made significant contributions and can be used by the care units and government to attendance the adverse psychological effects during Covid-19, it has some limitations. A larger sample, especially of nurses but also of healthcare workers like physicians and other heath supporters, 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, particularly during pandemic times. Then, more studies should be conducted to better understand this relation and endorse better working practices during alarming and other emergency situations.

6 Conclusions

This study's findings demonstrated that the COVID-19 pandemic significantly impacted healthcare professionals' psychological health, showing predictive effects of psychosocial risks in anxiety, depression and stress. Intensity and pace of work, work relationships, and emotional demands proved to be particular predictors of mental health disorders. The pandemic eventually triggered the development of studies in the mental health field. However, few studies have attempted to assess the relationship between psychosocial risks and mental health in work settings.

These results highlight the need to promote an adequate support network at work to prevent nurses' emotional stress and promote psychological well-being during the present global health crisis. Therefore, research in this area is essential to understand the psychosocial risks that affect nursing professionals and assess the less visible work-health relationships.

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Gender (In)Equality in the Labor Market: A Case Study of the Environmental Health Professionals

Carolina Suzano, Susana Paixão, João Figueiredo, and Ana Ferreira

Abstract Through this study, we seek to know the attitudes, representations and opinions of the Environmental Health Professionals surveyed, about a set of topics related to gender inequality. Centuries of deep-rooted discrimination and patriarchy have resulted in a huge gender power disparity in our society. Historically, the female gender has been constantly discriminated against, for being considered inferior to the male gender. This is a descriptive observational study, with a cross-sectional timeline and knowledge level II. The target population comprises two groups: men and women with degrees in Environmental Health and working in the field. The sampling design adopted was of the non-probabilistic type which employed convenience sampling. To collect the information, a questionnaire was built, using a Likert scale with 5 levels of agreement. Although men had more unequal and penalizing conceptions compared to women, these differences were not statistically significant. Therefore, there was a prevalence of gender stereotypes. This study allowed us to identify, analyze and assess Gender inequalities for Environmental Health Professionals. Most of the results found follow the literature closely and may be relevant to define strategies and programs for future investigations. Our study highlighted evidence of "why" gender equality is so important in terms of Health.

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1 Introduction

Centuries of deep-rooted discrimination and patriarchy have resulted in a huge gender power disparity in our society (Guterres 2020). Historically, the female gender has been constantly discriminated against, for being considered inferior to the male gender (Barracho and Martins 2010; Ferreira 2010). Social and political changes, especially during the period of feminist movements in the 60s and 80s, promoted the development of studies on women and the evolution of their participation in the labor market (Barracho and Martins 2010). In the labor market, cultural symbols, normative concepts, institutional structures and personal identities are reproduced, emphasizing and strengthening gender differences, which ultimately determine the roles they play in the process of social construction and in power relations (United Nations Development Programme 2019; World Health Organization 2018). Despite the global impetus and several advances, there are still some challenges, prejudices and gender inequalities, especially in the health sector (Newman 2014; Langer et al. 2015; Bachelet 2011). The health sector is the one that presents an accelerated growth in terms of female employability, as women represent 7 out of 10 professionals. Although the proportion of women in this sector has increased steadily in the last quarter of a century, the pattern of industry segregation remains (International Labour Organization 2017). As major health care providers, women contribute millions of euros to global health every year (Langer et al. 2015) and therefore their unrecognized contribution is one of the main reasons for the decline in mortality across all age groups, in the second half of the century (World Health Organization 2016; GBD 2016).

Recent global health strategies have begun to recognize how important it is to address the issue of gender inequalities as a way to achieve universal health coverage and maximize not only economic empowerment, but also the participation of women in the sector. This recognition promotes a new approach, shifting the focus from health as a cost and economic barrier, to an investment and a means of multiplying inclusive economic growth (World Health Organization 2016). In the area of Environmental Health, specifically in Portugal, females make up the majority of workforce (66.1% female to 33.9% male) (Ministério da Saúde). Occupational segregation is gender-neutral and has the consequence of affecting experiences in the labor market, as it manifests itself in different ways: restricted employment options; opportunities for a specific gender; stereotypes that lead to gender pay gaps and exacerbate unequal power structures within society (European Institute for Gender Equality 2017). It should be noted that, although women occupy approximately 70% of the posts in the health sector, they still remain segregated. We face a paradox, because even in “majority female” professions (such as Environmental Health), a minority of male employees generally have an “escalator”, reaching leadership positions faster than their peers.

Decent work involves creating a work environment based on the principle of equal opportunities for all, without discrimination, prejudice or harassment. This is an important objective that cuts across other forms of inequality, including occupational segregation and gender pay gaps (Newman 2014). Thus, it is expected that discrimination will continue to be present while the lowest paid jobs continue to present high rates of feminization, as well as in access to management positions tending to privilege the male gender (Salada 2004). The "Equal Remuneration Convention", held in 1951 by the International Labor Organization (ILO), first defined gender equality in terms of wages and aimed to ensure that men and women were equally remunerated for their work (World Health Organization 2008; Oelz et al. 2013; Murphy and Zheng 2016). Seventy years later, the Convention is still relevant, given that wage differentials are still the most common form of discrimination against women. The most recent ILO data estimate that the gender pay gap in the health and social care sectors is higher compared to other sectors (International Labour Organization 2017; Ribeiro 2014; Acker 1989). For Portugal, it is only with the ending of the national dictatorship in 1974 that the process of democratization and the implementation of measures to address gender inequalities begin (Duarte 2021). Currently, it is the responsibility of the State to promote gender equality, as mentioned in the National Strategy for Equality and Non-Discrimination 2018–2030: "(…) the elimination of gender stereotypes as factors that are at the origin of the discriminations that prevent the substantive equality that must be guaranteed to women and men (…)." (Diário da República 2018).

Responding to discrimination and prejudice in the health sector is a fundamental step towards achieving gender equality and, at the same time, making it a stronger, more flexible sector that defends the basic principles of human rights (Newman 2014). Given that gender analysis has focused mostly on service delivery and quality, largely ignoring the fact that women are not just recipients of health care, but one of the main elements for boosting health (Sörlin et al. 2012) this article seeks to understand the attitudes, representations and opinions of the Environmental Health Professionals in relation to gender inequality.

2 Materials and Methods

2.1 Study Design

The study is observational, descriptive-correlational with a cross-sectional temporal line. With regard to the Level of Knowledge, it fits into Level II.

Data collection for the study took place between December 2020 and March 2021.

2.2 Population and Sample

For the purpose of this investigation, the study population was defined as graduates in Environmental Health, of either genders, working within the field of Environmental Health. The inclusion of both genders would enable a diverse range of information and perspectives to be collated. To assess the prevalence of gender inequalities in the labor market in a group of workers (N = 1307), a theoretical prevalence of 38.7%* ($P = 0.39$) ($100 - 61.3 = 38.7\%$) was assumed, as provided for in published studies recently. A confidence level of 95% (standard values of $Z\alpha/2 = 1.96$) was assumed as decision criteria for sample estimation, for a maximum sampling error of 4% ($\alpha = 0.04$). The sampling method applied was of the non-probabilistic type and regarding the technique, it was by convenience. The study recruited 200 participants, of which 170 (85%) were female and 30 (15%) were male.

2.3 Instruments and Data Collection

For this investigation, the selected methodology was quantitative. In methodological terms, a questionnaire was built, which included a first part with biographical information (gender, age, educational qualifications, years of work activity, current responsibility in the profession, having or not having children). A second part of the questionnaire focused on a scale of attitudes, with several items, some of which are traditional in nature, others of an egalitarian nature, others, still, on the profession under study, on a Likert scale with 5 levels of agreement (Strongly Agree = 1, Partially Agree = 2, Neither Agree nor Disagree = 3, Partially Disagree = 4, Strongly Disagree = 5). The questionnaires accessed, through the online questionnaire platform Google Forms, and distributed to potential participants.

2.4 Statistical Analysis

Once the questionnaires had been collected data analysis took place, with all the information being used to build a database in the specialized software for data processing (IBM SPSS Statistics version 27).

For the application of parametric or non-parametric tests it was necessary to evaluate descriptive statistics through measures of kurtosis and asymmetry. Asymmetry was evaluated using Skewness statistics. The degree of flatness (kurtosis) was evaluated using the Kurtosis statistic. In addition to these two measures, the normal distribution was also important for the decision to choose the test. To evaluate this assumption, we used non-parametric tests: Kolmogorov-Smirnov with the Lilliefor's Correction factor for sample sizes >50 and/or Shapiro-Wilk for sample sizes less than or equal to 50 (Mello 2014; Pestana and Gageiro 2005; Marôco and Bispo 2005).

Thus, the Wilcoxon-Mann-Whitney test (non-parametric) was used, which allowed the comparison of means between two independent samples, as well as the one-way ANOVA test, to compare 3 or more independent groups regarding their means and when it was not possible to apply the test, we resorted to the non-parametric test, the Kruskal-Wallis test. Pearson's chi-square test (non-parametric) was applied in order to assess the existing association between qualitative variables. To measure the intensity of the relationship between ordinal variables, Spearman's Correlation Coefficient (non-parametric) was used. To estimate the statistical inference, a confidence level of 95% and a random error equal to or lower than 5% were taken into account. 2nd paragraph Materials and Methods should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail, while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Include any pre-registration codes.

3 Results

The study recruited 200 participants, of which 170 (85%) were female and 30 (15%) were male. Table 1 identifies the socio-biographical characteristics of the participants.

In Sect. 1, an attempt was made to understand the representations of men and women regarding the family and domestic sphere and their attribution of these spheres of responsibility and dedication to one or another gender.

Table 1 Socio-biographical characterization of respondents

		Gender					
		Female		Male		Total	
		n	%	N	%	n	%
Age	[18–24] years	26	15.3	2	6.7	28	14.0
	[25–30] years	57	33.5	12	40.0	69	34.5
	[31–40] years	38	22.4	13	43.3	51	25.5
	≥41 years	49	28.8	3	10.0	52	26.0
Highest academic qualification	Undergraduate degree	4	2.4	0	0	4	2.0
	Graduation	124	72.9	23	76.7	147	73.5
	Master	38	22.4	6	20.0	44	22.0
	PhD	4	2.4	1	3.3	5	2.5
Children	Yes	98	57.6	22	73.3	120	60.0
	No	72	42.4	8	26.7	80	40.0
Total		170	100.0	30	100.0	200	100.0

Table 2 Differences in roles and centrality in the family, depending on gender

Roles and family centering index—men and women (%)					
Gender	Mean	Standard deviation	N	Z	*p*
Female	88.8824	11.00591	170	−2.613	0.009
Male	83.3333	14.87496	30		
Total	88.0500	11.79235	200		

Mann-Whitney Test

The following analysis looks to assess the differences regarding roles and centrality in the family, depending on gender. Let's look at Table 2.

Although differences were found in the scores of the items that make up this section, when we compare men with women, it was possible to verify that females had, on average, a slightly higher score compared to males, that is, women revealed a firmer perception, although this difference is not very large.

According to the results presented in Table 3, there was the presence of statistically significant differences (p-value < 0.05), and, on average, the male gender presented a slightly more conservative view compared to women, for example associating women with the role of the mother and housewife, which indicates a level of conservatism in terms of gender equality.

In this phase of our study, we proposed to evaluate the correlation of the perception of egalitarian character at the organization level with the Index of Roles and Centrality in the Family and, also, with the Index of Stereotyped Socialization and Representation in the Profession, as shown in Table 3.

It was possible to verify the existence of a correlation, which tends to be positive, that is, individuals who revealed a reduction in gender differences in family responsibility assumed a higher index revealing social and professional stereotypes.

However, there was no correlation between the perception of balance in professional and family life with the perception of the roles assumed, either by men or women, at the level of centrality and family.

4 Discussion

Going through the entire investigation and based on the inferential analysis presented, it was possible to establish a set of conclusions regarding the subject under study. As previously identified, Environmental Health is a "mostly female" profession, and in there is higher representation of women (66.1%) compared to men (33.9%) (Ministério da Saúde). This difference in representation can be explained by the increase in the number of women entering the labor market in recent years, an opportunity that arose thanks to the implementation of measures aimed at combating gender segregation in the labor market and, consequently, combating to unemployment (Diário da República 2015). This study reflects this gender balance within

Table 3 Correlation of the perception of balance between family and professional life with the index of roles and centrality in the family and with the index of stereotyped socialization and representation in the profession

		Family and professional life balance	Roles and family centering index—men and women (%)	Stereotyped socialization index and profession representation (%)
Family and professional life balance	Coeficiente de Correlação	1.000	−0.058	−0.475
	p		0.416	0.000
Roles and family centering index—men and women (%)	Coeficiente de Correlação		1.000	0.121
	p			0.087
Stereotyped socialization index and profession representation (%)	Coeficiente de Correlação			1.000
	p			
N		200	200	200

Spearman's correlation coefficient

the profession, as the vast majority (85%) of participants were female. Initially, we anticipated the presence of inequalities, based on gender, in the structure of the profession. Through the analysis of statistical data, it was possible to ascertain these same inequalities. The women in the study revealed to be younger, compared to men, and a good part were concentrated in stages of life marked by strong family intensity, since they are the gender that most expressed having children. The highest concentration of women (62.3%) was in the range between 25 and 41 years onwards, when they generally find themselves in a phase of life marked by family responsibilities—the presence of children in ages that still need a lot of care, including assistance and care for family members. Females stood out for having held functions for a longer time in the area of Environmental Health than males. The data point to a symmetry between genders in terms of educational qualifications, however, it is worth noting the occupational segregation marked by the concentration of men and women in some specific areas. There was a strong segregation when analyzing the composition of the various areas: areas such as Environmental Management and Food Safety proved to be quite feminized, while the area of Occupational Safety and Hygiene showed to be occupied by a greater proportion of men.

During our study, answers emerged that confirm a duality between the ideal of a woman as a mother and housewife and that of a woman as an independent person, especially when the consequences of her professional activity on children and family life are invoked. The role of “caring” is thus associated with an obstacle to less traditionalist and individualizing conceptions of female identity. On the other hand, there was also an appreciation and emphasis of motherhood and childcare in the female identity; this finding proves the ambivalence and dichotomy of values and attitudes between an escape from the conventional polarization between “male” and “female” roles rigid and defined thanks to stereotypes. It was possible to verify, using statistical tests, that there is a significant difference between both genders in the perception and recognition of inequalities and discrimination based on gender.

5 Conclusions

It is impossible to have healthcare without the people who provide healthcare. With the growing global demand for healthcare and the shortage of professionals, there is an urgent need to increase the number of jobs. As women constitute the majority of workers in the health sector, it is of utmost importance and urgency to address the health implications of gender inequalities. The current account of gender in global health highlights missed opportunities and future opportunities, the need to place gender analyzes in the context of political influences and structural inequalities, and the need to use contemporary social movements to advance this issue.

This study allowed us to identify, analyze and assess inequalities at the level of Environmental Health Professionals. Most of the results found follow the literature closely and may be relevant to define strategies and programs for future investigations. Our study highlighted evidence of “why” gender equality is so important in terms of Health. We conclude that the quantity and quality of gender data is improving over time: women are making progress, but remain considerably at a disadvantage; men’s roles are expanding but are limited by restrictive gender norms. Despite this progress, conceptual deficiencies still persist, which means that we are only beginning to understand a part of a much more complex whole. In addition to quantitative gender equality, we must strive for a cultural transformation that allows for the inclusion of values of transparency, honesty, equity and justice (WHO 2002, 2011; Abu-Ghaida and Klassen 2004; McDonald 2000; Stanley 2017). Finally, the main conclusion of this article is that gender inequality in the labor market, in terms of health, can weaken both health systems and service delivery. However, an alternative, much more positive future scenario is possible. In line with current research and debates on gender inequalities, this study shows that the transformation of inequalities between men and women implies profound changes not only in the female condition, but also in the male condition, in identities and in private life.

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Work-Family Conflict and Guilt: Effects on Well-Being and Career Satisfaction

Cátia Sousa, Cristiana Gato, Gabriela Gonçalves, and António Sousa

Abstract Nowadays, and after successive changes at all levels, namely, in what is the concept of family, its standards and the demands placed on it, it has become difficult to balance professional and family roles. The incompatibility of these roles and the difficulties felt when trying to balance these spheres can lead to work-family and family-work conflict and consequently to feelings of guilt. These consequences can negatively affect individuals regarding their well-being and career satisfaction. Through a sample of 180 participants, 107 women and 73 men, aged between 21 and 71 years (M = 38.57; SD = 9.83), this quantitative study aims to analyze the influence of work-family conflict and guilt on well-being and career satisfaction. The results show that conflict is a predictor of guilt and both influence well-being but have no influence on career satisfaction. This reinforces the importance of developing family-friendly practices and policies by organizations, aimed at increasing the well-being and satisfaction of their human capital.

Keywords Work-family and family-work conflict · Work-family and family-work guilt · Well-being · Career satisfaction

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1 Introduction

The dual relevance of work and family to the well-being, quality of life and professional performance of individuals has contributed to difficulties in work-family interaction (e.g., Huyghebaert-Zouaghi et al. 2022). Therefore, researchers and managers have devoted greater attention to the work-family interface (e.g., Gillet et al. 2021; Li et al. 2021). However, some areas of this problem remain underexplored, such as well-being and career satisfaction. Changes in expectations of family roles, technological developments, and a greater expectation of individuals to "work anytime, anywhere" (Obrenovic et al. 2020) are factors likely to exacerbate situations such as work-family conflict and guilt, leading to a decrease in well-being, lower motivation, and commitment in both spheres of life (Gonçalves et al. 2017; Korabik 2015), which can certainly affect career satisfaction. Given the relevance of this topic for organizations and for the well-being of their human resources, this study aims to analyze the effects of conflict and work-family guilt on well-being and career satisfaction.

1.1 Work-Family Conflict and Guilt

The work-family interface has been widely studied over the last few decades (e.g., Eby et al. 2005; Netemeyer et al. 1996; see Kossek et al. 2021 for a revision). This growing interest is mainly due to the changes that have taken place in the world of work and in the structure of traditional families: the increase in women in the labor market, the increase in single-parent families, the increase in competition in the professional sphere, the decline in wages and, consequently, the increase in of the cost of living that led to the growth of couples with dual careers (Bianchi and Milkie 2010; Goldani 2002). All these transformations make it difficult to balance work and family, generating a conflict between these two universes, especially because, nowadays, individuals are not only employee, but they are also father/mother, husband/wife and, at the same time, they do household chores (Akintayo 2010; Gonçalves et al. 2018). According to Greenhaus and Beutell (1985), work-family conflict occurs when the pressures exerted by roles (family-work) become incompatible in the performance of tasks in the workplace (public) and in the family (domestic). Thus, the demands of both spheres can lead to two types of conflict: work-family conflict (WFC) and family-work conflict (FWC), that is, work-family conflict is bidirectional. These two spheres are independent, but at the same time reciprocal, they have different antecedents and consequences. Commonly, work-family conflict is negatively associated with workers' well-being (Allen et al. 2000) and is reflected in many areas of life, both professional and personal (e.g., lower job satisfaction, burnout, marital status, depression, emotional exhaustion, and alcohol abuse) (Eby et al. 2005; Ilies et al. 2012). This situation is a consequence of the need to make a choice between one domain in favor of the other, and is susceptible to generating negative emotions, such as frustration or guilt (e.g., Ilies et al. 2012; Korabik 2015). The guilt added to the work-family binomial results from the need to choose one sphere in favor of another (Conlin 2000; Gonçalves et al. 2018; Korabik 2015), namely when both are perceived as necessary. Thus, similarly to the WFC-FWC binomial, guilt can also be divided into two dimensions: work-family guilt, produced by work that interferes with family duties, and family-work guilt, when family responsibilities affect work (e.g., Korabik 2015). Work-family and family-work guilt is associated with several negative consequences, such as depression, less satisfaction with life, with organizational policies, with parenting and less time spent with children (Aycan and Eskin 2005).

Some studies have corroborated the relationship between work-family conflict and the resulting guilt (Korabik 2015). Sousa et al. (2018, 2020) observed that work-family conflict is a negative predictor of guilt. Gómez-Ortiz and Roldán-Barrios (2021) also point to the negative consequences of the work-family conflict on guilt. Thus, we advance the hypotheses:

- H1: Work-family conflict is a predictor of work-family guilt.
- H2: Family-work conflict is a predictor of family-work guilt.

1.2 Impact of Conflict and Work-Family Guilt on Well-Being and Career Satisfaction

Both work-family and family-work conflict and guilt have negative consequences for individuals. Several investigations have shown that work-family conflict is one of the main factors influencing workers' well-being (e.g. Fotiadis et al. 2019; Lin et al. 2019; Obrenovich 2020). Well-being emerges as one of the main key factors for maintaining a healthy and functional workforce, as it encompasses not only well-being in terms of health, but also well-being in life and work (Schulte and Vainio 2010). Although there is no agreed-upon definition of well-being, there are several common elements in many of them, for example, that well-being is more than the mere absence of negative circumstances, such as illness (Schulte and Vainio 2010), or that it is a subjective state of health, happiness, comfort, and life satisfaction, which includes a physical, material, social, emotional, and developmental dimension (Waddell and Burton 2006). Well-being can be considered as referring to the optimal psychological functioning of the individual (Deci and Ryan 2008). According to the OECD (2011) regardless of age or gender, one thing that every person has in common is the number of hours a day has. The way these 24 h are divided between different activities is a determinant of well-being. In this way, achieving a state of balance between work and personal life will correspond to the individual's central well-being (OECD 2011). In this context, developing work-life balance measures is of utmost importance, as working conditions and various other family policies strongly affect people's ability to balance work and life (OECD 2011).

This situation brings us to the question of career satisfaction. In other words, the difficulty of finding a balance between professional and family life can often affect career expectations, especially for those more family centered. These difficulties, in addition to generating conflicts and guilt, are likely to reduce well-being. In addition, this choice between work and family, leaving work in the background, may have consequences for career satisfaction. A career is all the experience gained from studies and professional experience throughout an individual's life. That is, it is a sequence of attitudes, activities or behaviors associated with the individual's work role during their lifetime (Arthur and Lawrence 1984). Career satisfaction refers to the individual's perception of career achievements to date and their prospects for future progress (Martínez-León et al. 2018). It reflects a balance between what individuals expect from their career development and the achievement of their overall career goals (Greenhaus et al. 1990; Martínez-León et al. 2018) focusing on personal satisfaction with various aspects of progress and career success (Parasuraman et al. 1996). However, in the context of work-family and family-work conflict and guilt, it is expected that career satisfaction will be negatively affected. In view of the above, the following hypotheses were raised:

- H3: Work-family and family-work conflict and guilt influence well-being.
- H4: Work-family and family-work conflict and guilt influence career satisfaction.

2 Methodology

2.1 Sample

The final sample is composed of 180 participants, 107 are female (59.4%) and 73 are male (40.6%), aged between 21 and 71 years (M = 38.57; SD = 9.83). Most participants are married or live in a common-law relationship (N = 105; 58.3%). About 31.1% (N = 56) of the participants have 2 children and 28.9% (N = 52) claim to have a child. As for educational qualifications, participants are distributed across all levels of education, the most common being secondary education (N = 82; 45.6%) and higher education at the undergraduate level (N = 63; 35%). At the level of professional activity, the data are dissimilar, however accentuated regarding the tertiary activity sector (N = 110).

2.2 Instruments

Work-Family and Family-Work Guilt Scale—the Portuguese adaptation by Gonçalves et al. (2018) from the scale originally developed by McElwain et al. (2005). It is a scale composed of 7 items that assess two dimensions: work-family guilt (4 items, e.g., item 2 "I feel guilty for not being able to take care of my family as well as I would like.") and family-work guilt (3 items, e.g., item 6 "I regret missing work due to family responsibilities”). Responses are given on a Likert scale from 1 (strongly disagree) to 7 (strongly agree).

Work-Family and Work-Family Conflict Scale—The WFC and FWC scales, adapted for the Portuguese population by Santos and Gonçalves (2014), were originally developed in English by Netemeyer et al. (1996). This scale, composed of 10 items, rated on a 7-point Likert scale (1—totally disagree to 7—totally agree) is a two-dimensional instrument that assesses the two dimensions of conflict: work-family conflict (5 items, e.g., item 1: “The demands of my job interfere with my family life”; item 4: “My job does not allow absences for family reasons”) and family-work conflict (5 items, e.g., item 7: “I do not need to perform professional tasks for the family commitments at home”; item 9: “My family life interferes with my professional responsibilities, namely punctuality, daily tasks and overtime”).

Career satisfaction—the Career Satisfaction Scale (CSS) by Greenhaus et al. (1990) was used, which was translated into Portuguese for the present study. It is a scale composed of 5 items that assess the degree of satisfaction with the career and its aspects (e.g., item 1 “I am satisfied with the success I have achieved in my career”; item 4 “I am satisfied with the progress I have made towards my promotion goals”), using a 7-point Likert scale (1—strongly disagree to 7—strongly agree).

Well-being—was assessed using the GHQ12 scale, developed by Goldberg and Williams (1988) and translated for the population by Carochinho (2006). It is a unidimensional measure that seeks to assess the mental health of the participant and consists of 12 items, evaluated on a 7-point Likert scale (strongly disagree to strongly agree). This scale is focused on two issues: (1) the inability to perform normal functions and (2) the emergence of new and distressing experiences. It is a scale evaluated inversely, that is, the higher the means, the lower the psychological well-being perceived by the participant.

All scales have good internal consistency values ($\alpha \geq .70$), with Cronbach’s alpha varying between .79 (well-being) and .91 (FWC and career satisfaction) (Table 1).

Table 1 Means, standard deviations and Cronbach’s alpha values of the variables under study

	M	SD	α
WF-FW guilt	3.09	1.40	.82
WF guilt	3.69	1.74	.85
FW guilt	2.31	1.55	.80
WFC-FWC	2.62	1.23	.89
WFC	3.21	1.69	.91
FWC	2.04	1.13	.86
Well being	4.71	1.19	.79
Career satisfaction	3.38	1.06	.91

2.3 Procedure

Questionnaires were applied on paper, in different institutions, places of employment and social environments, and through the snowball effect, with friends, family and friends. The time to complete the questionnaire was approximately 10 min. Participants were informed about freedom of participation, anonymity, and data confidentiality. No reward was offered.

2.4 Data Analysis

Data were analyzed using SPSS software (Statistical Package for Social Sciences), version 28.0.

3 Results

3.1 Descriptive Statistic

Table 1 shows the means, standard deviations, and internal consistency values of the variables under study.

Regarding guilt it has a mean of 3.09 (SD = 1.40), with the WF guilt dimension having the highest mean (M = 3.69; SD = 1.74). The WF-FW conflict has a mean of 2.62 (SD = 1.23), and similarly to the guilt variable, the WFC dimension also has the highest mean (M = 3.21; SD = 1.13). Well-being has a mean of 4.71 (SD = 1.19), that is, and being an inversely evaluated variable, participants have a low level of well-being. Career satisfaction stands at 3.38 (see Table 1).

3.2 Regression Analysis

To test hypotheses 1 and 2, simple regression analyzes were performed. It was possible to observe that the WFC explains about 42.1% of the WF guilt ($\beta = .652$, $p < .001$) and the FWC explains 13.3% of the FW guilt ($\beta = .371$, $p < .001$). For hypotheses 3 and 4, a multiple linear regression analysis was carried out with two models. Regarding hypothesis 3, although both models are statistically significant, it is the first model that only contemplates the WFC-FWC variable that has the greatest explanatory power on well-being (12.5%), since the WF-FW guilt variable does not present a statistically significant contribution ($\beta = .059$, $p = .498$). Concerning hypothesis 4, no model proved to be statistically significant ($p > .05$) (Table 2).

Table 2 Hierarchical regression for the prediction of well-being and career satisfaction

Models	Well-being			Career satisfaction		
	r^2	t	*p*	r^2	t	*p*
1. WFC-FWC	.125	5.15	<.001	.001	1.074	.284
2. WFC-FWC + WF-FW guilt	.122	.680	<.001	−.001	−.808	.408

4 Discussion

This study sought to analyze the effects of the WFC-FWC on WF-FW guilt, and of these on well-being and career satisfaction, through a sample composed of 73 men and 107 women professionally active and mostly married or living in common law. In conflict, it is the WFC dimension that has a higher mean, which suggests that participants experience WFC more than FWC. Regarding guilt, the results show that the WF guilt dimension is the one with the highest mean values, which means that people feel guilty when they leave the family in the background. The first (H1) and second (H2) hypotheses, WFC influences WF guilt—FWC influences FW guilt, were confirmed. The WFC has a positive impact on WF guilt as well as the FW conflict with FW guilt, although the latter has a lower result compared to the former. In other words, guilt is intrinsically linked to conflict. As for conflict, studies on the management of the professional and family role mention several factors that prevent the balance of these spheres, among which, the feeling of guilt for the lack of time for domestic and family activities (Strobino and Teixeira 2014). Thus, these results are in line with previous studies (e.g., Gonçalves et al. 2018), which point to conflict as a predictor of guilt feelings. About the influence that conflict and guilt have on well-being (H3), it is possible to emphasize that the predictive value is higher when conflict is analyzed with well-being. In relation to well-being, experiences at work and in the family reciprocally influence each other, whether negatively (role pressure) or positive (sphere facilitation) (e.g., Medeiros et al. 2017), thus confirming the third hypothesis. The fourth hypothesis (H4), conflict and guilt influence career satisfaction, was not confirmed. Conflict and guilt have no influence on career satisfaction. This result thus points to the need for further studies that focus on the antecedents of career satisfaction. Future research can also expand this study by deepening the organizational side, i.e., analyzing the strategies that organizations adopt (or not) to facilitate the combination of family and professional life, as well as the importance they attribute to well-being and to satisfaction and career expectations of its human resources. Another area of interest is to deepen the existence of possible differences according to the sector of activity of the individuals (e.g., primary, secondary, tertiary) since they have different characteristics in terms, not only of schedules, but also of job demands. Also, the impact of teleworking on these variables should be investigated in future studies, as, although studies show that teleworking under normal circumstances can be beneficial for the balance between work and family spheres, mandatory teleworking during the COVID-19 pandemic brought with it additional challenges, with the potential to increase conflicts between both spheres

(Andrade and Lousã 2021). In terms of practical implications, this study allowed us to understand the contribution of each of the variables involved and their predictive power. The results obtained are in line with what is the state of the art on the subject, highlighting the negative consequences in terms of health and well-being, which are associated with conflicts within the family. Special attention must be given by organizations, regarding the combination of variables under study, through the establishment of objectives and expectations in workers, which promote the maintenance of their individual well-being.

5 Conclusion

With the new course of social life, caused by the transformation of women in society, the increase in single-parent families and double-employment couples, there is a substitution of the patriarchal model for the egalitarian model. These transformations require some reflection on the relationship between family and work. In this line of thought, the issue of reconciling work and family emerges as a context of several changes both in the world of work and in the family institution. Faced with this scenario, it is important that organizations and individuals seek to balance these two spheres (Medeiros et al. 2017). Developing better measures of work-life balance is important and from the perspective of several authors (Guerreiro and Pereira 2006; Silva et al. 2015) these policies are not only beneficial for employees, but organizations also benefit from their implementation, by reinforcing the motivation and commitment of employees, reducing absenteeism, increasing productivity, expanding potential more qualified employees, valuing the organization, and increasing well-being and satisfaction at work. The current demands of the labor market, and of society in general, are in a way hampering the achievement of a balance between professional and family spheres, as well as the achievement of what are career expectations and satisfaction with it. This imbalance entails, in the long term, a risk to the physical, emotional, and psychological well-being of workers, so it should be considered by organizations as a psychosocial risk that must be mitigated (Gonçalves et al. 2017).

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Face Mask Speech Impairment, Evidences from Preschool to High School

M. D. Redel-Macías, R. D. Rodríguez-Cantalejo, N. Costa, P. Arezes, and A. J. Cubero-Atienza

Abstract The face masks are one of the best tools to prevent the spread of the SARS-CoV-2 virus. Although these could stop being used in a future, there are plenty of application where their use is needed. For this reason, their study in terms of health effects and speech intelligibility and articulation index could be interesting. In this research, a survey was carried out to know the effect of wearing face mask in different education levels. Besides, a study of the speech intelligibility, articulation index and sound quality evaluations were carried out to research which type of the face mask should be used in education settings. The results suggest that there is a correlation between the health effects due to the use of the face mask and the gender or the type of contract. Additionally, there are significant differences in terms of speech intelligibility, articulation index and loudness depending on the type of face mask used, the distance between students and teachers and if the students have hearing-impaired. Thus, this paper can provide a guidance on how to choose the best face mask to improve speech understanding when communicating with other people, especially in education settings.

Keywords Speech intelligibility · Articulation index · Health problems · Education

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1 Introduction

Due to the COVID-19 pandemic, the problems entailed by the use of face masks have been suffered by the general public. The fact is that the face masks are a piece of Personal Protective Equipment (PPE) used in many sectors, such as Medicine, Industry, and Construction, among others, in which they have a negative impact on speech perception. For example, Goldin et al. (2020) established that a simple surgical mask, like those used in operating rooms, could attenuate the spoken language level between 3 and 4 dB at a high-frequency range (2000–7000 Hz). Thus, the study of speech intelligibility is a relevant and pressing topic, especially now due to the pandemic and the widespread use of face masks.

For these reasons, the aim of this paper was to study oral communication at a school where teachers and students wore different kinds of face masks. A survey was also conducted of teachers at different educational levels in Spain with the main aim at analysing the correlation between the users' health effects and the use of face mask, as well as with the type of face mask used.

2 Materials and Methods

2.1 *Type of Face Mask*

In the market, it is possible to find different types of face mask. These could be classified into the following classes, accepted them by standards (UNE 2020a, b; MUAE 149:2001 2010; Reglamento (UE) 2016):

1. Cloth masks, according to UNE 0065:2021 (UNE 2020).
2. Surgical masks, according to Regulation BS EU 14,683:2019 (Standard 2019).
3. FFP (Filtering Facepiece) disposable respirators are standardized by the European Union, being classified into FFP1, FFP2 and FFP3; hence, they fall under the scope of Regulation (EU) 2016/425 (2016).

Although there are more types of face masks or protective equipment, this study will be focused in these three first type of mask, as these are the most popularly used by people.

2.2 *Experimental Set-Up*

2.2.1 Speech Acquisition

To gauge speech intelligibility in the classroom, a binaural head GRAS 45BB-4 and torso KEMAR with prepolarized 1/2″ microphones were used. For the measurement

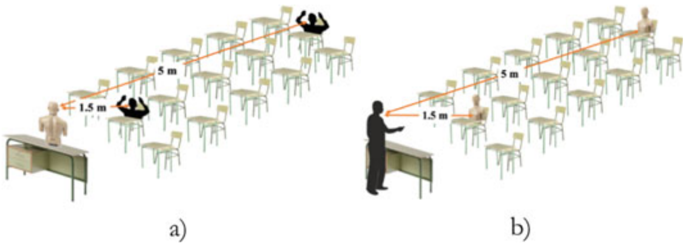

Fig. 1 Experiment set-up in the classroom: **a** binaural torso on teacher's desk and **b** binaural torso at student desks

of the background noise in the classroom, a microphone array of 96 MEMS microphones with recommended mapping frequencies between 514 and 24 kHz, from Gfai tech GmbH (Germany), was utilized.

2.2.2 Speech Stimuli

Several speech intelligibility tests were carried out in a classroom at a primary school with 25 7- year-olds. The test consists of the reading of the induced phonological register used to detect hearing impairment (Monfort and Juárez 1988) by a student at different places in the classroom (the nearest and farthest spots) using the face mask mentioned (cloth, surgical and FFP2). In this part of the test, the binaural torso was placed on the teacher's desk (Fig. 1a). The induced phonological register was then read by the teacher, and the binaural torso was placed at the nearest and farthest points in the classroom (Fig. 1b). All the participants had given their consent to participate. In cases of minors, their parents had to sign the corresponding consent forms. All the subjects also received instructions to speak in a natural, normal manner during the recording. The main aim of this part of the experiment was to measure speech intelligibility with different parameters (speech intelligibility and articulation index).

2.2.3 Survey and Statistical Analysis

A survey was carried out thought social medial networks (https://encuestas.webapps.uco.es/index.php/631871?lang=en). The survey was divided into four categories of questions. There were two questions about sociodemographic information, like age range, gender and city/country. After this there were questions about the type of contract (temporary, substitute and public worker), teaching activity level (Preschool, Primary School, Secondary/High school, Higher Education and Special Needs Education), and the type of classes (100% online, 50% of students attending class, and 100% in-person). The third group of questions were related to the face mask, including the type used (cloth or hygienic face mask without UNE EN certification; a cloth or hygienic face mask with UNE 0064–0065 filter, FFPX type, KN95, N95, UNE EN 14,683 surgical mask, or no mask), the number of hours wearing a face mask at work (<4, 4–8 and >8 h), and outside of work (<4, 4–8 and >8 h). The last group of questions was about the effect of the use of face masks on health (headache, sore throat, anxiety, skin problems, speaking louder, problems with oral communication, and fatigue or breathing problems) and the type of air circulation used during classes (opened windows, air circulation or both). All the qualitative variables, such as gender, were coded, for example, using 0 for 'Female', 1 for 'Male' and 2 for 'Others'. The other variables were all of kind scale variables. The responses "I don't know," "Id rather not say", and No Answer were coded as "0" in all variables. A total of 238 responses were received from Spain, United Kingdom and Portugal. The dataset was saved in Excel, Version 17; and SPSS Version 25. The dataset was analyzed using descriptive statistics and the relationships of the qualitative variables. Initially, data normalization was examined using the Kolmogorov–Smirnov test, showing that the sample was not normalized ($p < 0.001$). Additionally, the correlation test was carried out to determine associations between the differences (Pearson Correlation Coefficient).

3 Results

The analysis of the responses showed that most participants (56.3%) were female. 29.9% ranged in age from 41 to 50, 43.3% worked at a university, and 43.3% were public employees. Regarding the usual class types, around a 43.7% were 100% in-person and a 27.3% were with a 50% of the students attending to class. The percentage of women who answered the survey (56.3%) was higher than men (32.4%), and only one response was completed indicating another gender (0.4%). Many of the responses corresponded to tenured professors at an university (43.3%), and secondary school teachers (26.5%). Primary school teachers accounted for 11.3% of the responses; Preschool teachers, 4.2%; followed by Special Education teachers, at 3.4%.

Another important factor during this pandemic has been air ventilation in classrooms. Figure 2 shows the preference regarding ventilation at the different education levels. The main system to achieve air renovation was to open the windows, both in Secondary/High School and Higher Education (28% of the responses). Almost 10% answered that they used both systems (open windows and artificial air circulation) at the Primary, Secondary/High School, and Higher Education levels.

Regarding face masks used in classrooms, almost 60% of the survey respondents said that they used FFP-type face masks. The results also showed that teachers face mask used the FFP type (around 24%), see Fig. 3.

Table 1 shows the correlation between sociodemographic factors and health issues due to the use of face masks. Older people with public contracts ($p < 0.01$) wearing face masks more than four hours ($p < -0.05$) had skin problems. Also, a correlation was found between men ($p < 0.01$) with public contracts ($p < 0.05$) teaching 100% in-person ($p < -0.01$) and wearing a face mask for less than four hours ($p < -0.01$), as they suffered headaches ($p < 0.01$), sore throat ($p < 0.01$), anxiety ($p < 0.01$),

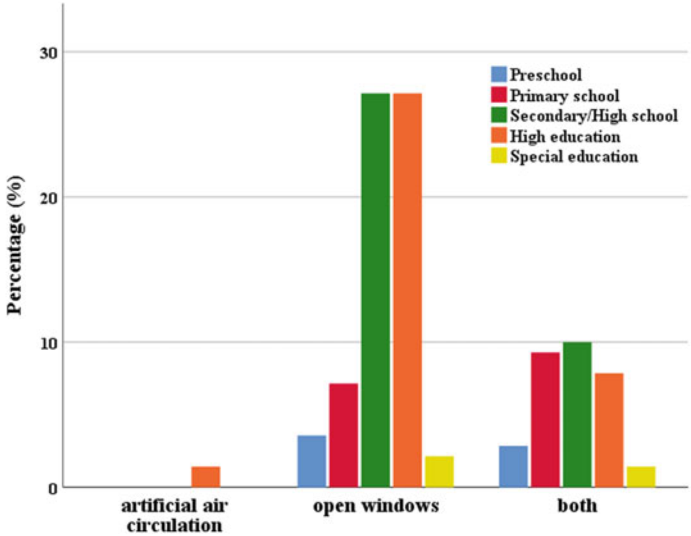

Fig. 2 System of air circulation during the classes

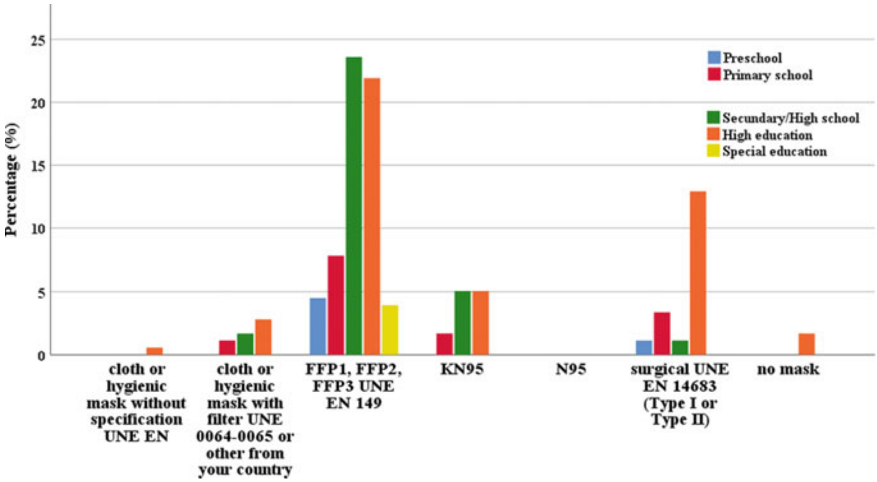

Fig. 3 Type of face mask used, by teaching activity level

skin problems ($p < 0.01$), fatigue ($p < 0.01$) impaired understanding of their oral communications ($p < 0.01$), and having to speaking louder in classes ($p < 0.01$). It is possible to see that teachers at the schools ($p < 0.01$) with 100% in-person classes ($p < -0.01$) and more than four hours of face mask usage ($p < -0.05$) all suffered the health complications mentioned above, except skin problems. In the case of substitute teachers, who usually wear a face mask for less than four hours (p

< 0.05), they only presented skin problems ($p < 0.05$). A relationship between class type and health effects was found. Obviously, in the case of 100% online classes there was no use of face masks ($p < -0.01$), or they were worn for fewer hours ($p < 0.01$), so adverse health effects were less frequent ($p < -0.01$). The type of face mask ($p < -0.05$) and the number of hours it was worn ($p < 0.01$) impacted the impaired understanding of teachers' oral communications ($p < -0.05$). Another important factor was the number of hours that face masks were worn: the greater the number of hours, the more skin problems teachers suffered ($p < -0.05$), and the more they had to speak louder ($p < -0.05$).

Health problems or issues was found to be present in 57.1% of the sample using face masks "Always", "Often" or "Sometimes", according to their responses. Moreover, these health issues seem to be linked to multiple variables, according to the chi-test and symmetric measurements (Table 1). The main health problems found were impaired understanding of their oral communications (almost 90% of the responses), followed by having to speak louder, at 50%; and fatigue or breathing problems, at around 51%.

Another key challenge when wearing face masks is the projection of sound in classrooms so that all students can understand the teachers' explanations. Thus, several measurements of speech intelligibility were carried out, following Fig. 4.

Table 2 shows the Pearson Correlation Coefficient based on type of children, whether they were hearing-impaired or not, the distance to the teacher's desk, and the type of face mask. It is possible to appreciate that there is a strong correlation between the distance and the total loudness perceived (p < 0.01). This means that the farther away the children are, the louder the teacher speaks. Also, a relationship was found between speech intelligibility and distance, indicating that, logically, reduced distances result in greater speech intelligibility ($p < 0.05$). Additionally, the Articulation Index and speech intelligibility were better in children without any hearing impairment ($p < 0.05$). In the case of face masks, this was found to be a key factor affecting the articulation index and speech intelligibility in classrooms. FFP2 and surgical masks were related to better articulation indexes ($p < 0.01$) and speech intelligibility ($p < 0.05$) compared to cloth masks worn by children.

Regarding the teachers and the degree to which they were understood, it is possible to see that there was no correlation with distance. This could be due to the fact that they had to speak louder and, in this regard, there was a correlation between total loudness level and distance ($p < 0.05$). A direct correlation between the type of face mask, the Articulation Index ($p < 0.05$) and speech intelligibility (p$p < 0.0.5$) was found. Thus, it seems that FFP2 masks resulted in the best Articulation Index, and speech intelligibility, with surgical and cloth masks yielding the worst results (see Table 3).

Table 1 Sociodemographic factors and health issues using face mask

	Age	Gender	Teaching activity level	Work contract	Type of classes	Type of face mask	Hours wearing face mask in class	Hours wearing face mask outside of class	Health effects headache	Sore throat	Anxiety	Skin problems	Speaking louder	Impaired understanding of oral communication	Fatigue or breathing problems
Age	1.000	0.094	0.000	0.540[a]	–0.078	–0.028	–0.192[b]	0.060	0.049	0.062	0.073	0.235[a]	−0.026	0.018	−0.105
Gender		1.000	0.262[a]	0.155[b]	–0.373[a]	0.014	–0.229[a]	–0.024	0.273[a]	0.362[a]	0.251[a]	0.464[a]	0.305[a]	0.317[a]	0.337[a]
Teaching activity level			1.000	0.064	–0.473[a]	0.087[a]	–0.182	0.061	0.317[a]	0.293[a]	0.340[a]	0.142	0.235[a]	0.168[a]	0.253[a]
Teaching activity level				1.000	–0.097	–0.026	–0.178[b]	0.104	−0.065	0.113	–0.011	0.148[b]	0.045	−0.005	−0.127
Type of classes					1.000	–0.279[a]	0.337[a]	–0.044	−0.251[a]	–0.283[a]	–0.218[a]	−0.147	−0.313[a]	−0.268[a]	−0.288[a]
Type of classes						1.000	–0.171[b]	–0.033	0.065	–0.031	–0.065	0.048	−0.013	−0.166[b]	0.031
Hours wearing face mask in class							1.000	0.128	−0.133	–0.043	–0.066	−0.186[b]	−0.154[b]	−0.109	−0.067

(continued)

Table 1 (continued)

	Age	Gender	Teaching activity level	Work contract	Type of classes	Type of face mask	Hours wearing face mask in class	Hours wearing face mask outside of class	Health effects headache	Sore throat	Anxiety	Skin problems	Speaking louder	Impaired understanding of oral communication	Fatigue or breathing problems
Hours wearing face mask outside of class								1.000	−0.100	−0.016	0.047	−0.044	0.015	−0.010	0.025

[a]The correlation is significant at the 0.01 level (bilateral)
[b]The correlation is significant at the 0.05 level (bilateral)

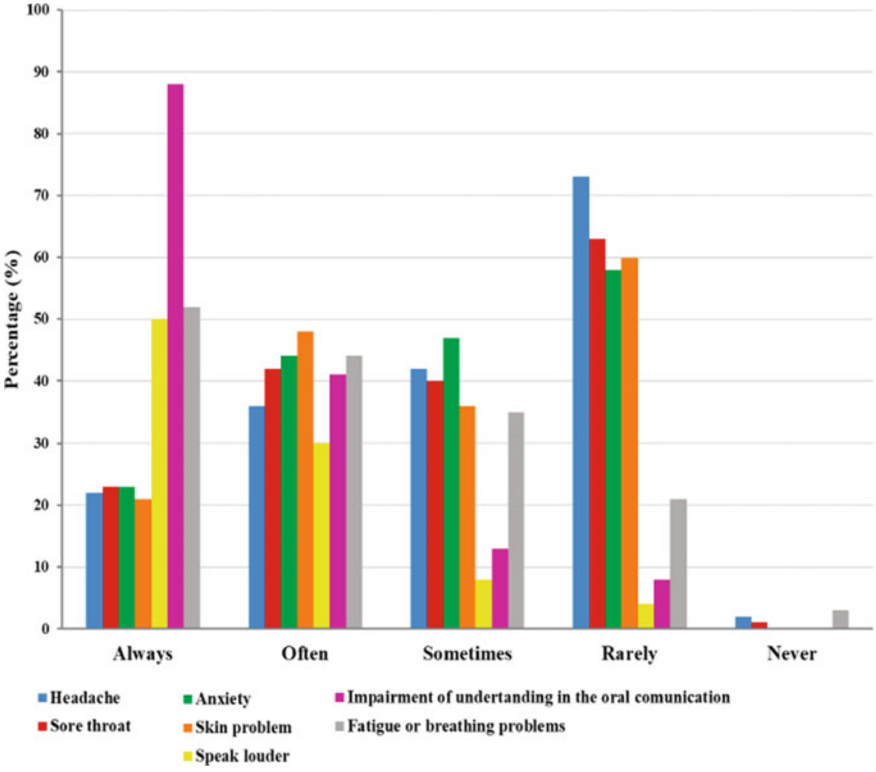

Fig. 4 Health problems due to the use of face masks

Table 2 Correlation between speech intelligibility and other factors in students (distance, type of children and type of face mask)

	Distance (m)	Type of children	Type of face mask	Total loudness level (sone)	Sharpness (Acum)	Articulation Index (%)	Speech intelligibility (dB)
Distance	1.000	0.000	0.000	0.820[a]	0.493	−0.353	0.648[b]
Type of children	0.000	1.000	0.000	−0.133	0.384	0.569	0.470[b]
Type of face mask	0.000	0.000	1.000	0.000	0.000	0.998[a]	0.968[b]

[a]The correlation is significant at the 0.01 level (bilateral)
[b]The correlation is significant at the 0.05 level (bilateral)

Table 3 Correlation between speech intelligibility and other factors in teachers (distance and type of face mask)

	Distance (m)	Type of face mask	Total loudness level (sone)	Sharpness (Acum)	Articulation Index (%)	Speech intelligibility (dB)
Distance	1.000	0.000	0.304[b]	−0.405	0.389	−0.118
Type of face mask	0.000	1.000	0.716	0.520	0.984[b]	0.995[b]

[a]The correlation is significant at the 0.01 level (bilateral)
[b]The correlation is significant at the 0.05 level (bilateral).

4 Conclusions

This study has analyzed the impact of the use of face masks in the health of the teachers during their classes through a survey. Moreover, the attenuation of the different face masks was evaluated in a classroom using a binaural torso.

Based on the results obtained, it seems that FFP2 masks were the face mask preferred by the teachers in their classes, followed by surgical masks type. Regarding to the related health effects, men had more health effects wearing face masks than women during their classes, showing headache, sore throat, anxiety, skin problems fatigue and impairment of understanding in the oral communication and speaking louder.

Regarding speech intelligibility, articulation index and sound quality parameters, it was found that the distance between students and teacher is an important factor in terms of loudness, articulation index and speech intelligibility, these being better when the distance is shortest. A strong correlation was found between the type of face mask and the results of articulation index and speech intelligibility. The students and teachers were better understanding when they wore FFP face masks. Also, this type of the face mask helped to understand better to children with hearing impairment.

To conclude, our analysis suggests that both surgical or FFP face masks could be the best options to be used in the different levels of education.

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Adaptation to Stress in Psychology Graduate Students

Clara Simães, Alexandra Costa, Catarina Morais, and A. Rui Gomes

Abstract This study analyzed stress adaptation in university students, considering the role of cognitive appraisal in the relationship between stress and burnout during the testing season. A total of 187 students from a university in the northern region of Portugal participated in the study. In the total sample, 154 were female (82.4%) and 32 males (17.1%), aged between 17 and 41 years old ($M = 20.72$; $SD = 3.28$). The evaluation protocol included a Sociodemographic Questionnaire, the Stress Questionnaire for Students, the Primary and Secondary Cognitive Appraisal Scale, and the Shirom-Melamed Burnout Measure. The results showed that 55.6% of the students perceived high-stress levels, mainly derived from academic evaluation and work overload. Cognitive appraisal mediated the relationship between the overall level of students' academic stress and the experience of burnout, mostly regarding physical fatigue and cognitive weariness. These findings reinforce the importance of considering the role of cognitive appraisal processes in understanding the dynamics of stress adaptation among university students. To promote healthy educational environments, we must attend to these effects regarding occupational safety and hygiene interventions within the academic context.

Keywords Cognitive appraisal · Burnout · University students · Academic stress

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1 Introduction

Stress arises when students perceive their personal and social resources as insufficient to deal effectively with new challenges imposed by the environment (Lazarus 1991). Stress is an integral and inevitable part of the academic journey (Labrague et al. 2017) since it is necessary to deal with new responsibilities potentially stressful during this period (Buchanan 2012). When stress occurs at a moderate level, it may be considered healthy and motivate goals achievement (Ramaprabou and Dash 2018). However, high-stress levels can lead to severe symptoms of anxiety, depression, or other psychological problems in students (Acharya et al. 2018; Leppink et al. 2016). These can result in adverse effects, such as low grades, failure (Frazier et al. 2018; Leppink et al. 2016), school dropout (Britt et al. 2017), alcohol and drugs abuse (Böke et al. 2019), violent behaviors (Alrawwad and Alrfooh 2014), and low self-esteem (Hudd et al. 2000).

Thus, it is essential to gather knowledge about these phenomena in students, going beyond understanding stress sources and consequences and comprehending how students evaluate, react, and adapt to these situations. This study aims to understand the stress adaptation process in Psychology graduate students during the academic year. Specifically, it analyzes the relationships between stress, cognitive appraisal, and burnout during one academic year, adopting the theoretical framework of the Interactive Model of Human Adaptation to Stress (Gomes 2014) and the cognitive-motivational-related model of stress and emotions proposed by Lazarus (1991, 1999). Both models reinforce the need to understand the stress adaptation process from an integrated and conceptual perspective, considering the adverse events, the cognitive appraisal processes (primary and secondary), and the individual responses (Gibbons 2010; Gomes 2014). The primary cognitive appraisal refers to evaluating the significance of a situation in terms of its importance, challenge, or threat perceptions, pointing out the personal relevance of the stressful event to someone's values, goals, beliefs, and intentions. The secondary cognitive appraisal involves the personal evaluation of the ability to cope with stressors, comprising the perceptions of coping and control over the stressful event (Gomes 2014).

There are several studies about stress among graduate students (e.g., Reddy et al. 2018; Weber et al. 2019); however, the majority do not consider simultaneously the transactional relationship between the adaptation to stress, cognitive appraisal, and stress consequences, which would be fundamental to test the transactional and interactive models of stress adaptation (Gomes 2014; Lazarus 1991). Moreover, there is a lack of evidence about how the adaptation to stress occurs over time, which is very important due to the dynamic nature of the stress adaptation process (Enns et al. 2018). This study intends to capture the entire dynamic process involved in the stress experience of students by using a longitudinal perspective and the conceptual framework of the transactional models of adaptation to stress. The adaptation to stress is an antecedent variable, the cognitive appraisal is the mediating variable, and burnout is the consequent variable. Burnout constitutes the consequent variable because of its high prevalence among students (Farrell et al. 2019; Gomes et al.

2022; Muzafar et al. 2015) and its consequences on their academic performance (Vizoso et al. 2019). This construct represents a psychological syndrome related to the experience of chronic job stress, which has not been successfully managed (Maslach and Leiter 2016; World Health Organization 2019). Burnout has extended from the professional to the educational environment (Eaves and Payne 2019; Jordan et al. 2020) and is characterized by physical fatigue, emotional exhaustion, and cognitive weariness (Shirom and Melamed 2006).

In sum, the present study aimed to capture the students' adaptation process during a school year that occurred before the pandemic lockdown. We used a critical incident methodology (Allen 2017; Flanagan 1954) related to the academic evaluation period and the repeated measures methodology (Singer and Willett 1996) in two phases. In order to study the negative effect of the chronic experience of stress on students' burnout, as proposed by the transactional models of adaptation to stress, we used specific measures in phases one and two of data collection. The first phase occurred during the academic evaluation period of the first semester of the school year (November 2019) and included the antecedent and mediation variables (i.e., stress and cognitive appraisal measures). In contrast, the second phase occurred after the academic evaluation period (February 2020) and involved the burnout measure—the outcome variable related to the experience of chronic academic stress. This data collection plan followed theoretical (Gomes 2014; Lazarus 1991, 1999) and empirical (Gibbons 2010; Gomes et al. 2022; Gomes and Teixeira 2016) guidelines of adaptation to stress, proposing that exposing to stress represents the first factor of the adaptation process (antecedent variable), followed by the cognitive evaluation of stressors (mediating variable) that, in turn, produce distinct effects on human functioning, represented in our case by the burnout experience (outcome variable). Burnout only occurs after people being repeatedly exposed to stress and this is why it was evaluated in the second phase of data collection. Thus, the following objectives were established:

1. analyze graduate students' psychological experience during a week of academic evaluation (critical incident);
2. test the mediating role of cognitive appraisal in the relationship between students' academic stress (i.e., overall level of stress) and burnout.

2 Materials and Methods

2.1 Design

We developed a quantitative and longitudinal study design with an exploratory and descriptive nature, which used the critical incident and the repeated measures methodology.

2.2 Participants

This study used a non-probabilistic sample for convenience, including 187 Psychology graduate students from Portugal North. The majority was female ($n = 154$, 82.4%), with a mean age of 20.72 years ($SD = 3.28$; min = 17, max = 41). Participants were preponderantly in the 4th year of the Psychology course ($n = 62$, 33.2%), followed by those in the 3rd year ($n = 50$, 26.7%), 1st year ($n = 39$, 20.9%), and, lastly, 2nd year ($n = 36$, 19.3%) of the course. The 5th-grade students were not included in the sample, as they had not taken exams anymore. Psychology was the first option of graduation course for 157 of the students (84%). Participants' average score on the course was 14.52 ($SD = 1.51$; min = 11, max = 19.4). Students reported an average of 12.28 h of studying per week ($SD = 10.50$; min = 0, max = 60 h).

2.3 Instruments

2.3.1 Sociodemographic Questionnaire

This instrument collected information on personal (e.g., sex, age) and academic (e.g., course year, number of study hours per week) characteristics.

2.3.2 Stress Questionnaire for Students (SQS)

This instrument was used to evaluate the students' perception about the sources of stress faced in their academic activities (Gomes et al. 2022). The questionnaire comprised two distinct parts. In the first part, students were asked to evaluate the level of stress that they usually feel in their academic life through a single item (0 = No stress; 2 = Moderate stress; 4 = High stress). In the second part, 28 items were presented regarding the potential sources of stress associated with academic activities, being the stress intensity evaluated on a 5-point Likert scale (0 = No stress at all; 2 = Some stress; 4 = Very high stress). Stress was measured through seven dimensions: (a) academic performance: stress resulting from the possibility of a school performance below that expected by the student (4 items; $\alpha = 0.89$ for this study); (b) academic evaluation: stress resulting from the evaluation moments of the teaching–learning process (4 items; $\alpha = 0.78$ for this study); (c) motivation: stress resulting from a low motivation to perform study activities (4 items; $\alpha = 0.83$ for this study); (d) learning: stress resulting from the student's possible difficulty in following the teaching–learning process (4 items; $\alpha = 0.89$ for this study); (e) work overload: stress resulting from excessive activities and school tasks (4 items; $\alpha = 0.92$ for this study); (f) future expectations: stress resulting from the student's lack of confidence about the usefulness and interest of studies for their future (4 items; $\alpha = 0.84$ for this study); and (g) financial problems: stress resulting from the impossibility of continuing the studies due to financial difficulties (4 items; α = 0.89 for this study). Confirmatory Factor Analysis confirmed good psychometric properties for the five-factor structure of the instrument (χ^2 (79 *df*) = 116.048, p = 0.004; χ^2/df = 1.469; RMSEA = 0.050, 90% C.I. [0.029; 0.069]; SRMR = 0.0717; IFI = 0.967; CFI = 0.967), and for a second order factor structure, (χ^2 (11 *df*) = 15.362, p = 0.167; χ^2/df = 1.397; RMSEA = 0.046, 90% C.I. [< 0.001; 0.096]; SRMR = 0.0258; IFI = 0.995; CFI = 0.994), which was used to test the hypotheses.

2.3.3 Primary and Secondary Cognitive Appraisal Scale (PSCAS)

This instrument, validated by Gomes and Teixeira (2016), was used to assess students' primary and secondary cognitive appraisal processes regarding their academic activities. The scale measures students' primary cognitive appraisal through the following dimensions: (a) importance perception: which indicates the extent to which the student evaluated the academic activity as significant and important for their personal wellbeing (3 items; α = 0.81 for this study); (b) threat perception: which indicates the extent to which the student evaluated the academic activity as disturbing and negative for their personal wellbeing (3 items; α = 0.85 for this study); and (c) challenge perception: which indicates the extent to which the student evaluated the academic activity as stimulating and exciting for their personal wellbeing (3 items; α = 0.68 for this study).

The scale measures students' secondary cognitive appraisal through the following dimensions: (d) coping perception: which indicates the extent the student felt to have personal resources to cope with the demands of the academic activity (3 items; α = 0.85 for this study); and, (e) control perception: which indicates the extent to which the student felt to have control over the processes of decision making of the academic activity (3 items; α = 0.73 for this study). The instrument presented 15 items, each measured on a 7-point Likert scale (0 = *Is not at all important to me*; 6 = *Is very important to me,* for academic activities importance). Thus, high scores on each subscale indicated higher perceptions of the corresponding dimension. Confirmatory Factor Analysis confirmed the five-factor structure of the instrument for this study (χ^2 (79 *df*) = 116.048, p = 0.004; χ^2/df = 1.469; RMSEA = 0.050, 90% C.I. [0.029; 0.069]; SRMR = 0.0717; IFI = 0.967; CFI = 0.967).

2.3.4 Shirom-Melamed Burnout Measure (SMBM)

This instrument evaluated the burnout levels regarding academic activities (Shirom and Melamed 2006). In the current study, we used the Portuguese version (Gomes et al. 2022), which consisted of 14 items divided into three dimensions: (a) physical fatigue: feelings of physical tiredness regarding academic activities, resulting in physical energy decrease (6 items; α = 0.95 for this study); (b): cognitive weariness: cognitive wear regarding academic activities, resulting in the decrease of the ability to think and concentrate (5 items; α = 0.96 for this study); and (c) emotional exhaustion: feelings of emotional exhaustion in the relationships to others, resulting in the decrease of the cordiality and sensitivity to other people's needs (3 items; $\alpha = 0.89$ for this study). The instrument measured the items on a 7-point Likert scale (1 = *Never*; 7 = *Always*). Higher scores indicated higher levels of physical fatigue, cognitive weariness, and emotional exhaustion, thus, pointing to higher levels of burnout. Confirmatory Factor Analysis confirmed the three-factor structure of the instrument for this study (χ^2 (72 *df*) = 157.118, $p < 0.001$; $\chi^2/df = 2.182$; RMSEA = 0.080, 90% C.I. [0.063; 0.097]; SRMR = 0.0442; IFI = 0.969; CFI = 0.969).

2.3.5 Procedures

The Ethical Committee of one of the authors' institutions of the paper approved the study (CEICSH 034/2019), which was authorized by the directors of a Psychology course from a university in the North of Portugal. We performed data collection in two phases: moment 1 (Mt 1) of data collection occurred four to six weeks after the beginning of the academic semester for university students and before the academic exams period (critical incident methodology), where we collected the measures of stress and cognitive appraisal; and moment 2 (Mt 2) of data collection occurred after the period of exams, approximately at the middle of the semester, where we collected the measure of burnout. All participants filled out the informed consent term before answering the questions through an electronic platform (Qualtrics). To pair the data between the two phases of collection and guarantee their use in future studies, students were asked for an identification code so that the researchers could not interpret their identity. In total, 320 students attended the course. Two hundred sixteen responses were received, representing a response rate of 67.5%.

2.3.6 Data Analysis Procedure

Data analysis was performed through quantitative research methodologies using the Statistical Package for Social Science (SPSS, v. 28, Inc. Chicago, IL). Initially, 23 participants were excluded from the total sample of 216 students since they did not participate in both phases of the data collection. Then, we also excluded six participants as they attributed reduced or no importance to their academic activity (subscale of "importance perception" ≤ 2 in the PSCAS) (Gomes and Teixeira 2016). We used descriptive statistics proceedings to analyze graduate students' psychological experiences during a week of academic evaluation. Then, we performed structural equation modeling analyses through AMOS 28.0 software to test the mediating role of cognitive appraisal in the relationship between academic stress and burnout dimensions. For each of the three models tested (i.e., direct, total, and partial), we performed adjustment analyses using the literature's mentioned indicators (Marôco 2014). Therefore, the indicators used were the following: the chi-square test (χ^2); the Root Mean Square Error of Approximation (RMSEA, Steiger 1990); the Standardized Root Mean Square Residual (SRMR) (Hair et al. 2009); the Comparative

Fit Index (CFI, Bentler 1990) and the Normed Fit Index (NFI, Bentler and Bonett 1980). To better understand the mediation process and the causal relationships in the model with the best-fit indices, we also analyzed the model's standardized direct, indirect, and total effects.

3 Results

3.1 Descriptive Statistics of the Study Variables

Table 1 shows the descriptive statistics of all variables under study (e.g., the sources of stress, the dimensions of the Primary and Secondary Cognitive Appraisal Scale, and the burnout levels).

Table 1 Descriptive statistics of the study variables ($N = 187$)

SQS: stress questionnaire for students	**n (%)**	**Min–Max**
No stress	4 (2.1)	–
Low stress	12 (6.4)	–
Moderate stress	67 (35.8)	–
Considerable stress	77 (41.2)	–
High stress	27 (14.4)	–
SQS: stress factors	**M (SD)**	**Min–Max**
Academic performance	2.90 (0.81)	0–4
Academic evaluation	3.05 (0.81)	0–4
Motivation	2.49 (0.85)	0–4
Learning	2.85 (0.89)	0–4
Work overload	3.02 (0.88)	0–4
Future expectations	2.46 (1.02)	0–4
Financial problems	1.95 (1.13)	0–4
PSCAS: cognitive appraisal	**M (SD)**	**Min–Max**
Importance perception	5.07 (0.94)	3–6
Threat perception	3.84 (1.28)	0–6
Challenge perception	3.64 (1.07)	0–6
Coping perception	3.30 (1.00)	0–6
Control perception	4.30 (0.96)	0–6
SMBM: levels of burnout	**M (SD)**	**Min–Max**
Physical fatigue	4.68 (1.37)	1–7
Cognitive weariness	4.16 (1.46)	1–7
Emotional exhaustion	2.40 (1.38)	1–7

Concerning the general stress levels in students, 55.6% reported feeling considerable to high stress in their academic activity, 35.8% reported moderate stress, and 8.5% reported feeling low to no stress. Regarding the seven stress factors of the SQS instrument, the academic evaluation and work overload dimensions were rated by students as the most stress-inducing, while the dimension of the financial problems appeared as the least stress-inducing. About the PSCAS instrument, the highest scores concerned the dimensions of importance perception, control perception, and threat perception. Concerning the SMBM dimensions, students expressed more physical fatigue and cognitive weariness, and less emotional exhaustion. Specifically, 128 students (68.4%) revealed physical fatigue problems, 66 (35.3%) cognitive weariness, and 12 (6.4%) emotional exhaustion. Considering the three dimensions of burnout, 31 students (16.6%) were in this burnout situation.

3.2 The Mediation Effect of Cognitive Appraisal in the Relationship of Stress and Burnout

This phase tested the mediating role of cognitive appraisal between students' overall level of stress and burnout. This analysis considered three possibilities: the direct model, the total mediation model, and the partial mediation model.

3.2.1 Students' Overall Level of Stress and Burnout

To test the relationship between the overall levels of stress, cognitive appraisal, and burnout, we performed three models: (a) the direct model, which established relationships between the overall level of stress and cognitive appraisal to burnout; (b) the total mediation model, which established relationships between the overall level of stress, through cognitive appraisal to burnout; removing the direct pathways from stress to burnout; and (c) the partial mediation model, which established relationships from the overall level of stress, through cognitive appraisal to burnout and from the overall level of stress directly to burnout. The results indicated that the partial mediation model obtained the best adjustment rates ($\chi^2(62) = 89.652$, $p = 0.012$, $\chi^2/df = 1.446$, RMSEA = 0.049 (90% C.I. [0.024; 0.070], p (RMSEA ≤ 0.05) = 0.509); SRMR = 0.046; CFI = 0.978; IFI = 0.978; GFI = 0.935 (see Table 2).

The differences between the chi-squared values of the direct effect model and the partial mediation model were statistically significant ($\Delta\chi_2$ (1) = 159.700; $p <$ 0.001), the differences between the direct effect model and the total mediation model were substantial ($\Delta\chi_2$ (2) = 133.283; $p < 0.001$), and finally, the differences between the partial mediation model and the full mediation model were also significant ($\Delta\chi_2$ (3) = 26.417; $p < 0.001$). These results indicated a better adjustment of the partial mediation model (Fig. 1).

Table 2 Mediation effect: structural model fit indices ($N = 187$)

Structural models	χ^2	df	χ^2/df	p	RMSEA	p-value (RMSEA $\leq$ 0.05)	RMSEA [LO90- HI90]	SRMR	CFI	IFI
Direct	249.352	63	3.958	<0.001	0.126	<0.001	[0.110; 0.143]	0.166	0.849	0.852
Total mediation	116.069	65	1.786	<0.001	0.065	0.099	[0.045; 0.084]	0.117	0.959	0.959
Partial mediation	89.652	62	1.446	0.012	0.049	0.509	[0.024; 0.070]	0.046	0.978	0.978

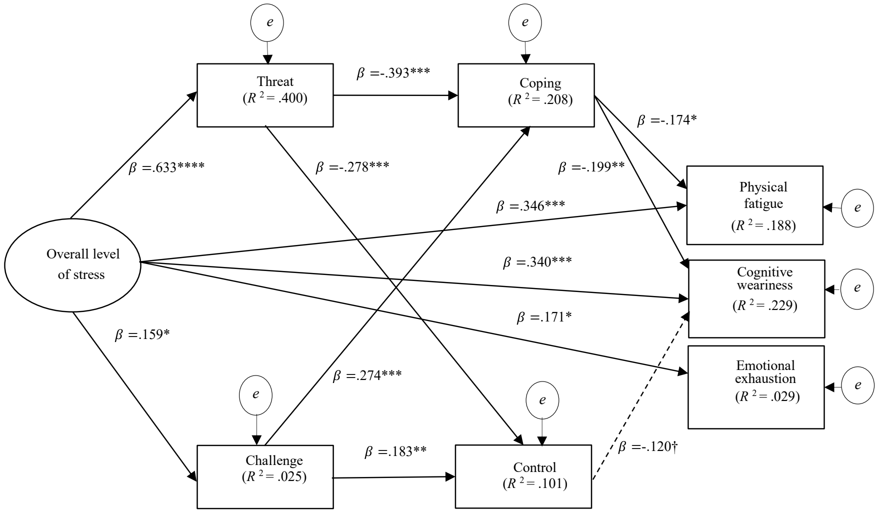

Fig. 1 Path analysis results for the partial mediation model ($N = 187$). Rectangles represent observed variables, the oval is the latent variable, arrows the significant direct paths, the dashed arrow refers to marginally significant direct paths ($p = 0.09$), and *e* represents the measurement error. *Note.* * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, †$p < 0.1$

As shown in Fig. 1, the model allowed to explain 23% of the variance associated with cognitive weariness and 19% of the variance related to physical fatigue. Additionally, the model explained 40% of the variance related to threat perception, 2.5% of challenge perception, 21% associated with coping perception, and 10% related to control perception.

3.2.2 Partial Mediation Model: Direct, Indirect, and Total Effects

Based on the best fit of the partial mediation model, it is now essential to analyze the direct, indirect, and total effects of the variables under study. Regarding significant direct effects, we found that higher levels of students' overall experience of academic stress increased the perception of challenge, but mainly students' perception of threat. Additionally, an increase in threat perception predicts a decrease in control and coping perceptions, but an increase in challenge perception indicates greater control and coping perceptions. Finally, a reduction in coping perception led to higher physical and cognitive fatigue. Students' overall experience of academic stress significantly increased all burnout dimensions (see Fig. 1).

As for the significant indirect effects, there was a relationship between students' overall experience of stress and physical fatigue and cognitive weariness, mediated by cognitive appraisal processes. Specifically, higher levels of academic stress were related to higher threat perception, which led to lower coping perception, ultimately decreasing physical fatigue and cognitive weariness. So, the negative impact

Table 3 Standardize Indirect and Total effects for the partial mediation model ($N = 187$)

	Secondary cognitive appraisal		Burnout dimensions		
	Control perception	Coping potential	Physical fatigue	Cognitive weariness	Emotional exhaustion
	Standardize indirect effect				
Overall level of stress	−0.147* (−0.229, −0,046)	−0.205** (−0.307, −0.114)	0.042** (0.014, 0.088)	0.058** (0.023, 0.104)	−0.002 ^{ns} (−0.023, 0.023)
Primary cognitive appraisal					
Threat perception	–	–	0.081** (0.032, 0.156)	0.111** (0.051, 0.183)	−0.004 ^{ns} (−0.051, 0.044)
Challenge perception	–	–	−0.056* (−0.109, −0.017)	−0.077** (−0.131, −0.037)	0.003 ^{ns} (−0.033, −0.038)
	Standardize total effect				
Overall level of stress	–	–	0.388* (0.224, 0.477)	0.398* (0.24, 0.491)	0.169* (0.044, 0.281)

Note *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. *ns* = p value statistically non-significant

of students' academic stress exacerbates the perception of threat; this threat decreases the coping perception, but in the end, coping may even reduce the physical fatigue and cognitive weariness of the students. Additionally, there was a significant indirect effect of challenge perception on burnout dimensions. Higher perceived challenges lead to higher coping perception, decreasing students' physical fatigue and cognitive weariness. Table 3 shows the indirect and total effects.

4 Discussion

The study of stress in the academic context has received increasing attention since it represents a problem that affects students' mental and physical health (Leppink et al. 2016). In this study, we chose to understand the phenomenon of human adaptation to stress in higher education students in the psychology course in the light of the transactional and interactive approach.

Regarding the first objective of this study, to analyze graduate students' psychological experience during a week of academic evaluation (critical incident), 55.6% of the students reported feeling high stress in their activity. These data are consistent with the literature, with several studies indicating that university students find their academic experience stressful (Wahed and Hassan 2017). That experience of stress seems to relate more intensely to the academic evaluations students undertake throughout their educational journey and the excess of activities and tasks to do. The literature also reports similar results (Pitt et al. 2017; Shdaifat et al. 2018).

Regarding the second objective of this study, it was tested the mediating role of cognitive appraisal in the relationship between students' academic stress and burnout. The results indicated that we could understand this relationship better by assigning a partial mediating effect to cognitive appraisal. Expressly, the partial mediation model assumes relationships between stress and burnout, which is in line with the literature (see Karaman et al. 2019), but mainly reinforces the mediating role of cognitive appraisal in this relationship, which confirms the theoretical models in this domain (see Gomes 2014; Lazarus 1999). In addition to considering the mediation pathways via cognitive appraisal, we should not disregard the direct paths between stress and burnout, which present significant relationships. Thus, the analysis of the mediation effect reinforces two essential points. First, the relations of stress to primary cognitive appraisal follow distinct paths. That is, the overall level of stress resulting from all sources of academic stress experienced by students exacerbated the perception of threat, which, in turn, negatively conditioned the secondary cognitive appraisal (decreasing control and coping perceptions); but, in the end, the perception of coping decreased the physical fatigue and the cognitive weariness of burnout.

The second point to retain from the partial mediation model is even more complex. From the start, results showed that the overall level of stress related to the potential sources of stress associated with students' academic activity could stimulate positive patterns of adaptation to stress. Specifically, higher levels of academic stress produced a greater perception of challenge in students, which, in turn, was related to a higher ability to manage stress at the secondary level (more coping and control perceptions) which, in the end, resulted in a decrease of physical fatigue and cognitive weariness (mainly via coping potential). Thus, we confirm the expected result in the process of adaptation to stress; that is, a higher perception of the challenge is associated with an improved ability to cope with stress and, consequently, lower the burnout experience, as proposed in the theoretical models that are the basis of this study (Gomes 2014; Lazarus 1999). Consequently, stress can be evaluated as positive and stimulating for the individual, as suggested in other studies (Ramaprabou and Dash 2018).

This study has an innovative character due to the inclusion of cognitive appraisal processes as a mediating variable between stress and burnout in university students. The results confirm and strengthen the transactional perspective (Lazarus 1991, 1999) and highlight the importance of cognitive appraisal processes in adapting to stress in the academic context.

Despite its innovative character, we must recognize some limitations of the study. As we focused on psychology university students, future research must diversify the target population, including students from different university courses, academic degrees, and those with particular academic statuses (e.g., worker students; student-athletes). Additionally, considering the pandemic lockdown, the effect of students' isolation regarding COVID19 infection, and the blended learning methodologies implemented as a remediation strategy constitute variables we must attend to in future research designs. Allied to that, expanding the data collection moments between the two academic semesters of the school year with the same protocol of measures, including a baseline measure of burnout, constitutes an option to implement.

5 Conclusion

We must highlight the main assumptions from this study. First, a significant percentage of psychology university students reported high stress in their academic activity due to the evaluations they face throughout their educational journey and the high number of academic tasks. Second, the relationship between the overall level of academic stress and students' experience of burnout is better understood through the partial mediation effect of cognitive appraisal. Aside from the direct effect of academic stress on burnout, the overall stress level could strongly exacerbate the students' perception of threat, decreasing control and coping perceptions, or, in a weaker relationship, produce a greater perception of challenge, increasing control and coping perceptions. Third, greater control and coping perceptions were related to a higher ability to manage stress, decreasing students' physical fatigue and the cognitive weariness of burnout.

Occupational safety and hygiene interventions guidelines must focus on the reduction of chronic stress by implementing life skills training programs (Gomes et al. 2019) that can help students to cope with academic sources of stress and to evaluate their education as more challenging, reducing physical fatigue and cognitive weariness of burnout (Gomes et al. 2022). And thus, increasing students' mental health promotes safety and healthy occupational environments. Intervention must consider the organizational level to develop favorable policies that promote occupational health and safety in the academic context. Specifically, academic leaders (course directors, professors) should coordinate efforts to propose realistic working plans to students that balance the amount of work required by each curricular unit along the semester and course, avoiding feelings of work overload in students and lack of time for rest and leisure activities. In sum, intervention strategies directed towards students and towards the design of curricular programs may increase students' ability to learn and progress along their formative process and prevent undesirable consequences of occupational stress.

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Assessment of Psychosocial Risks at Work in Staff of Clothing Stores

H. V. Neto

Abstract Psychosocial working conditions assume more and more importance in terms of occupational safety and health, which is why it is important to perform risk assessments that address the psychosocial factors at work. This text summarises and discusses the results of a psychosocial risk assessment conducted among Staff workers from a clothing trading company operating in Portugal. A consistent strategy of analysis and assessment of the psychosocial risks was put in place, which involved different data collection procedures (reports on safety activities, technical meetings, interviews, questionnaire to workers, etc.) and the application of the SSARA Method—Simplified Risk Assessment System adapted to psychosocial risks. The methodological procedure used made it possible to obtain a map of psychosocial risks for the Staff activity in each of the company's ten stores. The results show that the activity evaluated presents in general an acceptable incidence of psychosocial risks at work, since most of the risk factors evaluated fall under this category (63.5%) and there is no very high incidence of any risk factors. A positive psychosocial work environment in the stores evaluated was confirmed, which results from the good occupational safety and health policies and practices put in place by the company.

Keywords Occupational safety and health · Psychosocial working conditions · SSARA method · Portugal

1 Introduction

Companies are increasingly aware of the legal (and moral) obligation to assess the presence of psychosocial risk factors in their work environment. The general legal regime for the promotion of safety and health at work in Portugal (Law 102/2009, as amended by Law 3/2014) establishes that employers must ensure, on a continuous and permanent basis, the exercise of their activities in safe and healthy conditions

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for the workers, safeguarding, in particular, the identification and assessment of foreseeable risks in all the company's activities and the guarantee that exposure to psychosocial risk factors in the workplace does not constitute a risk to the safety and health of the worker (Article 15, point 2f).

Of all existing types of risks, psychosocial risks at work are perhaps those that can be best predicted in work environments, as they are intrinsic risks to persons (Neto 2015). Risk factors are only evident if there are workers in a certain work context, since these risk factors result from the characteristics of the people involved, from the interpersonal relations at work, from the work organisation models, from the demands of the work content, labour relations, among other aspects (Neto 2015; EU-OSHA 2007; Vivian and Neto 2021). Therefore, if people work in a certain context, this risk is likely to exist. But to be sure whether or not they are present, it is necessary to carry out an assessment.

The assessment of occupational risks can be defined as a dynamic process aimed at estimating the magnitude of the risk to the health and safety of workers in their workplace, arising from the circumstances in which the hazard may occur, in order to obtain the necessary information and adopt preventive measures that minimise the occurrence of accidents or occupational diseases (Soares and Neto 2019; European Commission 1996). As mentioned above, this assessment is a legal requirement, and must cover the psychosocial risk factors involved (Neto 2015; Schuller 2020). Precisely because of this requirement, a clothing trade company sought to develop a structured project that would allow them to obtain a comprehensive map of psychosocial risks at work, covering their different types of activities and commercial establishments in Portugal. Up to that point, the company still did not have a properly supported assessment of psychosocial risks aspect of work, which would allow it to integrate these factors into the company's global risk map.

The project involved the different functional aspects of the company but in this text, due to the multiplicity and volume of data collected, only some results of the Staff activity assessment will be summarised and discussed. This assessment covered 1102 workers with staff functions in the company's ten stores. It should be noted that a worker with staff functions in this company mainly performs tasks related to customer service (sales and after-sales), cashier service, supporting the unloading of orders in the warehouse, transporting products with a pallets-truck in the warehouse, ordering the stock and replenishing it at the store front, and reporting activities to supervisors/managers.

The study assumes special importance for several reasons. First, due to the scarce literature on the characterisation of safety and health conditions at work involving staff activities in commercial clothing stores, particularly with regard to the characteristics and quality of the psychosocial work environment. Secondly due to the great difficulty, lack of sensitivity/awareness and poor implementation of the legal obligation to implement psychosocial risk assessment in European organisations (EU-OSHA 2015, 2019; Beck and Lenhardt 2019; Neto 2015), especially in micro and small companies. Therefore, this study sends a positive signal and is an example of feasibility and potential of this type of exercise.

Psychosocial risks at work represent the probability of negative effects on the mental, physical and social health of workers, created by employment conditions, organisational, relational and personal/family factors that can interact with the mental function and psychosocial well-being of workers (Neto 2015, 2016; Gollac and Bodier 2011). In practical terms, describes the likelihood of personal and/or organisational damages occurring depending on the conditions of use, exposure or interaction with psychosocial risk factors arising from the work (the content itself, the way in which it is organised and controlled, the context in which it is developed, interpersonal relationships, etc.) and from the workers personal, family and social particularities (Neto 2015, 2016; EU-OSHA 2007; Vivian and Neto 2021).

Psychosocial risks at work turn out to be a dimensional designation that aggregates the different types of work-related psychosocial risks that may exist. In practice, there are different types, some of which have assumed greater importance and statistical incidence in the recent years (Neto 2015; Vivian and Neto 2021; EU-OSHA 2015, 2019). The main psychosocial risks at work today are professional stress (its negative aspect), burnout, violence at work (in its three dimensions: physical aggression, moral harassment and sexual harassment), job insecurity, labor discrimination and the interference of work with personal and family life (and vice versa) (Neto 2015; Vivian and Neto 2021).

Data from the ESENER—European Survey of Companies on New and Emerging Risks (EU-OSHA 2015, 2019) support the idea that the need to promote awareness and visibility of psychosocial risks remains current (Mazzer and Neto 2021), as their risk factors continue to be perceived as being more difficult to manage than other occupational risks (EU-OSHA 2015, 2019), or, in other cases, that they are not present in work contexts (EU-OSHA 2019; Mazzer and Neto 2021). In addition, as they are the second most reported work-related occupational health risk in the European Union (EU-OSHA 2019; Mazzer and Neto 2021), it is important to continue to demonstrate the need and importance of their assessment. As already mentioned, these professional risks predictably tend to be more present in work environments, since they are inherent to persons, and without workers, there will hardly be work organisations. Therefore, it is important to continue the effort to demonstrate that it is possible to assess these risks in an objective and sustained manner, as is the case with other professional risks. This study demonstrates precisely this situation.

2 Materials and Methods

Risk assessment involves characterising activities and execution contexts, identifying risk factors associated with the activities, estimating exposures, determining levels of risk and intervention, and defining an action plan to control risks. In other words, there must be a consistent strategy of analysis, assessment and intervention on the risks under study. It was precisely what was sought to be advocated in the project developed in this clothing trading company.

The approach proposed by Neto (2015, 2016), Soares and Neto (2019) was followed in this study, considering two phases in the process, the planning phase and an operationalization phase of the assessment procedure. The planning phase began with the definition of the particularities and objectives of this project, with a view to defining an action plan. Holding a preparatory meeting made it possible to secure the purposes and schedule of the project, the definition of the work team and respective division of tasks, the characterisation of the activities and workers covered. The meeting also had a methodological dimension to clarify doubts about the analysis of previous data, to approve the instruments and procedures to be used and to define the data collection approach. After everything was agreed, the company was able to validate the methodology and start internal communication and information processes to prepare services and workers for the subsequent stages (operational phase).

In order to implement the risk analysis operational procedures, activities were characterised from a functional and psychosocial point of view, so that the requirements of the functions and the existing conditions could be understood, in order to identify the existing risk factors and the workers exposed to such risks. As noted previously, this text will only focus on data referring to Staff activity in the stores.

For this characterisation, a dual approach was advocated, as supported by Neto (2015, 216), and based on the collection of data related to: (i) the physical, mental and ergonomic demands of the activities, based on a previous characterization of conditions supported by the company's safety technicians; and (ii) the workers' perception of their exposure to psychosocial risk situations and the characteristics of the psychosocial environment in which they work. Briefly, this dual risk analysis approach was essentially based on the following data collection procedures:

(i) completion of a form to characterise the preconditions of the activities in the company; (ii) analysis of documents related to existing working conditions and the practices carried out by the company's occupational safety and health services (e.g., risk assessment maps; report of previous psychosocial studies; COVID-19 Contingency Plan); (iii) interviewing a sample of managers and supervisors to understand their opinion on the specific requirements of the tasks performed and the existing working conditions; (iv) application of a questionnaire to identify psychosocial risk factors for workers in each store. The Psychosocial Risk Factors Identification Questionnaire, developed by Neto (2016), Soares and Neto (2019), was used and applied electronically using the Google Forms platform.

The procedures described were implemented during the year of 2021, between January and September, and were useful for characterising the work context in the stores, for specifying the psychosocial risks to be considered in the assessment, as well as for determining the degree of workers' exposure to the different inherent risk factors. The psychosocial risk assessment was carried out by professional activity and by store. In all, 72 psychosocial risk factors were evaluated, which were associated with different types of psychosocial risk at work, such as: Professional stress; Professional exhaustion; Work-family conflict; Absence/limitation of autonomy and participation at work, Violence at work, Lack of recognition and professional development, and Work precariousness.

In order to conduct the risk assessment procedure, a method already established in the company was used, even as a way of guaranteeing that the results obtained could be integrated into the company's general risk map. The company uses the Simplified Risk Assessment Method, which is based on the SSARA Method—Simplified Accident Risk Assessment System created and developed by the National Institute for Occupational Safety and Hygiene of Spain. However, some classification elements were adapted to the nature of the risks in question, as proposed by Neto (2016) in the use of SSARA Method adapted to psychosocial risks of work. Although these types of methods require maintaining the application principles, they must always be adapted to the type of risk (Soares and Neto 2019), because, for example, the exposure or severity criteria are not the same for all professional risks.

The method is based on the principle that the Risk level (NR) results from the combination of the Probability level (NP) and the Consequence level (NC), that is, $NR = NP \times NC$. In turn, the NP is determined as a function of the Deficiency Level (ND) obtained by the characterisation of the existing prevention measures and the Level of Exposure (NE) to risk, being expressed as the product of both parameters ($NP = ND \times NE$).

The various sources of information mobilised for the risk analysis, as already mentioned, were fundamental in order to apply the criteria and parameters associated with the applied assessment method. For example, data collected from documents and meetings (e.g. assessment of existing risks, characterisation of preconditions, measures to mitigate psychosocial risks already in place) helped to define the levels of deficiency of the internal occupational safety and health system. On the other hand, the data from the questionnaires applied to the workers contributed to determine the level of exposure to various risk factors. The combination of elements and application of the evaluation method parameters provided the risk levels and the definition of intervention priorities, in line with the criteria shown in Table 1.

Table 1 Intervention levels and timeline

Intervention level	NR	Recommended deadline	Meaning
I	1200 - 4000	Urgent – up to 1 month.	Critical situation. Urgent fix.
II	600 - 1200	Between 1 and 3 months.	Worrying situation. Short term correction.
III	200 - 500	Between 4 and 6 months.	Correct and adapt control measures.
IV	100 - 200	Between 7 and 9 months.	Improve if possible. Convenient justify gain.
V	0 - 80	No intervention required.	No specific intervention required, periodically monitor the situation.

Source Neto (2016)

3 Results

The implementation of the risk assessment procedure made it possible to obtain a psychosocial risks map for workers with Staff functions in each store. Although the nature of the activity is similar in the different establishments, the local contexts of execution are different, because the spaces and persons present are different (workers, customers, family members, etc.). For that reason, the assessment had to be segmented by store, thereby resulting in ten risk maps. However, given the volume of data, it will not be possible to share all these elements, so some summary tables of the incidents found are provided herein.

The questionnaire component involved 1102 workers, who represent, on average, around 88.3% of the Staff. The absence of certain workers during the period when the questionnaires were collected was due to Staff being on holidays or absent due to illness. Nevertheless, this did not prevent the information obtained from reflecting the work pattern of this activity in the company. In general, most of the Staff are women (79.1%), up to 30 years of age (67.2%), have been in the position for 3 or more years (69.5%), have secondary or middle education of schooling (62%), have a permanent contract (84.8%) and work part-time for about 20/25 h a week (78.3%). This makes up a relatively young female population with experience in the role, some of whom have activities that complement work in the clothing store (28.5%).

The company has internal occupational safety and health services, largely complying with the applicable legal requirements. The aspects that needed improvement had to do with the psychosocial risks, as before the current project, there was no global and structured assessment in this area and the training interventions did not properly address this topic. The fact that the company also has a set of measures to promote the psychosocial work environment, for example, health insurance for workers, a plan to prevent and resolve cases of harassment, legal and psychosocial support, gymnastics in the workplace, among others, means that the internal occupational safety and health system only presents a moderate level of deficiency. With the completion of the psychosocial risk assessment project, this deficiency will decrease even further in the future.

The fact that the level of deficiency it is favourable ends up having a great impact on the results of the assessment, since, as explained in the characteristics of the method, it will influence the level of probability, which, in turn, will have implications in the level of risk obtained. The robustness of the work safety and health interventions that was observed helps to explain the reduced incidence of psychosocial risks in Staff activity in these clothing stores. As Table 2 shows, the activity has, in general, an acceptable incidence of psychosocial risks at work, since most of the risk factors evaluated reveal an incidence in this category (63.5%). In any case, it is also important to note that 31.7% of risk factors show a moderate level of risk and 0.8% a high level. There is no very high incidence of risk factors.

Stores B and I are the ones with the most favourable psychosocial work environment for Staff, while stores E and F are those with more risk factors at moderate and high levels. Store J is the one with the most high-level risk factors. As the results are

Table 2 Distribution of the incidence of psychosocial risk in staff activity, by store

	Psychosocial Factors by Risk Level (%)				
Store	**Low (V)**	**Acceptable (IV)**	**Moderate (III)**	**High (II)**	**Very High (I)**
Store A	4.2	66.7	29.2	0.0	0.0
Store B	5.6	66.7	27.8	0.0	0.0
Store C	4.2	62.5	31.9	1.4	0.0
Store D	5.6	63.9	29.2	1.4	0.0
Store E	1.4	59.7	37.5	1.4	0.0
Store F	4.2	55.6	38.9	1.4	0.0
Store G	2.8	66.7	30.6	0.0	0.0
Store H	4.2	61.1	34.7	0.0	0.0
Store I	4.2	68.1	27.8	0.0	0.0
Store J	4.2	63.9	29.2	2.8	0.0
General Average	**4.1**	**63,5**	**31,7**	**0.8**	**0.0**

globally favourable, the risk factors are associated mostly with Category IV intervention levels, which leads to an improvement action where possible and with the benefits being justified (see Table 1). However, this scenario is not common to all the factors evaluated. As shown in Table 3, some psychosocial risks show Category III intervention results, which already calls for their correction within no more than 6 months. These cases include psychosocial risks of professional exhaustion, interference of work in personal and family life, interpersonal conflicts at work, physical violence at work, lack of professional recognition and job precariousness.

The incidence of these risks is transversal to the different stores, and tend to arise from aspects related to insufficient rest time between shifts, sleep disturbances that influence professional practice, schedules that do not allow sufficient time for family

Table 3 Predominant intervention levels in staff activity by store and type of psychosocial risk

	Store									
Type of psychosocial risk	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Professional distress - due to the pace and difficulty of work	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Professional distress - resulting from the pandemic context	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Professional exhaustion	IV	III	III	III	III	III	III	III	IV	III
Interference of work with personal and family life	III	III	III	III	III	III	III	III	III	III
Absence/Limitation of work autonomy	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Absence / Limitation of participation	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Professional role ambiguity	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Task conflict and overload	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Lack of social support at work	IV	IV	IV	IV	III	III	IV	IV	IV	IV
Interpersonal conflicts	III	III	III	III	III	III	III	III	III	III
Moral / Psychological harassment	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Physical and/or sexual violence	III	III	III	III	III	III	III	III	III	II
Professional recognition deficit	III	III	III	III	III	III	IV	III	III	III
Deficit of professional development possibilities	IV	IV	IV	IV	III	IV	IV	IV	IV	IV
Work precariousness	III	III	III	III	III	III	III	III	III	III

and friends, insufficient time to resolve personal issues, little or no harmonious relationships with work colleagues, and lack of training on psychosocial risks at work. It is also important to point out that the risk of physical and/or sexual violence reveals an already worrying incidence in Store J, mainly due to cases of exposure to situations of physical violence perpetrated by customers, requiring short-term interventions, preferably within no more than 3 months.

4 Discussion of Results and Conclusion

The psychosocial risks assessment of Staff activity showed an acceptable incidence in this clothing trade company, indicating the existence of a positive psychosocial work environment in the ten stores evaluated. This scenario inevitably stems from the good policies and practices of occupational safety and health and human resources management put in place in the company. With the entire range of mitigating and preventive measures that have been highlighted, there is a clear concern for the well-being of workers and a consistent commitment to the prevention of work accidents, occupational diseases and other damages that may be caused by the existing working conditions. This commitment to prevention is a fundamental bulwark of the positive results obtained, not least because the psychosocial risks and the lack of conditions can be costly and have negative effects for companies and societies (EU-OSHA 2014).

However, it is also worth highlighting a few more particulars that are relevant to understand these results. First of all, the fact that a large part of the universe of workers with Staff functions are young (less than 30 years old), which means that they have not been in the job market for long and consequently do not yet show accumulated work wear. For example, some studies show that aging can enhance a decrease in the physical and mental abilities of workers, reducing their ability to perform demanding tasks and maintain focus of attention (e.g. Ghosh et al. 2004).

Associated with this characteristic, it is also important to remember that these workers mostly work part-time (15–25 h per week), which means that they are less exposed to risk factors. Although activities that require a lot of interaction with the public/customers, such as those store Staff, are more subject to exposure to psychosocial risks at work (Hilton and Whiteford 2010), the fact that the vast majority work part-time also influences the exposure levels obtained.

It is also relevant to highlight the general level of job satisfaction evidenced. Most workers are satisfied or very satisfied with their working conditions, which is an important statement to the results obtained, because as evidenced by the literature, satisfaction with work tends to favour higher commitment and a feeling of psychosocial well-being in relation to professional activity (Vivian and Neto 2020, 2021; Rivera-Rojas et al. 2021).

In global terms, a positive view persists from the entire psychosocial risk assessment process carried out, not only because the entire data collection process took place without any obstacles, but mainly because there are no activities or stores with significant problems. There are some aspects that must be analysed and improved, but the risk levels found lead to the conclusion that there is a favourable psychosocial work environment in the universe of the stores. As some moderate or high incidence risk factors were found, an improvement action plan was prepared for the company. While the detailed explanation of the plan can´t be possible here, some priority measures can be mentioned, such as: (i) preparation of a two-year intervention plan, with a view to implementing measures to combat priority problems and then carry out a new assessment, so that the psychosocial risks maps can be updated; (ii) reorganisation of the shift system, since shift rotations were quite uncertain and short in duration. Longer rotation periods are recommended to facilitate adaptation and reconciliation between spheres of life, but, above all, that workers must be consulted in relation thereto (Wong et al. 2019); (iii) preparation of a training plan on psychosocial risks, to reinforce workers' knowledge about the importance of the psychosocial work environment and the existing internal measures. The workers themselves expressed interest in receiving training on stress management, time management, conflict management, team building, among others; (iv) increasing the number of Staff in times of high commercial affluence (e.g. weekends, Christmas), to reduce the work overload and intensity at these times.

This study demonstrated that it is possible to develop a psychosocial risks assessment in a sustained and objective way, and that its results can be integrated into the global risk map of companies. The management of work-related psychosocial risks is more or less difficult to manage, depending on the attention, commitment and rigour that safety technicians put into the process. They are professional risks like any other, requiring clear, objective and coherent approaches, carried out by qualified professionals, who, in the light of Portuguese legislation, are accredited occupational safety technicians.

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Prevalence of Burnout in Physiotherapists During COVID-19: A Systematic Review

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Abstract Burnout is characterized by emotional exhaustion and is caused by excessive and prolonged stress related to working conditions. Objective: to assess the prevalence of burnout in physiotherapists during the pandemic COVID-19. Methodology: a computerized search of articles published between December 2019 and July 30, 2021, in the PubMed, Academic Search Complete, MEDLINE, CINAHL Plus, and Web of Science databases and in the Google Scholar search engine was conducted to identify studies of burnout in physiotherapists during the COVID-19 pandemic. Results: 4 studies were included in this review, involving 684 physiotherapists. The studies analysed the number of participants, the characteristics of the sample, the assessment tool, intervention domain, and main outcomes. During the COVID-19 pandemic, physiotherapists exhibited moderate to high rates of burnout symptoms. Conclusion: results suggest that burnout symptoms during the COVID-19 pandemic are prominent among physiotherapists working directly with patients. The

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current results show moderate to high burnout symptom rates, which have increased compared to data published prior to the pandemic.

Keywords Burnout · Physiotherapy · COVID-19

1 Introduction

Burnout is a state of physical and emotional exhaustion that involves the development of a negative self-concept and a negative attitude towards work. This concept was first described in 1974 by Herbert Freudenberger, an American psychologist, who defined it as to fail, wear out or become exhausted by making excessive demands on energy, strength, or resources (Freudenberger 1974). Later, Maslach and Jackson, cited by Leiter and Maslach (1988), described burnout as a syndrome of emotional exhaustion, depersonalization, and reduced perception of personal accomplishment, which can occur among individuals who work with people in some way.

Emotional exhaustion refers to feelings of being emotionally overwhelmed and drained from contact with other people. Depersonalization refers to an insensitive response to these people, who are usually the recipients of someone's service or care. Decreased personal accomplishment refers to a decline in feelings of competence and achievement when working with people. The three main dimensions of burnout syndrome (emotional exhaustion, depersonalization, and personal accomplishment) exist on a continuum, starting with the individual's emotional and physical exhaustion in relation to their work. Individuals with emotional exhaustion end up not getting involved in situations that arise during their work because they feel apathetic and indifferent. With increasing emotional exhaustion, depersonalization and cynicism occur, with the individual showing a negative attitude and detachment in relation to their work and workplace, deteriorating job satisfaction. Thus, reduced personal accomplishment causes feelings of incompetence and decreased work productivity even in the face of achievement situations (Bridgeman et al. 2018). That said, in mid-2019, burnout syndrome was included by the World Health Organization in the 11th Revision of the International Classification of Diseases (ICD-11) as an occupational phenomenon (not classified as a medical condition) resulting from exposure to chronic stress in the workplace, characterized by feelings of burnout or energy depletion, increased mental distance from work, or feelings of work-related negativism or cynicism, and reduced professional effectiveness (World Health Organization 2019).

Health professionals are one of the most studied occupational groups and have been described as particularly vulnerable to burnout. Due to the demanding nature of their profession, these professionals experience a variety of physical and psychological symptoms caused by the increase in chronic work-related stress (Bridgeman et al. 2018; Maslach et al. 2001), presenting a high prevalence of burnout (Low et al. 2019; Woo et al. 2020). This chronic exposure to burnout can lead to decreased productivity, increased professional error, longer recovery time and lower patient satisfaction, thus impairing the quality of healthcare services (Panagioti et al. 2017;

Shanafelt et al. 2017). Physiotherapists, among other healthcare professionals, are at high risk of developing burnout (Corrado et al. 2019) due to the nature of their work, as they are in daily contact with the physical and psychological pain experienced by their patients. This can trigger emotional responses and lead physiotherapists to defend themselves, distancing themselves from relationships with their patients (Bruschini et al. 2018).

In the last year, humanity has faced the emergence of an unexpected infectious threat. Since its first appearance in Wuhan, China, in December 2019 (Zhou et al. 2020), the new respiratory syndrome has rapidly spread across all continents. Due to the global spread of the disease, the World Health Organization officially declared the disease COVID-19 as a pandemic on March 11, 2020 (World Health Organization 2020b). First-line health professionals against COVID-19 have shown, from the early stages of the pandemic, to be one of the most vulnerable groups and, due to the pressure on health systems around the world, the negative consequences on well-being of doctors and nurses were explored (Barello et al. 2020; Sasangohar et al. 2020). However, the COVID-19 pandemic has also exposed the importance of rehabilitation and the key role of physiotherapy during the different stages of the disease (World Health Organization 2020a). In addition, the government response to the pandemic in providing physiotherapy care to other populations, in general, was affected. As a consequence, of the pandemic, many physiotherapists were relocated to critical and intermediate units and/or had to adapt to telehealth interventions, suspending face-to-face contact. Therefore, the objective of this study is to determine the prevalence and risk of burnout, as well as to analyse potential predictors for its occurrence during the COVID-19 pandemic.

2 Methodology

This systematic review was reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Page et al. 2021).

2.1 Eligibility Criteria

The eligibility criteria defined for this review were: all studies that evaluated burnout only in physiotherapists (or that provided detailed data on this group) during the COVID-19 pandemic, using any burnout assessment instrument and published in English, Portuguese and/or Spanish. All types of studies (observational, cohort, cross-sectional and case–control) were considered and case studies, literature reviews, letters to editors and opinion articles were excluded.

2.2 Search Strategy

A computerized search of articles published from December 2019 to July 30, 2021 (last day of literature search) was performed in the following databases: PubMed, Web of Science, Academic Search Complete, MEDLINE, CINAHL Plus, and Google Scholar search engine, to identify studies involving burnout in physiotherapists during the COVID-19 pandemic. The following search expression was used: (burnout OR burn-out) AND (physiotherapists OR "physical therapists") AND (COVID or coronavirus). This time period was chosen to include research during the COVID-19 pandemic. After elimination of duplicate studies, the titles and abstracts of the included studies were screened and articles that were not related to the research topic were excluded. The full texts of the remaining articles were analysed in detail and data regarding the author, number of participants, sample characteristics (gender and age), assessment instrument, intervention area and data on the prevalence of burnout were collected for the included studies.

2.3 Study Selection and Data Extraction

References were exported to a data management software (EndNote X9), and duplicates were removed. The review was conducted following three steps. Records identified through database search and reference screening (Identification) and two reviewers (CO, AS) independently examined titles and abstracts, irrelevant studies were excluded based in eligibility criteria, and relevant full texts were analysed for eligibility (Screening). All relevant studies were included in the systematic review (Inclusion). Any disagreement was resolved by a third reviewer.

The same researchers were responsible for extracting the data from the included studies. Data regarding study information (author and year), subjects (sample size and relevant characteristics), demographics (age and sex), area of intervention, assessment instrument, and results were extracted.

3 Results

In the initial search of the electronic databases, Google Academic search engine and references, 438 potential studies were identified. After elimination of duplicates, 414 unique studies were screened by reading the title and abstract and 382 studies were excluded. Of the 32 studies fully reviewed, 28 were excluded and 4 studies were included in the review (Fig. 1).

The selected studies included a total of 684 physiotherapists, of which 499 were female and 174 were male (the gender of 10 physiotherapists remained unknown as the authors have not reported this information). Table 1 shows the data relating to the

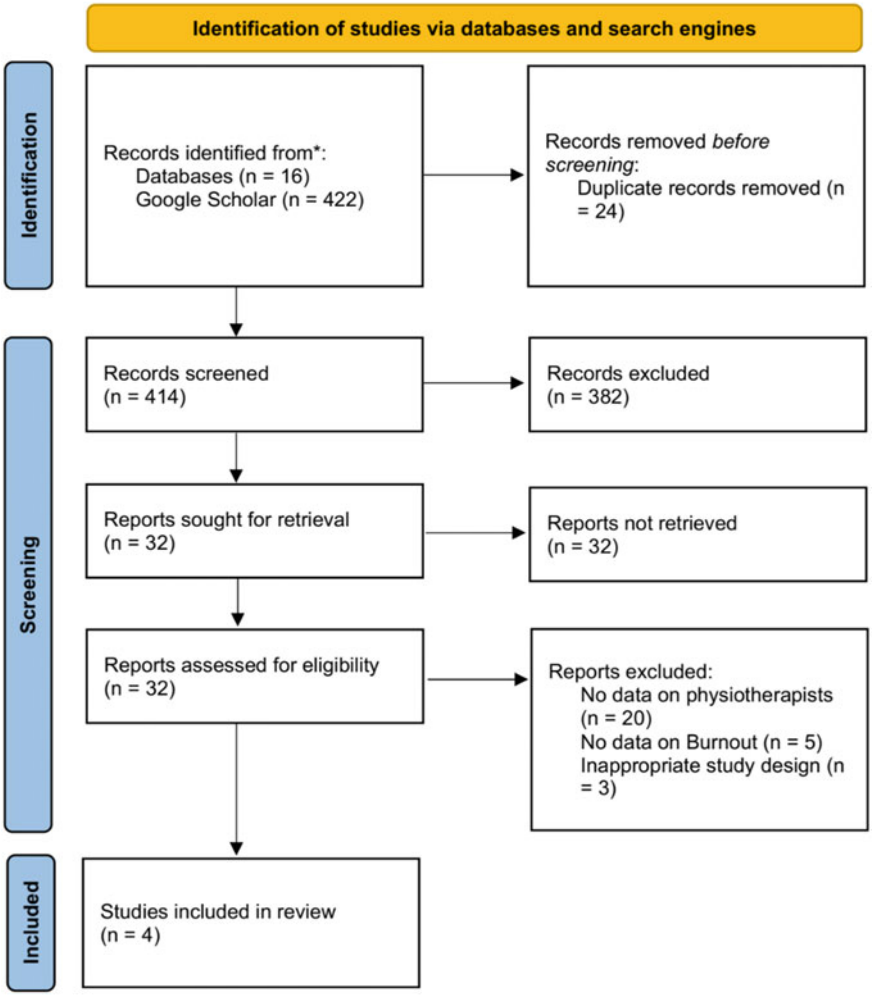

Fig. 1 PRISMA flow diagram illustrating the research process and selection of studies included in the review

author's name and year of publication, number of participants, sample characteristics, assessment instrument used, area of intervention in physiotherapy and the main results of the 4 included studies.

All studies used a validated instrument as an assessment tool, the Maslach Burnout Inventory (MBI) or the Copenhagen Burnout Inventory (CBI), to determine the prevalence of burnout. In studies that assessed burnout with the MBI prevalence of burnout by dimension was provided and in emotional exhaustion the highest prevalence was 80% and the lowest was 28.07%, in depersonalization the highest prevalence was 19.3% and the lowest was 10% and, in personal accomplishment,

Table 1 Summary of the studies included in the review

Study	Sample size	Sample characteristics	Assessment instrument	Area of intervention	Main results
Pniak et al. (2021)	n = 106	F: n = 69 M: n = 37	MBI	Hospital (intensive care and anaesthesiology; Orthopaedics and Traumatology; Neurology	$\overline{x}$; CI EE: 32,31; 29,47–35,15 (high level: >27)* DP: 16,25; 14,48–18,03 (high level: >13)* PA: 26,25; 24,41–28,10 (high level: 0–33)* Higher levels of burnout seen in men and intensive care and anaesthesiology
Urgilés (2020)	n = 82	N/A	MBI	Hospital (intensive care unit with COVID-19 patients)	10% presented burnout; EE: 80% high level; 10% moderate level; DP: 10% high level; 60% moderate level; PA: 20% high level; 70% moderate level
Vía Luna et al. (2021)	n = 57	F: n = 13 M: n = 44 Age: 39.19	MBI	Public Hospital (outpatient clinic; wards; intensive care unit; intermediate care unit)	n = 1 (1,75%) presented burnout; EE: n = 16 (28,07%) high level; n = 15 (26,32%) moderate level; n = 26 (45,61%) low level; DP: n = 11 (19,3%) high level; n = 10 (17,54%) moderate level; n = 36 (63,16%) low level; PA: n = 48 (84,21%) high level; n = 2 (3,51%) moderate level; n = 7 (12,28%) low level; Higher levels of burnout observed in women and wards

(continued)

Table 1 (continued)

Study	Sample size	Sample characteristics	Assessment instrument	Area of intervention	Main results
Jácome et al. (2021)	n = 511	F: n = 417 M: n = 94 Age: 33	CBI	Private sector; wards; intensive care unit; intermediate care unit	42% presented personal burnout (n = 213); 42% presented work-related burnout (n = 215); 25% presented patient-related burnout (n = 130); All burnout dimensions were significantly and positively associated with depression, anxiety and stress and negatively associated with resilience; Potential predictors of burnout: female gender, working directly with patients, diagnosing health problems, and working directly with COVID-19 patients

Note n: number of physiotherapists; F: Female; M: Male; MBI: Maslach Burnout Inventory; CBI: Copenhagen Burnout Inventory; EE: Emotional Exhaustion; DP: Depersonalization; PA: Personal Accomplishment; $\overline{x}$: mean; CI: confidence interval. * According to the instrument

the highest prevalence was 84.21% and the lowest was 20%. In the study using the CBI to assess burnout, the prevalence of personal, work-related, and patient-related burnout symptoms was 42%, 42%, and 25%, respectively.

4 Discussion

After analysing the studies included in the present review, the results seem to suggest that the prevalence of burnout in physiotherapists during the COVID-19 pandemic is moderate/high. A literature review carried out before the COVID-19 pandemic showed that the problem was indeed visible in this community, reporting slightly lower prevalence values (Fernandes 2020).

4.1 Assessment Instruments

Regarding assessment instruments, all studies used a validated instrument to assess the level of burnout in the study population. However, direct comparison of results is difficult since one of the included studies uses a different instrument than the other three. The assessment instruments used were the Maslach Burnout Inventory, used in the study by Pniak et al. (2021), Urgilés (2020) and Vía Luna et al. (2021) and the Copenhagen Burnout Inventory, used in the study by Jácome et al. (2021). The Maslach Burnout Inventory is a questionnaire composed of 22 items and subdivided into 3 subscales that assess emotional exhaustion (feeling of being emotionally overwhelmed and exhausted by work), depersonalization (indifference or detachment from the recipients of the service, care and/or treatment) and personal accomplishment (feeling of competence and successful achievement in working with people). The higher the scores on the emotional exhaustion and depersonalization subscales, the higher the level of burnout. Conversely, the lower the result in personal accomplishment, the higher the level of burnout. Thus, the population that scores higher on the first two subscales and lower scores on the third, according to the Maslach Burnout Inventory, presents a higher degree of burnout (Maslach et al. 1997). Urgilés (2020) and Vía Luna et al. (2021) reported low levels of burnout, however, it is important to note that there are worrying levels in the dimensions of emotional exhaustion and depersonalization, whose consequences can be overshadowed by a high level of personal accomplishment. High values in the personal accomplishment dimension may be, in part, helping to control the development of burnout as suggested by Karen (2019). Furthermore, these studies were restricted to small samples of physiotherapists. Pniak et al. (2021) showed high burnout rates in all three dimensions, thus showing a high level of burnout in physiotherapists working during the COVID-19 pandemic.

The Copenhagen Burnout Inventory is a 19-item tool that integrates three burnout subscales (personal, work-related and patient-related burnout). The personal burnout subscale assesses the degree of physical and psychological fatigue and exhaustion that the person attributes to factors that are not work-related. The work-related burnout subscale assesses symptoms attributed to work and the patient-related burnout subscale describes feelings of physical and psychological fatigue and exhaustion attributed to working with patients (Kristensen et al. 2005). Jácome et al. (2021) reported a large percentage of physiotherapists with personal burnout (42%), work-related burnout (42%) and patient-related burnout (25%). As already mentioned, a direct comparison of this study with the others included is not possible because different instruments were used. However, considering that the Maslach Burnout Inventory restricts burnout as a work-related phenomenon, we can assume that the level of burnout reported by Jácome et al. (2021) for work-related burnout is closer to the conclusions observed in the study by Pniak et al. (2021). Additionally, the study by Jácome et al. (2021) reported that lower levels of resilience and higher levels of depression, anxiety and stress were significantly associated with the three burnout subscales. In a pandemic situation, health professionals have high levels of anxiety, stress, and depression due to the fear of being contaminated and contaminating their family (Sasangohar et al. 2020), in addition to unpredictability and increased work intensity. These data are in line with other studies performed on healthcare professionals during the COVID-19 pandemic, suggesting that stress, anxiety, and depression are significantly and positively associated with emotional exhaustion and depersonalization and that resilience was significantly and negatively associated with exhaustion, emotional distress and depersonalization (Luceño-Moreno et al. 2020). It is well known that high levels of depression and anxiety weaken resilience and influence the way in which a stressful situation is faced and dealt with (Southwick and Charney 2012), making it more or less maladaptive.

4.2 Gender

Regarding gender, a greater participation of females (72.95%) is evident in the studies included in this review. This is not surprising, given that Physiotherapy is historically an area with a higher number of female professionals (Naylor et al. 2014; Schofield and Fletcher 2007). The study by Urgilés (2020) does not mention the gender of the participants, with Vía Luna et al. (2021) being the study with the highest proportion of male participants and the remaining studies with the highest proportion of female participants (Jácome et al. 2021; Pniak et al. 2021). Within the studies that provided gender data of participants, Pniak et al. (2021) is the only study in which higher rates of burnout were observed in male participants. In contrast, Vía Luna et al. (2021) and Jácome et al. (2021), although using different assessment instruments, reported that the female gender is a potential predictor of burnout. These results agree with those reported in most studies that have analysed the impact of COVID-19 on the mental health of health professionals in general (Barello et al. 2020; Ferry et al. 2021; Giusti et al. 2020; Jalili et al. 2021).

4.3 Age and Professional Experience

Concerning age, only two studies provided the average age of the study participants, 33 years old (Jácome et al. 2021) and 39 years old (Vía Luna et al. 2021), suggesting that the sample in these studies is from a young adult population. However, the study by Jácome et al. (2021) does not relate age with burnout data, as well as the study by Urgilés (2020) in which the age of the participants is not known. Although the study by Pniak et al. (2021) does not provide data on the age of the participants, it relates burnout levels with the years of experience of the study participants. In general, analysis that focused on the relationship between time of professional experience and burnout showed a high prevalence of the problem in all groups of physiotherapists who performed their duties during the COVID-19 pandemic, with a higher of burnout in physiotherapists who had been working in the profession for more than 20 years (followed by the group of 10–15 years). Only the group of subjects with experience in the range of 5–10 years presented moderate results in the emotional exhaustion domain, reflecting the fact that they were less affected by the problem (Pniak et al. 2021). Therefore, it is reasonable to suggest that older physiotherapists are at greater risk of burnout during the COVID-19 pandemic. Data prior to the pandemic showed a higher rate of burnout observed in physiotherapists between 35 and 40 years old and with more than 10 years of experience, in the study by Puszczałowska-Lizis et al. (2015), suggesting that younger physiotherapists report a lower burnout rate. In the study by Vía Luna et al. (2021), there was a high proportion of physiotherapists who had worked for more than 5 years reporting burnout. However, it is not possible to relate these data with those of Pniak et al. (2021), because professional experience groups were considered differently (less than 1 year, 1–5 years and more than 5 years of experience. However, it is suspected that younger physiotherapists have a lower burnout rate).

4.4 Area of Intervention

Studies included in this review reported data from physiotherapists working in hospitals (Pniak et al. 2021; Urgilés 2020; Vía Luna et al. 2021) and in different sectors (Jácome et al. 2021). Previous research suggested that institutions belonging to the public sector had a higher prevalence of Burnout than private institutions (Kim et al. 2020; Vivanco et al. 2018). However, depending on the area of intervention in physiotherapy, the level of burnout may differ. In the study by Pniak et al. (2021) physiotherapists worked in the departments of intensive care and anaesthesiology, orthopaedics and traumatology, and neurology, with the highest rate of burnout, reflected by the results in the three domains, being identified in the department of intensive care and anaesthesiology. In the study by Urgilés (2020), physiotherapists worked in intensive care units, with patients with COVID-19, presenting relatively low data on burnout. However, it is noteworthy that these physiotherapists reported a high level of scores in the domain of emotional exhaustion and moderate scores in the domain of depersonalization, which indicates a possible moderate level of burnout or risk of developing burnout. In addition, this study was carried out during the first wave, shortly after the World Health Organization officially declared the disease COVID-19 as a pandemic, and the data may still not reflect accurately the impact of the pandemic on the mental health of these professionals. In the study by Vía Luna et al. (2021), physiotherapists worked in outpatient, inpatient, telehealth, intensive care and intermediate care units, and the only case of burnout was observed in the inpatient unit. That said, it was possible to observe a moderate to high prevalence of burnout in Intensive Care Units, corroborated by Güler et al. (2019) and Silva et al. (2018), performed before the pandemic. Physiotherapists working in Intensive Care Units have a high prevalence of burnout, which can be explained by the fact that health professionals are in permanent contact with people with diseases, and in which the evolution may not be noticeable in the short term (Silva et al. 2018). In addition, due to the COVID-19 pandemic, the number of hospitalized people requiring care is greater and, in the unpredictability of the disease, professionals must deal with the imminent risk of death in a daily basis. Health professionals working on the front line and in intensive care units, including physiotherapists, have been shown to present risk factors for the development of anxiety, stress, and depression (Buselli et al. 2020; Castro et al. 2020), reporting higher levels of burnout syndrome compared to professionals in other sectors (Chuang et al. 2016).

As for the study by Jácome et al. (2021), a distinction was made between work status before COVID-19 (physiotherapists worked mainly in the private sector (50%) and wards (35%), but also in intensive care units and intermediate care unit, intensive care unit, continued and palliative care, and others) and work status during COVID-19 (working directly with patients, working with COVID-19 patients, telecommuting and without work). The authors found that levels of personal and work-related burnout were significantly higher in physiotherapists working directly with patients, when compared to those who were providing telehealth services or were not working at the moment. These data suggests that direct work with patients may be a predictor of personal and work-related burnout, and that working with COVID-19 patients appears to be a potential predictor of personal burnout, possibly due to fear of personal contagion and family transmission (Sasangohar et al. 2020).

4.5 Study Limitations

This study has some limitations. First, there were very few studies available for review, with relatively small sample sizes, making it difficult to generalize the results. However, to the best of our knowledge, all the available evidence was included in the review. During the analysis of the included studies, methodological issues were identified. such as variability in measurement instruments and studies that mainly report cross-sectional information at a specific point in the pandemic, making it difficult to determine the longitudinal impact of the pandemic on the mental health of physiotherapists. Moreover, although the published evidence report "burnout prevalence", the available instruments do not determine if a person has burnout, but rather if they have symptoms associated with burnout, which may indicate a greater or lesser probability of presenting the condition. Attention must be paid to this issue when interpreting the results of the existing evidence.

5 Conclusions

Burnout during the COVID-19 pandemic is noticeable among physiotherapists working directly with patients. The results of the qualitative analysis show moderate to high rates of burnout symptoms as well as in the subscales emotional exhaustion, depersonalization, and personal accomplishment. A comparative analysis of these findings with reference to related studies published before the pandemic shows that burnout symptoms among physiotherapists may have increased significantly during the COVID-19 pandemic. However, given the paucity of scientific evidence related to this specific problem, it would be important to continue research on burnout in physiotherapists, particularly after the third wave of the pandemic, providing a better understanding of the possible effects of social isolation and greater personal health risks related to work on the mental health of these health professionals.

Regarding the role of gender and age in the risk of developing burnout symptoms, the existing evidence does not allow definitive conclusions to be drawn due to the scarcity of studies, the small number of participants and the dissimilar gender and age distribution.

The available evidence provides a basis for possible risk factors, guiding future studies that should consider more variables such as the number of working hours, the number of treated patients, different areas of intervention and the professional relationship with other multidisciplinary team members. Future research should also explore strategies adopted by physiotherapists to deal with burnout, and possible interventions in the workplace that address physiotherapists' mental health to preserve the well-being of these professionals and prevent a decrease in productivity and quality of the services provided.

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Impacts of Shift Work, Intervention Strategies, and COVID-19: The Workers' Perspective

Daniela Costa and Isabel S. Silva

Abstract Shift work can have several impacts not only on the health and family and social life of the workers, but also at the organizational level. The literature has revealed that shifts involving night work and/or periods that are highly valued from a family and social point of view, such as weekends, are the most disruptive. In this paper, the results of an open-ended question about the experience of working in shifts and the impact that COVID-19 had on the lives of workers, at the time of data collection, have been presented and discussed. For that, the answers of 123 shift workers (98 involving nights and 25 without involving nights) were compared with the answers of 33 day workers. Negative impacts of working hours on health, family life as well as at the organizational level were reported mostly by shift workers. Reduction in working hours, teleworking, or flexible working hours were presented as some of the main strategies to reduce the effects of working hours. Finally, from the perspective of workers, COVID-19 has resulted in greater workload and greater work demands as well as causing family and health problems.

Keywords Work schedules · Health · Family life · Intervention · Pandemic

1 Introduction

Shift work, like any other work schedule, can have both advantages and disadvantages for workers. The economic (e.g., shift allowance) and temporal (e.g., availability to solve personal matters during the day) aspects are among the most advantages of shift work that have been mentioned in the literature (e.g., Carneiro and Silva 2015; West et al. 2012). On the other hand, the disadvantages focus on three main

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areas: health, family and social life, and organizational level. In terms of health, sleep, cardiovascular, and psychological problems have been highlighted (Bamonde et al. 2020; Narciso et al. 2014), with such impacts being associated with schedules that imply night work and, consequently, inversion of the sleep–wake cycle (e.g., Åkerstedt 2003; Knutsson 2003). Several human functions have a circadian rhythm, which, under normal conditions, is synchronized with exogenous clues such as the light–dark cycle (Åkerstedt 1990; Vitaterna et al. 2001). For example, melatonin, the main hormone produced by the pineal gland, typically known as the "sleep hormone", has a peak production during the night (Åkerstedt 2003). Shift work involving nights can disrupt such biological processes and trigger health problems, because the worker will be under constant stress to adapt to different work schedules and, consequently, rest times (Åkerstedt 1990; Costa 2003). Problems in marital and parental relationships and/or family management are the main difficulties that have been mentioned in terms of family life (Li et al. 2014; Wöhrmann et al. 2020). In fact, these problems tend to arise because shift work involves working in periods that are highly valued from a family and social point of view, such as evenings and/or weekends. Finally, at the organizational level, safety and productivity tend to be the most affected areas, especially in connection with night work (Alali et al. 2017; Folkard and Tucker 2003). For example, in the study by Folkard and Tucker (2003), the authors found that the risk of incident occurrences was approximately linear in a clockwise direction (morning-afternoon-night), with the night shift having the highest risk.

This hardship of shift work tends to be more evident when these work schedules are compared with conventional schedules (i.e., fixed hours from Monday to Friday practiced during the day). For example, in the study by Ferri et al. (2016), using a sample of nurses, the authors found that night shift workers reported lower quality and quantity of sleep, greater chronic fatigue, and more psychological and cardiovascular problems as compared to day workers. From another perspective, in the systematic review by Wöhrmann et al. (2020), work-family conflict was higher in shift workers than in day workers.

Despite the difficulties presented so far, when the world society goes through some kind of crisis such as economic (e.g., financial crisis of 2007–2008), geopolitical (e.g., war in Ukraine), or public health (e.g., COVID-19 pandemic), the experiences in the working world and, consequently, for workers will be different. Focusing on COVID-19, the research already carried out (e.g., Giorgi et al. 2020; Zhang et al. 2020) has identified impacts on the mental health of workers. For example, in the systematic review by Robinson et al. (2022) involving 65 articles, in the initial two months, after the World Health Organization declared COVID-19 as a pandemic (March and April 2020), general mental health symptoms increased as compared to pre-pandemic periods. On the other hand, other problems such as greater work-family conflict have also been associated with COVID-19 (Andrade and Lousã 2021; Ghislieri et al. 2021).

The present study is part of a PhD Project whose main objective is to contribute to the understanding of the impacts of shift work on the family and social life from the perspective of workers and their families. In this study, we intend to analyze the answers of workers (shift workers vs. workers assigned to normal hours) to an open-ended question about general opinions about work schedules and the impacts resulting from COVID-19.

2 Materials and Methods

2.1 Sample

The Project sample consisted of 583 shift workers involving nights, 178 shift workers without involving nights, and 333 day workers, with a national geographic distribution. Night shift workers were allocated to rotating systems that included rotation between different shifts (morning, afternoon, and night). In turn, shift workers without involving nights were rotated between morning and afternoon shifts, without night work. Both included weekend work. Day workers were allocated to fixed work schedules from Monday to Friday and during the day.

Of the 1094 participants, 156 answered the open-ended question (response rate of 14.3%) that we have analyzed in this study. Of these, 98 were shift workers involving nights (henceforth entitled "*With nights*"), 25 shift workers without involving nights (henceforth entitled "*Without nights*") and 33 day workers (henceforth entitled "*Normal*").

Table 1 presents a sociodemographic characterization along with professional and family situation of the workers. It is worth noting that the majority are female (52.6%) and with higher education (57.1%), with an average age of 42.04 (SD = 8.37). The health and civil aviation are the main sectors represented with 70.6% of participants.

2.2 Procedure

Data were collected at the national level through online questionnaires that were presented on a web page created for this purpose (https://projeto-horarios-de-trabalho6.webnode.pt). Numerous trade union associations and public and private organizations such as hospitals, companies, hotels, or social solidarity institutions were contacted. Once the contacts had been made, the organizations publicized the Project through their employees or associates. The study obtained a favorable opinion from the Ethics Committee of the University of Minho (CEICSH 098/2020) and is part of a PhD project funded by the Fundação para a Ciência e a Tecnologia (FCT) (SFRH/BD/147176/2019).

Table 1 Sociodemographic, professional and family characterization of the participants

Variable	With nights (n = 98)		Without nights (n = 25)		Normal (n = 33)		Total (N[a] = 156)	
	n	%	n	%	n	%	n	%
Gender								
Female	41	41.8	13	52.0	28	84.8	82	52.6
Male	57	58.2	12	48.0	5	15.2	74	47.4
Age								
M (SD)[b]	42.95 (8.50)		39.52 (9.05)		41.27 (7.14)		42.04 (8.37)	
Marital status								
Married	64	65.3	13	52.0	16	48.5	93	59.6
Union	31	31.6	12	48.0	17	41.5	60	38.5
Divorced	3	3.1	–	–	–	–	3	1.9
Sector								
Health	35	35.7	7	28.0	18	54.6	60	38.5
Civil Aviation	34	34.7	13	52.0	3	9.1	50	32.1
Security Forces	10	10.2	–	–	1	3.0	11	7.1
Industry	6	6.1	–	–	1	3.0	7	4.5
Social	3	3.1	–	–	3	9.1	6	3.8
Hospitality	3	3.1	3	12.0	–	–	6	3.8
Other	7	7.1	2	8.0	7	21.2	16	10.3
Seniority in the work schedule								
M (SD)[b]	16.55 (9.24)		13.52 (10.19)		8.39 (6.44)		14.34 (9.42)	
Number of years of marriage								
M (SD)[b]	13.77 (8.71)		10.68 (9.01)		11.91 (8.89)		12.88 (8.82)	
Number of people household								
M (SD)[b]	3.28 (0.88)		2.76 (0.83)		3.21 (1.02)		3.18 (0.92)	
Children's age								
Under 6 years	26	34.7	3	21.4	9	42.9	38	34.5
7 to 12 years	25	33.3	3	21.4	7	33.3	35	31.9
13 to 18 years	13	17.3	6	42.9	3	14.3	22	20.0
Over 18 years	11	14.7	2	14.3	2	9.5	15	13.6

[a]The obtained N can be different from the sample size (N = 156) due to missing values in some variables; [b] M (Mean), SD (Standard Deviation)

2.3 Instruments

The questionnaire consisted of four parts. The first part dealt with sociodemographic, professional, and family questions about the participants. The second part consisted of questions about the impacts of work schedules on family and social life, and a third part took account of other variables such as the organization's support in managing work schedules or personal well-being. In the final part, an open-ended question was asked from the participants "*If you wish, you can use the space below to make any comments or suggestions related to your work schedule and/or any of the other aspects mentioned in the other scales (e.g., impact of the COVID-19 on working hours).*". The analysis of the answers to this question was the main focus of this study.

2.4 Data Analysis

The data analysis was done from the content analysis (Amado 2000). It should also be noted that during this analysis process, namely the definition of the categorization system, it was presented and discussed within the research group to which the authors belong.

3 Results

The open-ended question obtained 203 answers, four of which were not considered for analysis, as they did not fit what was asked (e.g., "*Previously, I spent 19 years (1998 to 2018) in shift work.*"). Thus, in total, 199 responses were considered for analysis. It should be noted that this number is higher than the number of participants (N = 156), given that some workers mentioned more than one aspect in their answer. The answers were divided into several categories, the first two being "*positive aspects*" and "*negative aspects*" of work schedules, and within each category several subcategories were defined. Table 2 presents the frequencies obtained in each category and subcategory along with examples of answers given by workers, which illustrate the respective subcategory. In order to make the comparison between shift work and normal work more perceptible, the illustrations of answers in the case of the latter are marked by an asterisk. In the first category, workers mentioned, as the main advantage, the temporal reorganization that the shift work schedule allows, such as the availability to solve personal matters during the day. In the second category, the negative aspects were mostly mentioned by shift workers, primarily by those assigned to schedules that included night work. It should be noted that in the negative aspects, the main subcategories mentioned were problems related to the health of workers (e.g., sleep problems and psychological problems), family life (e.g., problems in the marital relationship and/or in the parental relationship), and at the organizational level (e.g., excessive workload and lack of organizational support).

Table 2 Frequency of answers to the categories "*positive aspects*" and "*negative aspects*" and respective subcategories

Positive aspects associated with work schedules (n = 10)			
Subcategories	With nights (n = 6)	Without nights (n = 2)	Normal (n = 2)
Temporal reorganization (n = 6) "*Even in personal terms, to deal with paperwork and the like it is much better to work in shifts because I have free weekdays which is the right time to deal with these issues.*"	4	2	–
Economic (n = 2) "*…it is what also allows you to give your children a better future.*"	2	–	–
Family life (n = 2) "*I worked in shifts for many years, and noticed the difference when I switched to this normal schedule. I feel that when I worked shifts, I didn't have time for my family, especially my children.*" [a]	–	–	2
Negative aspects associated with work schedules (n = 80)			
Subcategories	With nights (n = 56)	Without nights (n = 12)	Normal (n = 12)
Family life (n = 24) "*The one who has the most complaints is the daughter who says that she never wants to work shifts, and since the age of two, she has been forced to sleep at friends' houses when we can't get switched to other schedule.*"	20	3	1
Organizational level (n = 22) "*The most frustrating thing, after so many years of shifts, is the mismatch between operational needs and HR's adjustments that do not address these needs.*" "*My problem is not related to the type of schedule itself, but the amount of hours I have to be available for work.*" [a]	9	6	7
Health (n = 21) "*…there is definitely more physical and mental exhaustion.*"	18	3	–

(continued)

Table 2 (continued)

Negative aspects associated with work schedules (n = 80)			
Subcategories	With nights (n = 56)	Without nights (n = 12)	Normal (n = 12)
Economic aspects (n = 6) "*Shift work is extremely poorly paid*."	3	–	3
Quality of life (n = 5) "*Our quality of life deteriorates over the years*."	4	–	1
Social life (n = 2) "*…friendships are lost as we are never available to be a part of people's lives. In fact, we are always running contrary to others*."	2	–	–

[a] Answer given by a day worker

The third and fourth categories have been presented in Table 3. They refer to "*intervention strategies*" and "*legislative recognition of the hardship of shift work*" suggested by workers to reduce the impacts of work schedules. Regarding the "*intervention strategies*", both shift workers and day workers mentioned aspects such as a reduction in the daily working hours (e.g., six/seven hours of work per day), reorganization of breaks, increase in monetary compensation, flexible hours, or teleworking. In turn, the "*legislative recognition of the hardship of shift work*" was mentioned only by shift workers, both by the group with nights and the group without nights. Recognition of the weariness of working in shifts, attribution of a risk allowance, and lowering the retirement age were the aspects mentioned as being necessary, from the perspective of the participants, to be included in the legislation on this matter.

Table 3 Frequency of answers to the categories "*intervention strategies*" and "*legislative recognition*" and respective subcategories

Intervention strategies (n = 27)			
Subcategories	With nights (n = 16)	Without nights (n = 3)	Normal (n = 8)
Less working hours (n = 7) "*Less hours would certainly mean not only a better quality of life, but also more time for all the "tasks" we have with the house/household*."	3	2	2

(continued)

Table 3 (continued)

Intervention strategies (n = 27)			
Subcategories	With nights (n = 16)	Without nights (n = 3)	Normal (n = 8)
Breaks (n = 5) "*Lunch hours with two hours.*" "*I think it would benefit even more if I had a continuous shift, because right now I have a one-hour lunch break.*" [a]	2	1	2
Economic compensation (n = 4) "*…an extra salary should be regulated for all workers in this situation and/or an IRS tax benefit.*"	4	–	–
Teleworking (n = 3) "*Teleworking should remain an option.*" [a]	1	–	2
Schedule flexibility (n = 3) "*Schedules should be more flexible.*" [a]	1	–	2
Promotion of equality among colleagues (n = 2) "*…there are colleagues who, for personal reasons, do not work in shifts, consequently overloading the others.*"	2	–	–
Advance notice of shift change (n = 2) "*Having the schedule more in advance to plan some things.*"	2	–	–
Worker's opinion (n = 1) "*Workers should be able to choose to work regular hours.*"	1	–	–

(continued)

Table 3 (continued)

Legislative recognition of the hardship of shift work (n = 17)			
Subcategories	With nights (n = 16)	Without nights (n = 1)	Normal (n = 0)
Weariness (n = 8) "*…to be considered a fast-wearing profession.*"	8	–	–
Retirement age (n = 7) "*I believe that since shift work (including nights) is very stressful, we should be retired earlier.*"	6	1	–
Risk allowance (n = 2) "*…risk allowance for shift workers.*"	2	–	–

[a]Answer given by a day worker

The fifth category concerns the "*impacts of COVID-19*" on the lives of workers (Table 4). The workers mainly mentioned the increased working hours and work volume that the pandemic caused along with problems in family life and mental health.

Table 4 Frequency of answers to the category "*impacts of COVID-19*" and respective subcategories

Impacts of COVID-19 (n = 42)			
Subcategories	With nights (n = 23)	Without nights (n = 10)	Normal (n = 9)
More working hours (n = 15) "*COVID-19 has made my work schedule a lot worse, with a lot of professional demands, chaotic work schedules, and a lot of overtime.*"	9	4	2
Problems in family and social life (n = 9) "*With almost no time to be together and with fatigue, there are more discussions, but above all more distance and less affective connection.*" [a]	4	3	2
Higher volume of work (n = 5) "*COVID-19 has exposed and aggravated the already known and commonly accepted work overload.*"	4	–	1

(continued)

Table 4 (continued)

Impacts of COVID-19 (n = 42)			
Subcategories	With nights (n = 23)	Without nights (n = 10)	Normal (n = 9)
Psychological problems (n = 4) "*COVID-19 has completely changed emotional stability.*" [a]	3	–	1
Physical problems (n = 4) "*Extreme tiredness.*"	1	1	2
Uncertainty (n = 2) "*The layoff, lagged, and split schedules brought a lot of instability.*"	1	–	1
Teleworking (n = 2) Positive—"*In personal terms, the pandemic provided the best period of my professional life with teleworking.*" Negative—"*I hate being in teleworking.*"	–	2	–
Constant shift change (n = 1) "*Due to COVID-19, my company (…) changes my previously published schedules almost daily and sometimes with very different weekly shifts.*"	1	–	–

[a] Answer given by a day worker

Finally, the last category was named "*general comments*" (Table 5). In this category, the opinions and suggestions by the workers were considered.

4 Discussion

The results of our study indicate that shift work, especially involving night work, is perceived as having more negative impacts on the health and family life of the worker. In fact, the literature (e.g., Bamonde et al. 2020; Wöhrmann et al. 2020; Zhao et al. 2021) has shown that psychological problems, sleep problems, or parental and marital relationships are the main negative effects of these work schedules. For example, Åkerstedt (1990) argues that these impacts of shift work, especially involving night work, on the health of workers arise from the disruption of the circadian rhythm. In this perspective, it become fundamental for the organizations to take into account several aspects in the management of shift work. This importance is highlighted by workers when they advocate strategies such as reducing working hours, flexible working hours, or restructuring of breaks. Authors such as Root and Wooten (2008)

Table 5 Frequency of answers to the category "*general comments*" and respective subcategories

General comments (n = 23)			
Subcategories	With nights (n = 13)	Without nights (n = 3)	Normal (n = 7)
Opinions (n = 21) "*With age, it becomes more and more difficult to work shifts.*" *"My work schedule, despite being good, becomes bad, because it is not compatible with my boyfriend's. Therefore, a schedule that is one of the best becomes irrelevant when the person closest to us has a totally different one."*[a]	11	3	7
Suggestions (n = 2) "*The impact of health problems caused by shift work should be more in-depth.*"	2	–	–

[a]Answer given by a day worker

or Wöhrmann et al. (2020) have advocated the use of those strategies that can reduce the impacts of shift work on workers' health and the conflict between work and family. In addition to organizational changes, shift workers also talked about the need for changes at a higher level. Several workers pointed to the recognition of the hardship of shift work through the attribution of a risk allowance or the lowering of the retirement age as necessary changes at the legislative level.

Another aspect addressed in this study was the impacts that the COVID-19 pandemic had on the lives of workers. In this perspective, the participants revealed that the pandemic challenged several aspects, with the increased working hours and work volume, problems with mental health and family life were the main mentioned aspects. Recent literature (see for example, Ghislieri et al. (2021) or Zhang et al. (2020)) has shown this same evidence, that is, the demands caused by the pandemic tend to lead to an increase in work-family conflict and/or psychological problems in workers. For example, in the study by de Pinho et al. (2021) carried out in a Portuguese context, the authors found that nurses had high levels of stress, depression and anxiety during the COVID-19 pandemic. These results must be taken into account since the aspects mentioned by the workers are already impacted by organizational variables such as work schedules.

While analyzing the results, some limitations should be taken into account. Although the heterogeneity of the sectors of activity can be an advantage from the point of view of a greater generalization of the results, it can also hide the specificities of a given sector of activity. Therefore, studies are suggested that allow a deeper understanding of the aspects mentioned by sectors of activity and occupational groups. In terms of developing studies on the impacts of shift work and the pandemic, particularly on family and social life, it could also be interesting to have the perspective of third parties (e.g., partners, children) in the understanding of such impacts, beyond the perspective of the workers themselves.

In sum, the results of our study indicate that shift work, particularly that involving night work, when compared to standard hours, is more associated with problems for the health and family life of workers. On the other hand, the minimization of such impacts points to the need for several levels of action, with the organizational (e.g., flexible working time management practices) and legislative (reinforcement of compensation measures of hardship) levels standing out in our study. If shift work itself represents difficulties in different spheres of workers' lives, these end up being amplified in a pandemic context given the additional demands that this context itself imposes.

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Team Leaders' Strategies and Employees' Professional Isolation, Burnout, and Performance During COVID19

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Abstract Telework has progressively increased in the past decades, providing organizations and, consequently, leaders, with new challenges. The COVID19 pandemic not only doubled the number of teleworkers, but reinforced these challenges, by forcing some organizations and employees to abruptly adapt to this new reality. In this manuscript, we aimed to explore the role of the strategies implemented by leaders to manage their teams in employees' sense of professional isolation, burnout, and perceived performance. Thus, data was collected from 1149 teleworkers during the COVID19 pandemic, who answered an online questionnaire. At that time, 79% were working exclusively from home, and 91% had never had a previous experience of working remotely. The results showed that the strategies implemented by leaders to manage their teams contributed to reduce employees' sense of professional isolation which, in turn, is associated with lower feelings of burnout and higher perceptions of performance. The study reinforced the role of leadership in the context of teleworking and, specifically, the importance of leaders being attentive to team members' specific needs in order to help improving their wellbeing.

Keywords Leadership · Virtual teams · Telework · Wellbeing

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1 Introduction

In March 2020, the Word Health Organization (WHO) recognized the existence of a global pandemic caused by the SARS-COV-2 virus, commonly known as the COVID-19 pandemic. Given these circumstances, and to reduce the spread of the virus, Governments around the world decree mandatory confinements, which restricted the mobility of citizens, enforced the use of a facial mask, and demanded physical distance between individuals of different households (Cheng et al. 2020). Consequently, the work processes changed abruptly and unexpectedly, namely by the massive adoption of telework. If before the COVID-19 statistics already pointed to an increasing number of teleworkers around the world, after the pandemic announcement this indicator more than doubled (Eurostat 2021). In 2019, approximately 5.5% of EU workers aged from 20 to 64 years-old worked from home, whereas in 2020 this number increased, on average, to 12.4%. It is also worth noting that, in 2020, the urban areas and the capital regions of Germany, Luxembourg, the Netherlands and Portugal the teleworkers represented one fifth of the workforce (Eurostat 2021).

Telework is defined by the International Labour Office (ILO) as a regime where the information and communications technologies (ICTs) allow employees to regularly perform their work remotely, either from their home or from any other location, outside the company's site (ILO 2021). Also, telework environment presupposes the existence of adequate ICT tools and favourable physical conditions, for example, avoiding distractions and maintaining silence (Carillo et al. 2021). However, these conditions where not guaranteed during the multiple COVID-19 locked downs: in 24 h, individuals were required to work from home responding remotely to work demands and face-to-face to personal or family duties. Home become the place where all daily activities were done—being, at the same time, the space for work, leisure, family, and occasionally, an improvised school for remote classes (Pennington 2021; Uddin 2021).

The COVID-19 crisis has provoked a serious blow to the lives of people all over the world, impairing several areas of their daily lives and jeopardising their wellbeing. It is, therefore, urgent to provide recommendations which can contribute to the improvement of individuals' mental health (WHO 2020). Specifically, companies were challenged to find strategies adapted to a "new" reality and capable of maintaining positive levels of wellbeing and performance among their employees following the United Nations Sustainable Development Goals (SDG) (United Nations 2020). In doing so, companies can mitigate the consequences of COVID-19 on the work relation and directly contribute to the achievement of SDG 3 (i.e., socio occupational health and wellbeing) and SGD 8 (i.e., employment, decent work and social protection for all). Thus, this study aims to provide empirical evidence on the relationship between supportive work environment and teleworkers wellbeing in a context of crisis.

From the employees' point of view, telework can be perceived as either a positive or negative experience. Some scholars suggested that this work regime is associated with increasing flexibility, autonomy, and productivity which might contribute to a better wellbeing (Ter Hoeven and Van Zoonen 2015). On the other hand, others see telework as having the potential to produce the opposite effect in the COVID-19 context, and professional isolation is pointed out as the most influential factor regarding work adjustment for individuals working remotely (Carillo et al. 2021). Professionally isolated workers are those who feel that their networks of social relations are insufficient (Kutoane et al. 2021). The result is an unpleasant work experience as individuals hold the believe that they are unconnected with others and for that matter are not able to influence their working context (Golden et al. 2008). Indeed, telework can facilitate the feeling of professional isolation since workers lack social comparison with a significant group. Hence, they have more difficulty to determine how they should respond to work events (Golden et al. 2008). Literature suggests that specific remote working conditions might worsen the feeling of professional isolation in teleworkers (cf. Golden et al. 2008). For example, having no opportunity to choose working remotely, working from home in a full-time basis, being sent home indefinitely and no opportunities for face-to-face interactions. All these conditions were felt during the COVID-19 pandemic. Therefore, there are reasons to believe that during this period a widespread feeling of professional isolation was felt amongst teleworkers.

The access and effective use of ICTs can be seen as an advantage for teleworkers since they can stay connected with colleagues which reduces feelings of isolation for those who are working remotely (Lal and Dwivedi 2009; Sewell and Taskin 2015). However, this vision carries the risk of constraining workers into a situation where they must be constantly visible to their workplace (Sewell and Taskin 2015). Previous research (Charalampous et al. 2018) suggest that the available technology, which allows teleworkers the use of multiple communication channels, increases the intensity of their work activities, the constant work interruptions (e.g., incoming emails or instant messages), and the temptation to continue working beyond working hours. In the end, the pressure to be always "online"—whether to work or to socially interact with colleagues—makes it harder to disconnect physically and mentally from work and to recover between workdays, with consequences on teleworkers ill-being (Molino et al. 2020). Telework, seems to increase levels of stress and exhaustion (Toscano and Zappalà 2020).

Maslach (1976) described burnout as a state of worker exhaustion which refers to a lack of emotional resources to perform their tasks. In this case, the workers detach themselves from others and work, i.e., their feelings about people shift towards cynical and they poorly deliver their work. Currently, burnout is one of the most important work-related psychosocial threats. It is felt among distinct types of professions and occupational groups with significant costs for both individuals, organizations, and society at large (Edú-Valsania et al. 2022; Epstein et al. 2020; Medina et al. 2021). The negative impact of burnout on distinct realms of human life justified the World Health Organization (WHO) to include this syndrome in the 11th Revision of the International Classification of Diseases (ICD-11; WHO 2019).

In order to mitigate both teleworkers professional isolation and burnout levels, companies should promote a positive adaptation to the new work regime, namely by helping employees on building better personal resources and fostering their motivation on task performance (Chen and Eyoun 2021). Whereas, in telework, workers are physically dispersed, leaders might play a crucial role in the maintenance of team's positive outcomes. Previous research, carried out in face-to-face work context, suggests that leaders can shape employees' work experience and organization environment (Inceoglu et al. 2018; Kelloway and Barling 2010; Nielsen and Taris 2019). For instance, leaders support was found to play an important role on decreasing workers' social isolation feelings (Charalampous et al. 2018) and on burnout (Tafvelin et al. 2019). However, working from home brings news challenges to the leader's effectiveness that should be addressed.

Lyons and colleagues (2009) discussed the specific needs of the virtual team leader by presenting a set of strategies which can support leadership functions in that context. In the management of virtual teams, collaborative technology effective communication and proximity between the leader and the team emerges as a critical strategy to foster team's success. For example, Lyons and colleagues (2009) suggest that miscommunications can be mitigated when the leader of virtual teams clarifies and establishes procedures, expectations, individual's areas of expertise and interdependency and sets challenging, but attainable, goals. They also suggest that when team leaders provide regular updates and constructive feedback regarding team member's progress, they manage to create a close relationship using collaborative technology. In doing so, the leader can identify emerging performance problems and act upon them and in the end, reward and recognize the effort of each of the team members (Lyons et al. 2009). Altogether these strategies seem to provide clues on how the support of a leader, whose team is virtually connected, could predict positive team members' outcomes, namely their wellbeing. However, this relationship has never been empirically tested. So, the first hypothesis of this study aims to address this gap.

Hypothesis 1 A positive perception of the strategies implemented by leaders to manage teleworking teams predicts lower levels of professional isolation and burnout.

Recognizing that high employee professional isolation and burnout are costly for both organizations and individuals, its consequents request more research attention (Chen and Kao 2012). Studies before COVID-19 pointed out that workers' well-being can predict performance and performance quality (Peiró et al. 2019). For example, Taris and Schaufeli (2018) discuss under the effort-recovery theory the effects of workers un-well-being (i.e., fatigue) on performance. In fact, fatigued workers may lower their performance since they may choose to perform sub optimally or fulfil only part of their task. The same can be true for teleworkers whose well-being is affected by feelings of professional isolation and burnout. Indeed, previous studies have already shown the damaging effects of professional isolation on performance when evaluated by teleworker's supervisors (Golden et al. 2008). This relationship was also established in telework pandemic context (Toscano and Zappalà 2020). The direct negative influence of social isolation on workers' perceptions of productivity was also confirmed. This result underlines the importance of social relationships and that the experience of loneliness is strongly related to the subjective perception of productivity. The role of burnout as a negative predictor of productivity was also explored, particularly, in non-telework settings. Indeed, burnout leads to lower productivity and effectiveness, and work disruption (Greenglass et al. 2001). As previously stated, the unique features of teleworking in the pandemic COVID-19 context may decrease employee's wellbeing. In line of the previous literature, it could be argued that workers' ill-being is related to performance difficulties. In fact, Mihalca and colleagues (2021) discuss how teleworkers stress during COVID-19 affects their productivity and performance. In brief, performance is a consequent of wellbeing but other constructs, such as the leader support, can also play a role on influencing workers performance.

Research suggests that leaders who support individuals to achieve their work goals contribute to not only to employees' well-being, but also to improve their performance (Chen and Kao 2012; Inceoglu et al. 2018; Kelloway and Barling 2010; Nielsen and Taris 2019). Thus, the support from leaders can have a direct effect on performance, but also have an indirect effect through well-being. These direct and indirect effects have been established in the face-to-face working regime; however, it deserves to be further researched in the teleworking context. So, in the second hypothesis of this study wellbeing is proposed as a mediator between the supportive role of the leader and the teleworkers performance:

Hypothesis 2 Professional isolation and burnout mediate the positive relationship between the strategies implemented by leaders to manage teleworking teams and the team members' perceived performance.

2 Materials and Methods

2.1 Participants and Procedure

Data was collected using a self-report questionnaire and disseminated using a Qualtrics® link. The questionnaire was spread between November of 2020 and April of 2021 using several online platforms (e.g., LinkedIn, Facebook Groups) and several protocols with different organizations were established. These organizations belonged to a wide range of sectors (e.g., Education, Public Administration, Financial, among others). In the case of data collected in specific organizations, participation was still anonymous and confidential, but the organization received a report with the overall results of their employees—participants were informed of this arrangement before answering the questionnaire. After reading the informed consent, participants completed demographic information, and provided their perceptions regarding the leadership strategies implemented by their managers to facilitate their remote work, their feelings of professional isolation and burnout, as well as their perceptions regarding their performance in remote work.

An initial sample of 1195 employees were collected. However, 46 participants were removed from the dataset because they were not working remotely (neither partially nor full-time) or were unemployed and, therefore, did not meet the inclusion criteria. Thus, a final sample of 1149 workers were considered. Participants were mainly females (71%), married (62%, 27% single and 11% divorced), completed a higher education degree (81%, 15% completed high school), and aged between 21 and 69 years-old ($M = 44.63$, SD = 10.05). They are from the Education sector (59%), Public Administration (24%), Financial (7%), Consultancy (3%), Information and Communication (2%), and Administrative Services (2%). At the time of data collection, 79% of participants were working exclusively from home and 21% were engaged in a hybrid regime (but working remotely most of the weekdays). Most participants had never had a previous experience of working remotely neither in the organization they were working at that time (95%) not in a previous employment (91%).

2.2 Measures

2.2.1 Team Leaders' Strategies

Lyons and colleagues (2009) proposed 10 strategies that enable team leaders' to successfully manage their virtual teams. Participants were asked to rate their agreement (*1 = completely disagree, 5 = completely agree*) regarding on whether those strategies (e.g., "My leader fosters a team mentality; set goals that require teamwork"; 10 items) were implemented by their leaders. A Confirmatory-Factor Analysis revealed good psychometric properties for the unidimensional structure of 10 items: χ^2 (31 *df*) = 121.394, $\chi^2/df = 3.916$, RMSEA = 0.054, 95% CI [0.044, 0.064], p (RMSEA $\leq$ 0.05) = 0.250, SRMR = 0.021, CFI = 0.986, pCFI = 0.679, GFI = 0.976, pGFI = 0.550; TLI = 0.979. Therefore, a global score was computed based on the average of their responses ($\alpha = 0.91$ for this study).

2.2.2 Professional Isolation

Participants perceptions regarding professional isolation were assessed using a 7-item measure developed by Golden and colleagues (2008). For each statement, participants rated how frequently (*1 = never, 5 = always*) they felt that way (e.g., I feel lack of social connection with my co-workers). A Confirmatory-Factor Analysis revealed good psychometric properties for the unidimensional structure of 7 items: χ^2 (11 *df*) = 48.368, $\chi^2/df = 4.397$, RMSEA = 0.055, 95% CI [0.040, 0.071], p (RMSEA $\leq$ 0.05) = 0.276, SRMR = 0.024, CFI = 0.986, pCFI = 0.516, GFI = 0.987, pGFI = 0.388; TLI = 0.973. The average of their responses was calculated to form a single professional isolation score ($\alpha = 0.83$ for this study).

2.2.3 Burnout

An adaptation of the Maslach Burnout Inventory (Maslach & Jackson, 1981) was used to evaluated participants' perceptions of job burnout. For each of the ten statements (e.g., I feel emotionally drained from my work), they rated how frequently they felt that way (*1 = never, 5 = always*). A Confirmatory-Factor Analysis revealed adequate psychometric properties for the unidimensional structure of 10 items: $\chi^2(31\ df) = 258.324$, $\chi^2/df = 8.333$, RMSEA = 0.081, 95% CI [0.072, 0.090], p (RMSEA $\leq$ 0.05) < 0.001, SRMR = 0.066, CFI = 0.957, pCFI = 0.659, GFI = 0.955, pGFI = 0.539; TLI = 0.938. Thus, a total score of Burnout was computed by averaging their responses ($\alpha = 0.87$ for this study).

2.2.4 Perceived Performance

Participants' perceptions of their performance while working remotely were assessed using the "Productivity" dimensions of the E-Work Life Scale (Grant et al., 2018). Thus, participants rated their agreement (*1 = completely disagree, 5 = completely agree*) with four statements (e.g., "E-working makes me more effective to deliver against my key objectives and deliverables"). A Confirmatory-Factor Analysis revealed adequate psychometric properties for the unidimensional structure of 4 items: χ^2 (1 df) = 3.505, $\chi^2/df = 3.505$, RMSEA = 0.047, 95% CI [0.000, 0.104], p (RMSEA $\leq$ 0.05) = 0.429, SRMR = 0.008, CFI = 0.998, pCFI = 0.166, GFI = 0.998, pGFI = 0.100; TLI = 0.990. A total score of perceived performance was calculated based on the average of their responses ($\alpha = 0.81$ for this study).

3 Results

3.1 Preliminary Data Analysis

The first step consisted of checking the normality assumptions using the values of skewness [−3, 3] and kurtosis [−10, 10] (cf. Kline 2011). Both skewness [−0.52, 0.34] and kurtosis [−0.49, 0.69] were within the criteria values established by Kline (2011), concluding that no severe deviations from normality were found ($-0.52 > sk < 0.34$; $-0.49 > ku < 0.69$) and, therefore, path analysis could be conducted to test the sequential mediation hypothesis.

3.2 Path Analysis Results: Relationship Between Team Leaders' Strategies, Professional Isolation, Burnout, and Performance

The path analysis results showed that the proposed model (cf. Fig. 1) is an excellent fit to the data: χ^2 (1) = 0.927, χ^2/df = 0.927, RMSEA < 0.001, 95% CI [0.000, 0.077], p(RMSEA ≤ 0.05) = 0.772, SRMR = 0.008, CFI = 1.00, pCFI = 0.167, GFI = 1.00, pGFI = 0.100, AIC = 18.927, BCC = 19.006, MECVI = 0.017. The results of all direct and indirect (mediation) effects summarized on Table 1. A careful analysis of the direct paths shows that a more positive perception regarding the strategies implemented by leaders, leads to a lower sense of employees' professional isolation and burnout. Additionally, higher perceptions of professional isolation also predicted perceptions of burnout and both professional isolation and burnout negatively predict employees' perceived performance. Regarding the indirect effects, all mediations are significant. This means that professional isolation mediated the relationship between leadership strategies and burnout, and between leadership strategies and perceived performance. Similarly, burnout mediated the relationship between leadership strategies and perceived performance. Furthermore, the sequential mediation proposed in this study was also significant, as both professional isolation and burnout mediate the relationship between leadership strategies and perceived performance.

In sum, and as expected, the strategies team leaders implemented have direct effects in lower levels of professional isolation and burnout (H1), but also an indirect effect on employees' perceived performance. Specifically, the notion that leaders implemented a series of strategies to help employees cope with working during the pandemic helped to decrease their sense of professional isolation which, in turn, contributed to lower levels of burnout and, consequently, to a higher perception of performance (cf. Fig. 1), supporting H2.

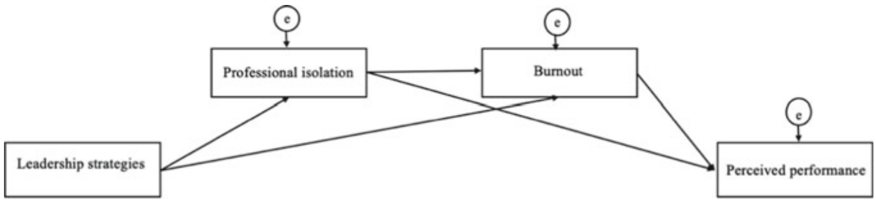

Fig. 1 Proposed model tested using path analysis

Table 1 Parameters' estimates of the proposed model

	b	SE	p	β
Direct effects				
Team Leaders' strategies → Professional isolation (H1)	−0.295	0.030	< 0.001	−0.280
Team Leaders' strategies → Burnout (H1)	−0.164	0.023	< 0.001	−0.172
Professional isolation → Burnout	0.485	0.022	< 0.001	0.535
Professional isolation → Performance	−0.211	0.031	< 0.001	−0.225
Burnout → Performance	−0.208	0.028	< 0.001	−0.244
Indirect effects				
Team Leaders' strategies → Burnout (via professional isolation)	−0.143	0.018	0.011	
Team Leaders' strategies → Performance (via professional isolation)	0.061	0.011	0.004	
Team Leaders' strategies → Performance (via burnout)	0.035	0.008	0.019	
Team Leaders' strategies → Performance (via professional isolation and burnout) (H2)	0.030	0.006	0.008	

4 Discussion

Research on leadership support has already shown that leaders play a crucial role in shaping the workers' wellbeing and performance in face-to-face work contexts (e.g., Avolio et al. 2009). The present study contributes to the literature on leadership since it addresses how specific strategies on managing teleworkers can be effective in predicting the wellbeing and performance of workers. The focuses on employee's wellbeing as a direct outcome has been neglected in favor of employees' performance and, when considered, wellbeing is seldom used as a multidimensional concept (Inceoglu et al. 2018). Thus, another merit of this research is to approach wellbeing as a multidimensional construct. Following Van Horn and colleagues (2004), two of the dimensions of wellbeing were considered: the social dimension, which concerns the social relationships at work (i.e., professional isolation); and the affective dimension, which comprises emotional exhaustion (i.e., burnout). Finally, it also contributes to the literature of teleworking during COVID-19 since data was collected during the pandemic lockdowns.

The relationship between leaders' strategies in managing virtual teams and teleworkers' wellbeing was the first to be examined. Results fully supported H1. The confirmation of this hypothesis emphasizes the importance of adapting leaders' strategies to teleworking teams (Lyons et al. 2009). This seems particularly relevant when the teleworking context emerges from a global crisis, as the COVID-19 pandemic (Carillo et al. 2021; Cheng et al. 2020). Thus, as facing a rapid transformation in the work regime, leaders had to change their team coordination strategies without any preparation. Even with little preparation for the telework context, leaders who were able to manage their virtual teams by implementing strategies such as effective communication (i.e., defining expectations and establishing procedures and goals) and a close relationship (i.e., provide regular updates and constructive feedback) contributed to foster their team members' wellbeing (i.e., reduce the feeling associated with professional isolation and burnout). In the same vein, Contreras and colleague (2020) argue that when managing teleworking teams, leaders need to pay special attention to the way they communicate, interact, and give feedback. This is even more relevant when organizations are facing turbulent periods. In such context, organizations rely mostly on a top-down communication and, consequently, leaders can have information that is not available to their subordinates unless they share it with them (Günther et al. 2022). The combination of both, a sudden change in work regime (from face-to-face to teleworking) and a pandemic crisis, might create a perfect storm in the management of teams. Indeed, there is a lot of new procedures in place to which teams need to adapt and comply, and the manager has possibly become the only link between workers and organisation, during this period. As a result, if failing to implement strategies that increase a positive work atmosphere, where teleworkers feel connected and involved with their team, leaders may fail to prevent teleworkers illbeing and contribute to feelings of isolation among team members (Contreras et al. 2020).

Further, the leaders' strategies and wellbeing were also examined as an antecedent of teleworkers perceived performance. More specifically, since perceived wellbeing reflects the effect of individuals' emotional disposition in mental health (Quoidback et al. 2010), it was considered as a possible mediator between leader strategies and teleworkers performance. The results fully supported H2 as leader strategies had a stronger effect on work performance when mediated by employee lower levels of professional isolation and burnout. Individuals who feel simultaneously less distant from their work environment and less exhausted, even if working remotely, take more advantage of the leader's strategies, revealing higher perceptions of work performance. Regarding the direct link between leadership and wellbeing our results are in line with previous literature on the topic. For example, Chang and colleagues (2011) qualitative study on virtual teams suggest that when team's leaders can adequate the strategies to the virtual setting (e.g., spend more time with their team and communicate more frequently) their teams tend to achieve better performance. Nevertheless, the result of the current study goes beyond this direct relation between leadership and performance, that was already established in the literature. Indeed, the results support the direct effect between leaders' strategies on performance, as well as an indirect effect through employee's well-being. These findings are even more relevant since the relationships established in the conceptual model concerns teleworkers and the management of virtual teams. Thus, it shows that these paths are significant for both face-to-face (e.g., Chen and Kao 2012; Inceoglu et al. 2018; Kelloway and Barling 2010; Nielsen and Taris 2019), and in telework.

Overall, the results highlight the positive role of the leader in teleworking context. Like in face-to-face regimes, the influence of leaders might impact on followers' identification with them, the organization, the team, and the job which, in turn, could explain the positive effect on employees' wellbeing (Inceoglu et al. 2018) and performance. Another important aspect that may contribute to explain the results is related to the specificity of the sample collected. Most of the workers who answered the questionnaire may be considered knowledge workers, who have, according to the literature, a more positive view of this regime (Charalampous et al. 2018). Indeed, for this kind of workers working outside the traditional office environment reduces the number of interruptions leading to higher levels of concentration which improves the outcomes of telework (Charalampous et al. 2018). That is, for a sample of knowledge workers the strategies of the leader can be better accepted because these workers, when teleworking, tend to display more positive outcomes (e.g., higher job satisfaction and commitment and lower stress related to job demands—daily tasks and commuting) (Kelliher and Anderson 2010). However, they also reported working long hours (Grant et al. 2013), which is an expected result in the sense that knowledge workers heavily rely on ICTs, which allow them to stay connected when working from different locations (Inceoglu et al. 2018). Thus, the intensity of work and the pressure to be always online will decrease their levels of wellbeing like any other teleworkers (Toscano and Zappalà 2020).

5 Conclusions

The strategies of the leader are fundamental to well-being and performance in a teleworking context. Moreover, when workers show wellbeing at work, the strategies used by the leader seem to have a more positive effect on team performance. Employees' wellbeing contribution to improving teams' performance is undeniable. In fact, wellbeing is by itself, a worthwhile moral value that organizations should stand for and promote. Despite it can sometimes be difficult for managers to recognise it. Therefore, this study has important practical implications for organizations, as it highlights the importance of the strategies implemented by leaders to manage virtual teams that could lead to higher levels of wellbeing, and in consequence, improve the performance perceptions. Taken together, the results reinforce the need for leaders to remain alert to each team member specific needs, especially facing the challenge of physical distance. As teleworking becomes part of the present (and post-pandemic) reality, organizations need to adapt to it and prepare their leaders, so they can be able to use management strategies in a reliable and efficient manner, resulting in positive outcomes for their teams.

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Telework and Women Workers in the Context of the Covid-19 Pandemic: The Case of the Federal Judiciary in Brazil

Evelise Antunes, Marta Santos, Tânia Incerti, and Frida Fischer

Abstract **Introduction:** During the pandemic, the social roles of women were accentuated which were added and distributed in: worker, "housewife", mother and teacher. The objective of this study is to contextualize the social roles of women and the impact of telework, highlighting the case of those who worked at the Brazilian Federal Judiciary during the Covid-19 pandemic.
Material and Methods: Thematic content analysis of open interviews during the pandemic. Eight women workers from different positions in a Judiciary Section participat-ed.
Results: Three main themes are identified: work activity, life outside work, and work time. New tasks, a new way of managing work time and the need to estab-lish clear boundaries to ensure a balance between life at work and life out-side. What was already known is reiterated, women continue to do more hours of domestic tasks, and above all they are the ones who take care of the children.
Conclusions: For women in telework, the two spaces - public and private - merged and become confused. Redesigning the temporalities of work and life in these work-places needs to be accompanied by social level policies that ad-dress caregiving responsibilities and gender equality.

Keywords Telework · Women · Covid-19 · Pandemic · Judiciary

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1 Introduction

The beginning of 2020 was characterized by the pandemic of the new coronavirus SARS-CoV-2, which causes Covid-19, which continues to alarm the world because it is a biological risk with high transmissibility and high power of infectivity and fatality (World Health Organization 2020).

As the pandemic evolved it aggravated economic and social conditions and telework has been encouraged worldwide (International Labor Organization 2020). Public and private organizations have established work arrangements, including remote work/telework, which were never seldom experienced. Teleworking became more visible, as a temporary solution for numerous organizations, helping to reduce costs and maintenance of work continuity and jobs (Eurofound 2020).

However, inequality in the participation of men and women at work is perpetuated in telework (Eurofound 2020; Samek Lodovici et al. 2021). The World Economic Forum (2021) stated that the pandemic added 36 years to the time needed to reduce the gap between men and women, which went from 99.5 to 135.6 years. Brazil ranks 93rd among 156 countries, far from parity. One of the factors behind this deterioration is the stagnation of economic advances, access to telework, the need to provide family care, and women working in sectors most affected by confinement (World Economic Forum 2021).

Some studies point to an uneven impact on telework. Women were more affected, as household chores and childcare remained asymmetric, being more assigned to them, further affecting those who have children (Barros et al. 2020; Durães et al. 2021; Eurofound 2020; Samek Lodovici et al. 2021).

Brazilian judiciary system is divided into state, federal, labor, electoral, military and higher courts. National data on female representation reveal asymmetry in the occupation of positions in the Judiciary, the higher the career level in the Judiciary, the lower the female participation. Federal female titular judges represent 29.5% of the total number of judges (CNJ 2019). Historically an institutional environment more receptive to men than women (Bonelli and Oliveira 2020; European Commission for the Efficiency of Justice 2020; World Economic Forum 2021).

As COVID-19 spread in Brazil, the Brazilian Federal Judiciary deter-mined compulsory telework starting March 2020. Before the pandemic, workers who carried out telework were set higher goals than those who performed the same activity at the workplace. However, for the workers who were forced to work from home there was no such obligation (Antunes et al. 2022; Antunes and Fischer 2020).

Therefore, this chapter, aims to contextualize the social roles of women and the impact of telework, highlighting the case of professionals who worked in the Brazilian Federal Judiciary at the beginning of the Covid-19 pandemic.

2 Material and Methods

Based on the narrative literature review the impact of telework on domestic life are discussed (Baethge et al. 2019; Galvão and Ricarte 2019). These aspects make up a discussion that aims to contribute to the original interpretation of concepts in the public domain, offering a fresh look at a scientific issue of current interest.

This is a case study (Crowe et al. 2011) carried out in a Section of the Brazilian Federal Justice System. In-depth interviews were conducted with eight female workers in the Brazilian Federal Judiciary (Table 1). They are public employees, enjoy stability, career progression, and the possibility to receive extra wages. All had completed higher education, bachelor's in law. All interviews were transcribed, and thematic analysis was performed with software MAXQDA Plus 2022 (Fig. 1) (Braun and Clarke 2006).

We chose to highlight the experiences of working women in the thematic category home/work balance. Results are part of an ongoing doctoral study, approved

Table 1 Characterization of the participating women workers

Subject	Working time in judiciary	Position (manager or technician)	Number of children	Previous telework experience
Serra da Estrela	26 years	Manager	2 (9 and 16 years old)	No
Loureda	22 years	Technician	2 (10 and 19 years old)	Once a week
Oeiras	21 years	Technician	1 (9 years old)	Twice a week
Esmeriz	22 years	Technician	Does not have	No
Évora	20 years	Manager	1 (13 years old)	No
Valença	14 years	Technician	Does not have	Twice a week
Elvas	20 years	Technician	1 (20 years old)	Twice a week
Meã	26 years	Technician	Does not have	Full time

Source Survey data, 2021

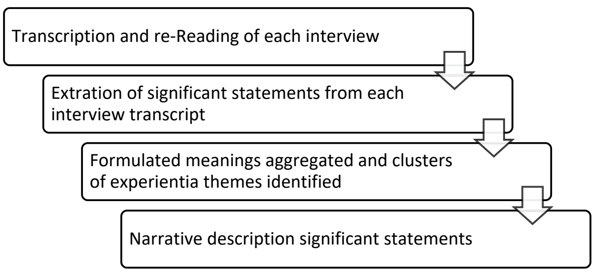

Fig. 1 Stages of thematic analysis of the interviews. *Source* Elaboration of the authors

by the Ethics and Research Committee of the School of Public Health, University of São Paulo, as Certificate of Submission for Appreciation Ethical—CAAE: 15180319.9.0000.5421.

3 Results and Discussion

The interviews revealed different experiences in teleworking during the pandemic. Although half of the women had previously experienced it partially, full teleworking revealed other challenges. The thematic map illustrates the main themes (Fig. 2).

3.1 Multitasking

As the new coronavirus pandemic outbreaks started and the implementation of precautions to prevent spreading the virus, people were either laid off from their jobs, and millions of workers, especially women were allowed to carry out their work activities in remote mode, limiting access to public space (Eurofound 2020, 2021; European Agency for Safety and Health at Work 2021; International Labour Organization—ILO 2020).

Even with all the changes in the world of work and the resources of technology, domestic tasks are still present in the life cycle of women (Chancel et al. 2022). When women have paid jobs and a consolidated career, they often delegate "their"

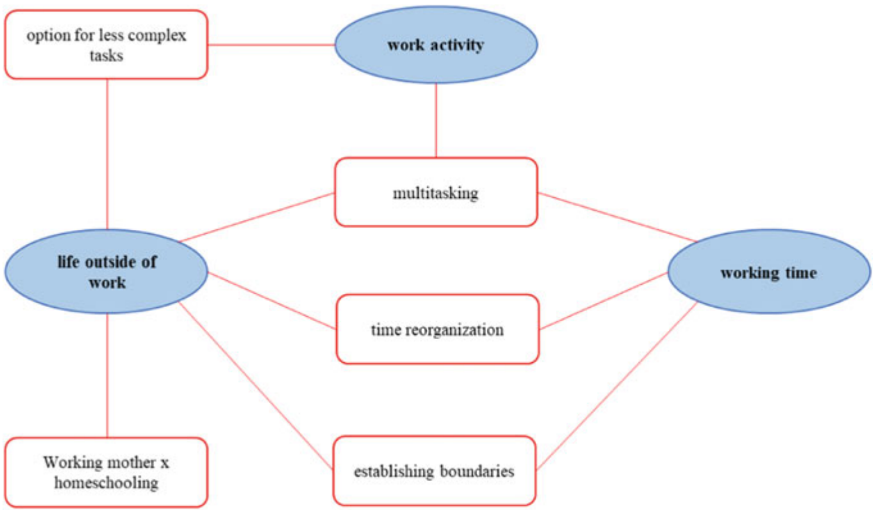

Fig. 2 Thematic map of the interviews. *Source* Elaboration of the authors

domestic and caregiving duties to other women so as not to overburden themselves. (Hirata and Kergoat 2007; International Labour Organisation 2019). Let's see what one of the interviewees told us:

> The husband wants to let off steam, talk about work. He talks as if I have a lot of time available. Subjects that we would talk more at night or on weekends, now it's at any time. So my husband kept talking, as if I wasn't doing anything with my life. The youngest daughter was very complicated in the beginning because I had to sit next to her and give her some orientation during the classes. "You have to write down that the teacher said that the assignment is on such and such a page". And before, even though my life was very busy, I managed to deal better than I do at home 24 hours a day. Because my paid work is very demanding. (Loureda)

Nevertheless, women who did not have children were also impacted during the pandemic. They assisted in the care of parents, brothers, sisters, and family. Historically, women have always had their activities and social roles linked to the domestic environment, having or not another job. As Bruschini (2000) exposes, this delimitation serves to maintain a patriarchal family model, especially considered and still experienced at capitalist society. Model in which men are supposed to have productive activities linked to public environment and women responsibilities related to domestic tasks, related to the reproductive "function". Consequently, working from home may not improve the quality of women's working lives, but rather reinforce traditional gender roles.

3.2 Time Reorganization

The International Monetary Fund indicates that although women do teleworking during the pandemic, they are also the ones who have more difficulty access to licenses in case of illnesses. "Female workers who lack access to adequate leave in case of sickness or disproportionately shoulder care responsibilities may have to cut down their activities or even leave their jobs entirely" (Brussevich et al. 2020, pp. 11, 12).

However, this is not the case for female judiciary workers. Before the pandemic, in some sectors, there was the possibility of teleworking (Antunes and Fischer 2020). Therefore, many women requested it to reorganize their time between home and work tasks. The interviewee Loureda reports a situation that exemplifies this context:

> […] so much so that I asked for a teleworking day back there, like, because it was for that thing, sometimes I need to take my son to the doctor, my daughter has gymnastics, so it ended up being rushed, it was to adapt to a situation that I had at home, not necessarily because I thought teleworking was ideal. And after the pandemic my opinion has changed many times. It's not easy. (Loureda)

However, during the pandemic, the two spaces—public and private—merged and became confused, and the working woman was forced to take care of the house and the work, overloading herself even more, given the merging of social spaces in a single geographic distribution.

In view of the experience of a "multiple" shifts imposed on workers who have children or other dependents, there is a need for them to find additional time in their day to do their work, whether by starting to work very early in the morning, or working until late at night (D'Andrea 2022). They also interrupted the working day in smaller segments, with breaks for childcare, housework, home education, among others. This situation was reported during the interviews, let's observe the following excerpt:

> There are uninterrupted work demands, in the morning, afternoon and evening, including every Saturday and Sunday. I was tiring because home chores continued, so I have to prepare meals, wash clothes, take care of children homework, helping the youngest, studying together with the oldest son, so there's all those things. (Serra da Estrela)

So, what stands out here is the emergence of a new way of managing working time. In a staggered manner, women start working very early, extending to the night hours, working on weekends.

3.3 Option for Less Complex Tasks

The historical construction based on the socio-sexual division of work, is present in the qualification for work activities, in the rules that regulate and discipline the work. In other words, it constitutes an organizing basis for the inequalities present in the world of work and is also present in the division of domestic tasks, which, in most cases, are the sole responsibility of women. These, even when performing paid work activities, are overload to take care of household chores.

Collaborating to this understanding, we resort to Bruschini (2000):

> The constant need to articulate family and professional roles limits the availability of women to work, which depends on a complex combination of personal and family characteristics, such as marital status and the presence of children, associated with the age and education of the worker, as well as the characteristics of the family group, such as life cycle and family structure. These factors affect females, but not participation of males in the labor market. (pp. 16–17)

The speech of a manager exemplifies the fact that a female worker has to choose to leave a more qualified paid job due to her family role, let's see:

> One of the people who worked in the office left. She asked to leave the office because she could not perform complex tasks, because she has a small daughter, then it was difficult for her being able to prepare a judiciary sentence. For example, she needed something less complex, the person also feels bad because she could not prepare anything, so she felt bad for the team and the boss demands, then she changed function […]. (Evora)

Therefore, there was the option to do fewer complex tasks to reconcile working life and private life. Mental suffering was perceived by colleagues as they had productivity goals.

3.4 Working Mother X Homeschooling

The closure school and early childhood education centers led activities to be carried out in the domestic space. In this context, the care and organization of these activities were also the responsibility of those responsible for kids. Studies showed the same when there was an attempt to share home activities, the burden fell on women (NORC at the University of Chicago 2020).

In Brazil, one cannot lose sight of the gender differences involved in the telework experience during the pandemic. The allocation of care to females implied in productive activities in the domestic environment, with a great burden of tasks and demands to the women, especially in a scenario of suspension of school activities for children and adolescents (Durães et al. 2021).

In this sense, the ideal of motherhood, as mentioned by Vivas (2019) oscillates between the sacrificed mother, at the service of the family and children, and the superwoman, capable of achieving everything by combining paid work, caring for the children and housework. To achieve these goals, women started working in the early hours of the morning till late at night. However, stress and guilty do their part in their daily lives. The extract from Évora's interview exemplifies this combined role experienced by women:

> Now in terms of daily tasks, I think everyone had to do a lot: prepare food, cleaning, taking care and paying attention to the children, being a teacher, not being able to do physical activity. Also, I think everyone speeded up but not everyone managed to maintain the rhythm of activity (Évora).

Fernández (1994) states that

> Domestic tasks is seen as inherent to women's nature; women are naturally intended to "care" for children, and within this care would enter the task of educating them. By considering it in such a way, the value of productive work is taken away from it, devaluing the task itself, and those who perform it. (pp. 109)

In view of the above, it is possible to infer that the time allocated by women is greater that spent by men, as women need to care for children, their educational activities carried out at home schooling, and domestic activities. All of those factors contribute to women, especially teleworking mothers, feeling more stressed, tired and depressed during the new coronavirus pandemic (Barros et al. 2020). Here the multiple tasks are integrated with new tasks, such as that of "teacher".

3.5 Establishing Boundaries

> […] speaking of me, before I have weekends and holidays. Now weekends I try not to work, but it is an exception. Holidays I'm already trying not to work. So, when there's a lot of things… before it was morning, afternoon and evening, now (I work) an hour or two more, not every day. (Serra da Estrela)

We understand that it become important to define the limits of working time more clearly. A battle to be fought, considering that telework promotes the deconstruction of the boundaries between the sphere of work and the private environment (intimate, family). The establishment of borders is in contradiction with other ideas of teleworking (which is natural because we do not all work in the same way).

Flexibility and comfort carrying out work in the domestic space can be a fantasy. The alleged satisfaction and management of free time by the employee, means, in practice, the appropriation of the worker's domestic space for the benefit of the organization with the potential to affect working conditions and life outside of work (Durães et al. 2021). The following statement illustrates this:

> [...] when I go back to normal, I will go back not because I did not like teleworking. It is more for a question of goals, because I will not be able... I am managing to maintain more of my goals be-cause I am working outside the hours, because, in a regular day I cannot manage to maintain. (Esmeriz)

Aspects regarding the restrictions imposed by the new work organization were evidenced during this current research. The possibility of continuous family contact, being more present for the children, were some of the positive notes reported by participants. The interviewees told us:

> […] we also have to restrict a little, because there will always be work, if I want to work every Saturday and every Sunday, I must do, but then, I don't have a life either. I have my family and I don't give up on that, to spend the weekend with my family. This is something that we can put aside from time to time, but we can't take it as a rule. (Oeiras)
>
> But, you know, it's gratifying to be with family, to be able to have lunch together, have a coffee, dinner, things that I didn't do, I only saw my daughter or my husband sometimes in the evening hours, so this telework is being very good because of this, staying with my family. (Elvas)

4 Conclusion

Public and private spaces merged and blended for women working as teleworkers during the pandemic. The study of the women in the federal judiciary represent the minority of the Brazilian population as they have a stable and well-paid job. Even so, female workers were forced to take care of domestic and professional work, overwhelming themselves, as they needed to manage two social spaces in a single geographical place.

Redesigning the temporalities of work and private life require to be accompanied by social policies addressing caregiving responsibilities and gender equality. Since this is a case study, the sample size is limited. As possible ways forward, it is suggested that cross-sectional and longitudinal field research could verify the impact of this new work organization in the medium and long terms and at different frequencies, locations, and intensities. However, public policies must be implemented in a democratic context that prevents gender inequalities but allows for different rules when gender inequality is present.

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Emotions and Attitudes Towards Safety—Relationship Between Affective Commitment and Safety Attitudes Among Construction Employees in North Macedonia

Ljupcho Efremov

Abstract Studying the relationship between attitudes towards work safety and affective commitment is of great scientific importance because it is about factors which have substantial influence on individual and group behavior at work. Attitudes towards safety are important in dangerous circumstances (life risk or possibility for injuries) among construction workers, while the study of emotions in relation to safety attitudes provides new perspective for safety. The objective of the study is to test whether emotionally committed employees have more positive attitudes towards safety, while less committed have negative valence towards safety. The hypothesis was that employees with higher degree of affective commitment have more positive attitudes towards safety compared to employees with lower degree of affective commitment. The interviews were conducted with 90 construction employees (high school education) in North Macedonia. The results are in favor of the hypothesis e.g., committed employees have more positive attitudes towards safety. The explanation is that there is a tendency to match attitudes towards safety with the emotions that employees have about the organization. The study offers valuable information that can be used in trainings that create positive attitudes with the aim to reduce fatal and non-fatal injuries during everyday work.

Keywords Safety climate · Emotional commitment · Construction

1 Introduction

The notion that that people spent most of their time at work accent the significance of studying the relationship between safety climate and affective commitment. The interdependence of private and professional and possible spillover adds to the importance of further exploration of this relationship. Due to abovementioned reasons, the relationship of attitudes towards safety and affective commitment offers great contribution to psychology of labor.

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To start the topic, the story of the journalist Miriam will be used. She worked in the local newspaper in a small city in Great Britain. The story is taken from the web page of the International Labor Organization (International Labor Organization, 02.04.2010). The story starts when one day her superior asked her to follow the speech in honor of World Safety Day (28 of April) given by the Minister of Labor. The publisher wanted Miriam to write a text about the death of four miners in the local mine. While doing her research on the topic, access to information about prevention of risks changed the perception of Miriam for safety at workplace. She started exploring her current situation and researched different methods to reduce own risks. She went through all the pages of employers (World News Association, Broadcasting Associations, Unions or Governments) to get more information on safety among journalists. She realized that there are many systems that can help her with safety at workplace and coping with risks from the perspective of prevention and risk reduction. "I knew that there were problems that can have negative impact on my health in my workplace, but I never thought that someone else makes research in that area", she wrote.

2 Key Concepts Description

The theoretical basis of research will be presented in two parts. The first part is about attitudes towards safety, while the second is about affective commitment.

According to Al-Bayati (2022) "construction safety culture" represents policies and principles that guide safety decision-making (i.e., the firm's management level), while on the other hand "construction safety climate" represents the manifestation of construction safety culture (i.e., principles and policies) in construction workplaces (i.e., the firm's project level). Attitudes towards safety are part of safety climate in each organization. Data taken from different studies (Mearns et al. 2001; Zohar 2000) show that perception of safe working are directly and indirectly related to injuries at workplace. The term safety climate is introduced by Zohar (1980; as cited in Currie and Cooper 2008). The author states that safety climate is a type of organizational climate that distinguishes between organizations with high degree of accidents and organizations with lower degree of accidents. Cox and Flin (1998; as cited in Currie and Cooper 2008) write that safety climate is about perception of workplace and therefore measurements of safety climate offer valuable approach and are focused on perceptions that employees have about management and supervision, risk taking, safety rules and practices, trust, openness, and support from the environment.

Safety climate, as defined by different authors (Mearns and Flin 2001; Rundmo 2000; as cited in Currie and Cooper, 2008) is about attitudes that employees have about working safely and are useful indicator for culture of work safety in one organization. For Cox and Flin (1998; as cited in Witt 2007) safety climate is about representations that employees have about safety culture.

The abovementioned definitions show the conceptual differences in safety culture and safety climate. These two terms bear a resemblance to each other in the literature;

therefore, it is important to distinct them. The reason for parallel usage is because there is inconsistency in literature about these two concepts and there is lack of consensus in the usage of the terms. Certain authors (Flin et al. 2000; as cited in Witt 2007) accent that the debate for superiority of culture over climate is prolonged and is subject to different special treatment among safety researchers.

Mearns et al. (2001) treat evaluation of safety climate as a leading indicator for functioning of safety climate practices. The abovementioned authors claim that benefits of evaluation of safety is about identification of weaknesses that safety practices have before those weaknesses are manifested as injuries at the workplace. Application of this principle reduces the need to wait for the system to show mistakes and afterwards to identify the weaknesses. The overall principle is about accepting organizational, managerial, and human factors as key factors for injuries apart from technical factors at workplace (Weick et al. 1999; as cited in Witt 2007).

Cox and Cheyne (2000) conduct a research that included different methods for creating instrument for the evaluation of safety climate. The authors monitor and make evaluations in several companies in petrochemical industry. The research is conducted on offshore oil platforms. Apart from that, independently they conduct interviews and focus groups which are basis for development of questionnaire for work safety. The inventory measures presence of nine attitudes towards safety climate: Personal priorities and need for safety, Personal risk evaluation, Safety priority, Supportive environment, Communication for safety working, Inclusion in safety working, Supervisor's safety engagement, Safety rules and procedures and Working environment. The authors mention only partial data about the research due to data confidentiality. Data are about one organization that is included in the project and show good and bad aspects of the process of implementation of systems for work safety in organization. Management engagement for safety was one of the best evaluated aspects in organization. However, communication, environment support and inclusion of employees were weakest aspects that needed change. These findings emerged both from interviews and focus groups. Apart from that, differences between different profiles and level of management were found. Managers had more positive attitudes towards environment of support, inclusion, personal risk evaluation and work environment compared with employees who worked on oil drilling sites. Also, communication and personal priorities were more positive for manager and employees in oil production compared to employees who worked on oil drilling sites. Explanation for these differences is that affiliation with certain group is related to different safety culture. Research results were used as benchmark for several initiatives for improvement of work safety. Managers decided actively to promote safety at work, and it was decided to hire coach for trainings. Also, special attention was given to safety at work in organizational newspapers and meeting for discussion of safety at work were promoted.

Deepak and Mahesh (2019) conclude that changes in construction sites occur frequently and that often cause accidents and fatalities. Their conclusion is that there is no learning from previous mistakes and describe this opportunity as a potential suitable mechanism to "re-invent the wheel" to prevent accidents to reoccur in the near future. The final goal is to implement knowledge management strategies to enforce safety rules and regulations and to develop a positive safety culture for future construction projects.

Çiftçioğlu et al. (2021) explored safety culture and defined indicators for measurement. The indicators for measuring safety culture were safety follow-up audit reporting, employees' self-awareness, operational safety commitment, management's safety commitment and safety orientation. The authors constructed a fuzzy model with five inputs and one output. The inputs were the five factors mentioned above, and the output generated is the safety culture result, with range between 0 and 1. The model they proposed produced reliable results indicating the safety culture level from the perspective of employees. Also, the authors mention that the model can be used and understood by the practitioners from various sectors. The limitation of their study is that it is performed within only one gun factory (time and money constraints and due to difficulty of finding a second similar workplace). The authors propose next studies to be performed with different manufacturing organizations and to focus on improving safety performance with safety culture.

Witt (2007) conducted research about job satisfaction and attitudes towards safety climate. The author used shortened version of the instrument of Cox and Cheyne. Findings from the research support the thesis that perception of safety climate is related to job satisfaction.

The research of Al-Bayati (2022) evaluates the relative importance of construction safety culture. His paper provides a road map for achieving higher levels of construction safety culture and climate, while having in mind that all actions are important. The framework created within the study emphasizes the overall influence of safety personnel and aims for creating higher levels of construction safety culture that can positively influence the construction safety climate. The conclusion is that safety personnel should initiate effective interactions to communicate the shared responsibility of safety management. Also, the author noted that competency and leadership skills of safety personnel are crucial and therefore must be carefully assessed by upper management during the hiring process. The study findings show that workers and frontline supervisors have shared responsibility in developing a healthy safety climate. The study provides important findings for improvement of overall safety performance in construction workplaces. The result is better construction safety management and reducing fatal and nonfatal injuries.

Organizational commitment (also known as loyalty towards the organization) has been described through different ways e.g., acceptance of goals and values of organization, willingness to work hard due to the organization or a wish to stay in the organization (Porter et al. 1974; as cited in Riggio 2003).

Van Stuyvesant (2007) wrote that there is increased interest lately about studying of organizational commitment due to relationships between employees and organizations in which they work. According to this author, this is due to several reasons. Mostly it is because forms of commitment are found to be good predictors of different types of performances, absenteeism and leaving the job. Silverthorne (2004; as cited in Van Stuyvesant 2007) states that together with the intention to stay in the organization, participation of employees is directly related to organizational commitment.

Idris and Dollard (2011) examined psychosocial safety climate (PSC), work conditions, and emotions in the workplace. Their hypothesis was that PSC has an indirect effect on specific negative emotions (e.g., anger, depression) via job demands and an indirect effect on positive emotion (e.g., engagement) through job resources. The research was conducted among 269 public and private employees from the State of Selangor, Malaysia. The results showed that PSC was negatively related to job demands and positively related to job resources. On the other hand, there were mediating effects where job demands carried the effect of PSC on anger and depression, while job resources carried the effect of PSC on engagement. Another finding was that job demands were negatively related negatively to engagement, and this was a result of anger and depression.

Catino and Patriotta (2013) conducted thorough analysis among pilots about cognition, emotions, and safety Culture in the Italian Air Forces (ITAF). Their analysis consisted of 37 qualitative interviews, analysis of flight mishap cases reported in ITAF's flight safety magazine and observation of briefing and debriefing sessions of pilots. They found that errors often come from sequential action chains that arise from habitual behaviors and that become visible only when unforeseen circumstances occur. Another finding is that cognitive appraisal of risky situations triggers emotions of variable intensity. The most important finding is that cognitive and emotional experiences of errors are grounded in the broader safety culture of an organization. This serves as a supportive context for error reporting and encourages the sharing of information and knowledge about error experiences. Their analysis reveals that cognition, emotion, and safety culture interact through sensemaking processes that can affect learning outcomes.

Zhu et al. (2022) examined the relationship between employees' perception of happy music and their creative performance. Also, they included mediating effect of psychological safety in this equation. The data collection was among 315 employees in the three largest hotels in Mainland China. The end results show that there is a positive relationship between employees' perception of happy music and creative performance. The examined relationship was mediated by perceived psychological safety. The employee felt psychologically safe, and they had creative outcomes during listening happy music in the workplace.

Petitta et al. (2020) conducted cross-country research that sought to identify the simultaneous effects of affective job insecurity and financial stress in relation to employee safety injuries and accidents under-reporting. Also, their aim was to examine the emotional contagion of positive/negative emotions at work and their contribution to economic stress. Data was collected among 498 US and 366 employees in Italy. The results show that that financial stress has primary mediating role between emotional contagion and poor safety outcomes. The conclusion is that income-and employment-related stressors are predictors of safety-related outcomes.

Tixier et al. (2014) conducted a controlled experiment in an augmented virtual environment with 68 participants to test the hypothesis that there is no relationship between emotional state and perceived risk. The goals of the authors were to (1) induce specific emotional states using highly effective video clips, (2) objectively measure emotional states with a validated questionnaire, and (3) objectively measure risk perception using a validated scale and operational definitions of potential outcomes. After data collection, authors used multivariate statistics to reduce the dimensions in the dataset and measure relationships between emotional states and risk perceptions. The obtained results were consistent with theories of affect heuristic for general risk perception (events that had negative affect were perceived as riskier). The results showed that anxious, fearful, and disgusted subjects had the highest relative risk perception and that specific emotions such as anxiety and fear lead to the activation of self-protective processes. On the other hand, sad and unhappy subjects had a lower relative risk perception than anxious, fearful, and disgusted subjects. Some of the important findings were that subjects in the positive group tended to perceive less risk than the neutral group because their positive emotional states is prone to risk aversion when potential losses are large.

Bhandari et al. (2020) examined if emotions influence people's ability to recognize hazards, assess safety risk, and make decisions within an occupational safety context. They created conceptual model on the influence of incidental and integral emotions on hazard identification, risk assessment, and decision-making skills using the current literature from construction safety, risk perception, and decision science. The authors conducted controlled laboratory experiment with 73 participants that were placed in a high-fidelity augmented virtual construction environment. The results did not show direct relationship between induced emotional states and hazard-identification performance. However, the authors conclude that emotions, which are not objective evaluations, could be the primary driver of safety-related decision making. The contribution of the study provided details for improvement of safety training programs and well-being of the employees.

Meyer and Allen (1991; as cited in Van Stuyvesant 2007) state that organizational commitment is defined by two perspectives. The first perspective is behavioral, while the second is about organizational commitment as attitude towards the organization. Behavioral commitment is about the processes with which the employee becomes part of the organization and develops certain appropriate behavior. The second perspective is about processes through which employees connect with the organization and the degree to which their goals and values fit with the organization. The typology of Allen and Meyer (1990; as cited in Zain and Gill 1999) is a model to simplify definitions about commitment and therefore the authors propose a three component model to integrate different conceptualization. The three components are as follows:

- Affective commitment is about emotional attachment of employee with organization.
- Continuance commitment is about attachment as perceived cost related to leaving the organization.
- Normative commitment is about feeling obligation to stay in the organization.

Affective commitment is about prolonging of work in current organization due to emotional attachment, inclusion in the organization and identification with the organization (Allen and Meyer 1990; as cited in Van Stuyvesant 2007). The explanation is that there is emotional attachment of the employee with goals and values of the organization and with the role of employee in pursuing those goals and values.

Apart from those aspects, it is stressed that prolonging the work in the organization is agreeing with goals and values of organization. This means that if employee has strong emotional relationship with the organization, then that employee will stay in the organization because of the wish to stay.

Findings from different research (Finegan 2000; Fritz et al. 1999; Vanderberg and Lance 1992; as cited in Riggio 2003) show that organizational commitment is related to congruence with organizational values and values of the employees. Organizational commitment, according to the results of research of Gilbreth and Ivanchevich (2000; as cited in Riggio 2003), becomes weaker under the influence of perceived chances to find a job in another organization.

All of the above-mentioned papers draw the path for objective of the study which defines emotionally committed employees as more inclined towards safety, while less committed employees have negative attitudes towards safety.

The hypothesis tested was that there is a positive relationship between attitudes towards safety climate and affective commitment towards the organization e.g., the prediction is that employees with higher degree of affective commitment have more positive attitudes towards work safety (among nine aspects). Committed employees have a positive attitude towards the organization and therefore there is a tendency for congruence of attitudes towards safety climate and general picture that those employees have about the organization.

3 Materials and Methods

3.1 Procedure and Instruments

The questionnaire consisted of three parts: attitudes towards work safety, questionnaire for affective commitment and questions about demography (these questions are relevant variables for control). What follows is explanation of used instruments and procedure.

Attitudes towards safety climate are explored with questionnaire for attitudes towards safety climate. The questionnaire is created by groups of experts (University of Loughborough, UK, accessed 12.08.2009). The questionnaire for attitudes towards safety climate is a carefully planned and evaluated instrument that was created on demand from several companies in the petrochemical industry (Offshore Safety Division of the HSE, Chevron UK, Chevron Gulf of Mexico, Ship Shoal/Eugene Island, Mobil North Sea, and Oryx UK).

The instrument that was used consisted of 43 items grouped in nine scales. The inventory measures nine attitudes towards safety climate: Personal priorities and need for safety (5 items), Personal risk evaluation (4 items), Safety priority (4 items), Supportive environment (6 items), Communication on work safety (5 items), Inclusion in work safety (3 items), Supervisor's safety engagement (7 items), Safety rules and procedures (3 items) and Working environment (6 items).

Affective commitment is explored with questionnaire for organizational commitment created by Zain and Gill (1999). The questionnaire is created based on the questionnaire by Allen and Meyer (1990; as cited in Zain and Gill 1999). The version that was used has 8 items that measure affective commitment.

The questionnaire was given individually to respondents, after weekday working time on the working sites or during weekends in respondent's homes. The data was collected before the pandemic. Respondents were briefed about the study and were asked to give consent for voluntarily participation in the interview. There was short explanation before the fulfillment of questionnaire, that participation is voluntarily and anonymous. Duration of interview lasted from 20 to 40 min. The first part of the interview contained demographic information and the questionnaire for attitudes towards safety climate. The second part included the questionnaire for organizational commitment. The questionnaires were printed. The employees were given hard copies with explanation how to answer the different options.

3.2 Statistical Procedure

The tested hypothesis was that employees with higher degree of affective commitment have more positive attitudes towards safety compared to employees with lower degree of affective commitment. Averages on each of the nine dimensions of safety were compared between employees with high and low affective commitment. To test the hypothesis, the data for affective commitment was recoded in three groups (33% high, 33% middle and 33% lower). For the needs of the research only two groups were used (employees with high degree and employees with low degree of affective commitment). To test the assumptions, average values of each of nine aspects of work safety are compared between employees with high degree of affective commitment and employees with lower degree of affective commitment. T-test for independent samples was used for testing the assumptions whether employees with higher affective commitment had more positive attitudes (higher average on nine dimensions) towards safety compared to employees that were less emotionally committed.

3.3 Sample

The research is conducted on a purposive sample of 90 employed persons with high school education from the construction sector in North Macedonia. Apart from education, the following variables are considered as relevant variables: gender (male only), age (employees aged 30–45), experience and hierarchical level (only executors of first level workers are examined). The abovementioned variables are based on relevant empirical research which shows relationship of abovementioned variables with safety climate. This type of purposive sample was used due to importance of safety for employees working in construction and high rates of injuries/mortality in this segment.

Table 1 Summary of results testing

Attitudes towards safety climate	Degree of affective commitment	Mean	SD	t	df	p
Personal priorities and need for safety	Low high	3.98 4.11	0.35 0.49	−1.20	58	0.24
Personal risk evaluation	Low high	2.44 2.53	0.73 0.67	−0.48	58	0.63
Safety priority	Low high	2.60 3.35	0.70 0.91	−3.58	58	0.01
Supportive environment	Low high	2.97 3.36	0.34 0.68	−2.84	58	0.01
Communication for safety working	Low high	2.51 3.02	0.57 0.79	−2.83	58	0.01
Inclusion in safety working	Low high	3.23 3.98	1.02 0.96	−2.94	58	0.01
Supervisors' safety engagement	Low high	2.62 3.25	0.64 0.88	−3.15	58	0.01
Safety rules and procedures	Low high	3.45 3.53	0.88 0.88	−0.36	58	0.72
Working environment	Low high	2.35 2.62	0.51 0.71	−1.69	58	0.10

4 Results

The table that follows presents results from prediction testing. The testing is performed with t-test for independent samples. Statistical tests show that hypothesis is confirmed in five out of nine situations so the hypothesis can be considered as confirmed. The results in Table 1 show that employees in high risk profile (construction) with high level of affective commitment compared to employees with lower level of affective commitment have more positive attitudes regarding following safety aspects: Safety priority ($p < 0.01$), Supportive environment ($p < 0.01$), Communication for work safety ($p < 0.01$), Inclusion in work safety ($p < 0.01$), and Supervisor's safety engagement ($p < 0.01$).

5 Discussion

The purpose of the study was to test relationship between emotions and safety attitudes. The hypothesis that there are more positive safety attitudes among employees with higher level of affective commitment compared to employees with lower affective commitment was accepted for the following safety aspects: safety priority, supportive environment, communication for work safety, inclusion in work safety and supervisor's safety engagement.

Since acceptance of hypothesis for safety priority among employees with high degree of affective commitment, there is a belief about safe work in the organization. Acceptance of hypothesis for supportive environment is because employees with high degree of affective commitment are connected to the organization and other employees. Related to this is emotional engagement (high degree of affective commitment) that this group invests in the organization and has expectations about reciprocal investment by the organization. Another outcome related to abovementioned factors is confirmation of hypothesis for communication. Employees with high degree of affective commitment are included in safety at work because inclusion in safety is reward for their connection to the organization. Hypothesis for supervisor's safety engagement is confirmed because more committed employees perceive those supervisors to strive for safety. Accordingly, their affective commitment towards the organization makes them affective towards supervisors and there is a tendency to evaluate supervisor positively due to affective commitment. The reasons for confirmation are due to congruency of attitudes e.g., there is a tendency to match attitudes towards safety with the overall representation that employees have about the organization. The general notion that emotion is related to safety is supported by the work of Tixier et al. (2014) who found that events that had negative affect were perceived as riskier. The results showed that the group that was anxious, fearful, and disgusted subjects had the highest relative risk perception while the positive group tended to perceive less risk than the neutral group. The explanation was that their positive emotional states made them prone to risk aversion when potential losses at stake were large. Another complementary finding is found in the work of Bhandari et al. (2020). Their conclusion is that emotions, not objective evaluations, could be the primary driver of safety-related decision making. The results are intended for improvement of safety training programs and well-being of the employees.

On the other hand, the hypothesis that there are more positive safety attitudes among employees with higher level of affective commitment compared to employees with lower affective commitment was rejected for the following safety aspects: personal priorities and need for safety, personal risk evaluation, safety rules and procedures and working environment. Hypothesis for personal priorities and safety needs is not confirmed because employees from both groups (high and low degree of affective commitment) have low level of awareness about work safety. Low level of risks in the job is present among two groups (high and low degree of affective commitment) and it is related to risk evaluation and therefore hypothesis for risk evaluation is not confirmed. Hypothesis for rules and procedures for safety work is not confirmed because employees in both groups (high and low degree of affective commitment) have low level of awareness about the rules and procedures for safety e.g., are not familiar with rules and procedures. Work environment is about conditions (equipment, daily targets, time and human resources) in the environment that contribute to work safety. Absence of those conditions results in rejection of hypothesis for employees in both groups (high and low degree of affective commitment) and general picture for absence of abovementioned conditions in construction is reflected. This is in line with findings of Cox and Cheyne (2000) who found that affiliation with certain group is related to different safety culture. The context for such results can be found in the work of Deepak and Mahesh (2019) who found out that frequent change in construction sites leads to accidents and fatalities.

Findings presented in this paper shed light on the relationship between work safety and affective commitment. Implications for practical application of the information gathered with the research can be used by Safety Departments and Human Resource Departments in organizations in which there are risks for fatal and non-fatal injuries at workplace. Usage of the results for safety training suggests that employees would get higher affective commitment towards the organizations and would work safely. Application of different practices for increasing affective commitment by supervisors in combination with safety training will lead to safe working. The above-mentioned outcomes lead to a "win–win" situation that has positive benefits for both parties (employees and organization). Apart from that, there is a constant need for raising awareness for safety climate among employees. The call for work safety follows up the story of journalist Miriam (stated at the beginning of the paper), who got deeper insight about the problem of safety-at-work. As a result of the comprehensive research, she started thinking about own occupation and risks in journalism. The written article was directed towards raising awareness for safety at work and names it: My Life, My Work, My Safe Work. The outcome for the death of four miners in the local mine is as follows:

> The tragedy from past week, in which our city lost four brave miners shows us how important are problems related with risks at workplace. Events like that make us question risks related to our own workplaces. In this article I had intention to make a profile of several risks that local employees face, but I found out that I should not look further than my workplace in order to discover many opportunities for risk reduction… .
>
> (International Labor Organization, 02.04.2010)

The article of journalist Miriam promotes care for wellbeing and health of people. Important implication that comes out of this research is that organization of work should include anywhere possible, information about safety at work. The study provides details that can be used in trainings to enhance affective commitment towards the organization and to combine this with safety trainings with the final goal to reduce fatal and non-fatal injuries during everyday work.

Further research should include employees of higher levels and in different organizations and different industries where safety plays substantial role. Also, interviews with human resources managers and safety managers can add value to the study and confirm stated reasons for the abovementioned relationship. The study can be expanded through in-depth interviews or focus groups with the same employees included in the sample regarding further exploration of safety culture and affective commitment towards the organization.

The limitations of the study come from the sample, single company, and employees from one industry (construction). The current sample includes employees that are first level executors in construction industry. The situation is similar in other construction companies, but this notion needs empirical validation. Apart from that, the study can be conducted in other industries where safety is important.

The conclusion that comes out of testing the relationship between safety climate and affective organizational commitment is that assumptions about relationship of variables are partially confirmed. The hypothesis was tested nine times with different safety aspects e.g., that employees with higher degree of affective commitment had more positive attitudes towards safety compared to employees with lower degree of affective commitment. Employees with high degree of affective commitment have more positive safety attitudes regarding safety priority, supportive environment, communication for work safety, inclusion in work safety and supervisor's safety engagement compared to employees with lower degree of affective commitment. The results are congruent with former studies which match attitudes towards safety with emotions that employees have about the organization. The results obtained on 90 construction employees in North Macedonia point out implications for safety trainings with aim to reduce risk in dangerous occupations.

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Occupational and Environmental Health

Epigallocatechin-3-Gallate (EGCG), An Alternative to Extenuate Occupational Risk Factors Outcomes?—An Interventional Study

Carina Ladeira, Mário Pádua, and Edna Ribeiro

Abstract Introduction: Occupational risk factors are major players for increased risk of cardiovascular diseases and cancer. Studies support a protective role of Epigallocatechin-3-gallate (EGCG) in disease onset, with associated antioxidant properties and reactive oxygen species production. We aimed to evaluate the in vivo effects of EGCG intake on cardiovascular risk factors, DNA damage and oxidative DNA damage. Methods: Voluntaries were enrolled in this interventional study with safeguard of all ethical considerations. Peripheral blood was collected at the beginning and after 90 days of 225 mg EGCG ingestion per day. Lipid profile and liver function parameters were assessed using colorimetric methods. Vitamins A and E in serum were quantified by HPLC–DAD. DNA damage and oxidative DNA damage were assessed through comet assay. Results: Vitamin A, as well as the lipid profile and liver function parameters, were not affected by EGCG intake, whereas serum levels of vitamin E, DNA damage and DNA oxidative damage increased after EGCG consumption. Discussion/Conclusions: EGCG induce low-level oxidative stress which may trigger protective antioxidant systems associated with vitamin E. Further research is crucial to understand the extent of EGCG effects and its potential as an alternative to extenuate occupational risk factors outcomes.

Keywords Occupational risk factors · Epigallocatechin-3-gallate (EGCG) · Hematologic parameters · Oxidative DNA damage · Antioxidant defence systems

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1 Introduction

Occupational risk factors are currently considered major players in the onset of human diseases, as evidence from several cohort studies in Europe, USA and Japan, which included over 600,000 individuals, indicate that work stressors and occupational exposure to chemicals such as lead, are correlated with an increased risk for cardiovascular diseases such as incident coronary heart disease and stroke (Kivimäki et al. 2015; Poręba et al. 2011). Additionally, increased incidence of different types of cancer can also be related to occupational exposures (Pukkala et al. 2009).

Epidemiological and interventional studies support a protective role of green tea in the development of several diseases, including cardiovascular diseases and cancer (Singh and Li 2012). Green tea, prepared from the dried leaves of the plant *Camellia sinensis* (Theaceae), is one of the most popular beverages worldwide, and it is known to contain catechins, dietary polyphenolic compounds associated with a variety of beneficial health effects. The widely renowned biological actions of catechins have been associated with their antioxidant and free radical scavenging properties (Aydin et al. 2015; Singh and Li 2012). Epigallocatechin-3-gallate (EGCG), the major polyphenol in green tea, has been shown to inhibit cancer cell growth and tumorigenesis in vitro (Ahmed et al. 2004) and in animal models (Kaur et al. 2007; Yang et al. 2009), during the initiation, promotion and progression stages, particularly by eliminating cancer cells through induction of apoptosis but also by protecting normal cells against genotoxic hazards (Kuroda and Hara 1999; Lambert and Elias 2010; Roy et al. 2003). Also, interventional human studies using catechins as supplement, observed a decrease of plasma oxidized LDL in comparison with controls (Nami et al. 2007), and in smokers it was verified a reduction of benzo[a]pyrene adducts (Hakim et al. 2003; Schwartz et al. 2005), however the study from Eichenberger et al. (2009), did not find significant effects of green tea extract on oxidative stress markers.

On the other hand, our previous study have demonstrated that EGCG consumption is able to impact plasma molecular profile (Ruben et al. 2020), and several studies have suggested genotoxicity and carcinogenic potentials of EGCG, by showing induction of oxidative stress and DNA damage through the generation of reactive oxygen species (ROS) (Aydin et al. 2015; Kanadzu et al. 2006; Lu et al. 2013) in human lymphocytes (Lu et al. 2001), cancer cell lines, xenograft tumors, and mouse liver. Therefore, EGCG seems to have a dual role as antioxidant and pro-oxidation, and these effects were suggested to be due to H_2O_2 generation by polyphenols in solution.

As previously stated, ROS react with cellular components, causing oxidative damage to biomolecules and specifically oxidative DNA damage which may involve the cleavage of single and double-strands of DNA (Aydin et al. 2015). This type of DNA lesion is able to be detected by comet assay (Collins 2004, 2009), a technique used for the assessment of protective effects of antioxidants on DNA damage in human nutrition studies (Gillian et al. 2008) with or without the addition of the repair enzymes, such as formamidopyrimidine N-glycosylase (FPG), to characterize DNA lesions due to the repair of oxidized bases (Collins et al. 2001).

The aim of this study was to perform an interventional study to evaluate the effects, in vivo, of EGCG intake during an interventional study with 90 days duration in cardiovascular risk factors, namely lipid profile and liver function parameters, vitamins A and E levels, DNA damage and oxidative damage in individuals' lymphocytes which ingested commercial capsules of green tea extract (225 mg EGCG/capsule), in order to assess its potential as an alternative to minimize occupational risk factors effects in the onset of cardiovascular diseases and cancer.

2 Methods

2.1 Study Population and Design

This is an interventional, uncontrolled, prospective, longitudinal and of individual analysis study, which included 30 healthy individuals (with no previously diagnosed pathologies). Inclusion criteria considered were adult voluntaries (ages superior to 18 years old and less than 65 years old) with no acknowledged previously diagnosed pathology of any type. Exclusion criteria applied were included viral infections, consumption of tea and forgotten capsules on consecutive days during the study. Data was analyzed under blind conditions.

2.2 Supplementation and Questionnaires

Commercial capsules of green tea extract with 225 mg EGCG/capsule (My Protein®) were provided for all the participants in the study with the instructions to take 1 capsule daily. EGCG dosage was selected considering that, 400 mg and 800 mg of EGCG intake, which are considered safe doses previously used in human clinical trials (Identifier:NCT00942422, n.d.) result in peak serum concentrations in the range of 100–400 ng/mL (Chow et al. 2003a, b). Thus, the selected dosage is considered safe. The participants filled up 2 questionnaires, the first in the moment of the first blood collection (T0; June) with questions regarding demographic data such as age, gender, weight (cm), height (kg) and smoking habits. In the second questionnaire, after 90 days (T90; September) of the interventional study, the participants were asked to report adverse effects through the intervention, namely alterations in the nervous system (headaches, migraines, mood swings); gastrointestinal system (heartburn, reflux, diarrhea, cramps, weight loss/gain); cardiac and respiratory effects and information regarding potential missing capsules intake.

2.3 Collection of Biological Samples

Peripheral blood of the volunteers was collected in a tube with anticoagulant ethylenediaminetetraacetic acid (EDTA) VACUETTE® for Comet assay and in a serum tube with no anticoagulant VACUETTE® for assessment of lipid profile and liver function parameters and HPLC determination of Vit E [α-tocopherol]/μM and Vit A [retinol]/μM, using standard blood collection procedures at time 0 (T0) and after 90 days (T90) of the daily ingestion of 225 mg EGCG/capsule. All samples were refrigerated at 4 °C until processed in the laboratory.

2.4 Lipid Profile and Liver Function Parameters

Blood samples (serum tubes) were centrifuged at 5000 rpm for 5 min and lipid profile parameters determination was preformed using colorimetric methods Triglycerides (mg/dL, LPL/GK/GPO-PAP); Cholesterol (mg/dL, LPL/GK/GPO-PAP); HDL (mg/dL, PEG/CHOD-PAP) and Friedewald calculus for LDL (mg/dL). Liver function parameters namely, transaminases GOT (UI/L) and GPT (UI/L) were assessed using colorimetric methods (IFCC com act. P5P) and GGT (UI/L) trough Colorimetry kinetics. All parameters were determined in the Laboratory of Clinical Analyses—General Lab, Lisbon.

2.5 Comet Assay

Lymphocytes were isolated from blood samples collected by use of a Ficoll-Paque® gradient and placed in RPMI1640 medium, cryopreserved in a freezing mix (90% v/v of FBS and 10% v/v DMSO) and stored at −80 °C for comet assay analysis. For the analysis of DNA damage and oxidative DNA damage, a modification of the comet assay (originally described by Singh et al. 1988), was performed to assess the DNA oxidation in these cells (Collins et al. 2012; Collins 2014). Briefly, cells were thawed at 37 °C and centrifuged to eliminate freezing mix; it was diluted 30 μL of cell suspension was diluted in 140 μL of 1% low melting-point agarose (Pronadisa), and 70 μL of this mix was transferred as a drop onto the slide pre-coated with 1% standard agarose (SeaKem®), in a total of 2 drops per slide, and each was then covered with a coverslip to set the gels. As positive control, cells were treated with 100 mM H_2O_2 were used as a control. Afterwards, slides were then placed in a lysis solution (2.5 M NaCl, 0.1 M Na_2EDTA, 10 mM Tris and 1% Triton® X-100, pH 10), for 1 h at 4 °C. For oxidative damage detection, slides were incubated with the FPG (kindly donated by Prof. Andrew Collins) for 30 min at 37 °C. After this treatment, all slides were submerged into an electrophoresis solution (10 M NaOH and 0.5 M EDTA) for 40 min at 4 °C and subsequently electrophoresis was conducted in the same solution under 20 V for 20 min at 4 °C. After washed and air dried, the gels were stained with DAPI. The scoring of 100 comets per slide was performed with Comet Assay IV Perceptive Instruments® software. The visualization of the slides was performed by a single observer (Collins 2012).

2.6 High Performance Liquid Chromatography (HPLC)

Blood samples (5 mL) were collected in serum tubes and centrifuged at 5000 rpm for 5 min; serum samples were put in 1.5 mL microtubes and stored at −20 °C. Vitamins A (retinol) and E (α-tocopherol) were determined in the serum using reverse-phase high-performance liquid chromatography with a diode array detector (HPLC–DAD; Thermo Scientific Surveyor, USA) adapting the method described in Jaworowska and Bazylak (2014) and Ladeira et al. (2015). Vitamins A and E were separated on a 200 × 4.6 mm Hypersil-BDS C18 column (Thermo Scientific®) with a 10 × 4 mm precolumn Javelin BDS C18 (Thermo Scientific®) using pure methanol as the mobile phase. Tocopheryl acetate was used as internal standard. Detection was performed by Diode Array at 325 and 295 nm for retinol and α-tocopherol, respectively. Chromatograms were integrated automatically by the system software Xcalibur 2.0.

2.7 Statistical Analysis

Data obtained were organized using the IBM SPSS software, through which all the statistical treatment was performed. The level of significance was established at 5%. Kolmogorov–Smirnov test was applied to verify the differences between the values of each variable in T0 and T90, with the aim to access whether there is statistical evidence that they follow a normal distribution. Descriptive statistics, case study analysis and inferential statistics (Student's t test) was performed.

3 Ethics Statement

This work was developed in a context of a research study for graduate thesis dissertation of Laboratory Biomedical Sciences degree of Escola Superior de Tecnologia da Saúde, Instituto Politécnico de Lisboa, Portugal. All volunteers provided a signed written informed consent before enrolment in the study in accordance with the Helsinki Declaration and Oviedo Convention and in Agreement with the Portuguese Law nº 58/2019 de 8 de agosto regarding data protection.

4 Results

Before enrollment in the study, voluntaries signed a written informed consent and at T0 before blood collection completed a demographic questionnaire with data regarding age, gender, weight (cm), height (kg) and smoking habits from which results are summarized in Table 1. After the 90 days intake of EGCG voluntaries responded to a second questionnaire regarding potential secondary effects including alterations in the nervous system (headaches, migraines, mood swings); gastrointestinal system (heartburn, reflux, diarrhea, cramps, weight loss/gain); cardiac; respiratory. No adverse effects were reported by the volunteers.

4.1 Lipid Profile and Liver Function Parameters Are not Affected by EGCG

Potential effects of 225 mg EGCG daily intake in lipid profile (Triglycerides, cholesterol, HDL, and LDL) and liver function parameters (AST, ALT, GGT) were evaluated trough using standard laboratory colorimetric methods and kinetics. No significant differences between the average values of the analyzed parameters were observed at T0 and T90, as demonstrated in Table 2, which indicated that EGCG 225 mg daily consumption does not affect lipid profile and liver function in vivo.

4.2 Serum Levels of Vitamin E Increase After EGCG Consumption

Serum variations of α-tocopherol (vitamin E) and retinol (vitamin A) potentially associated with EGCG 225 mg capsule consumption for 90 days, were assessed by HPLC. Vitamin E serum levels have significantly increased (31.48 and 35.26 respectively, Student's t test $p = 0.041$), however no significant effects in serum levels of vitamin A were observed between T0 and T90 (2.73 and 2.47 respectively, Student's t test $p = 0.419$), as demonstrated in Fig. 1.

Table 1 Characterization of voluntaries enrolled in the study

Male	Female	Age	Height (cm)	Weight (kg)	Smoker	Non smoker
10	20	19–43	155–195	45–108	1	29

Table 2 Lipid profile and liver function parameters determination prior (T0) and after 90 days (T90) of EGCG 225 mg daily capsule consumption

	Triglycerides (mg/dL)	Cholesterol (mg/dL)	HDL (mg/dL)	LDL (mg/dL)	AST/GOT (UI/L)	ALT/GPT (UI/L)	GGT (UI/L)	Ratio LDL/HDL
T0 (mean ± std. dev.)	107.77 ± 45.07	183.4 0 ± 37.88	61.60 ± 13.81	100.30 ± 28.59	24.23 ± 8.9	25.37 ± 8.39	19.13 ± 18.82	1.68 ± 0.49
T90 (mean ± std. dev.)	119.17 ± 41.44	181.67 ± 31.11	63.53 ± 14.85	93.97 ± 22.18	25.40 ± 9.29	30.73 ± 22.01	22.07 ± 25.38	1.55 ± 0.53

Results are presented as (mean ± SD; N = 30)

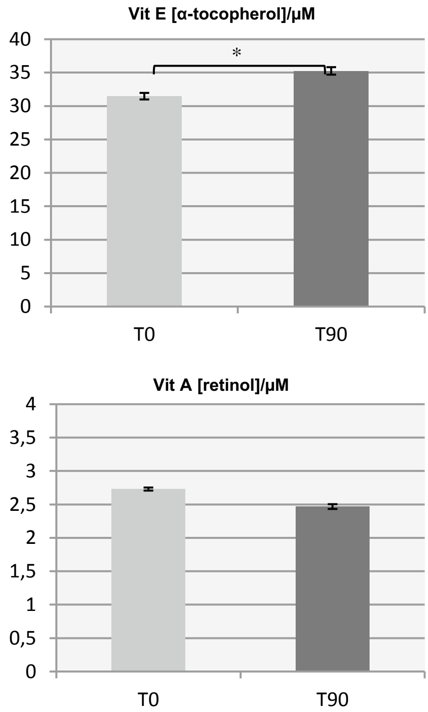

Fig. 1 HPLC determination of Vit E [α-tocopherol]/μM and Vit A [retinol]/μM average prior to EGCG consumption (T0) and after 225 mg EGCG daily capsule for 90 days (T90). Experiments were replicated three times. Student's t test (* $p < 0.05$)

4.3 *EGCG Consumption Induces DNA Damage and Oxidative Damage*

Global DNA damage and oxidative DNA damage—particular type of DNA damage caused by the oxidation of the nucleotides, were both assessed by comet assay. Descriptive statistics is presented in Table 3, where is possible to verified that regarding both parameters assessed—% DNA damage and % DNA oxidative damage—there is an increase after 90 days of EGCG intake (19.77 ± 12.70 and 19.87 ± 5.65) in comparison with T0 (10.40 ± 11.08 and 13.33 ± 8.17), respectively. In order to observe the distribution of the DNA damage and DNA oxidative damage, Fig. 2 showed that in general T90 samples presented slightly higher increase of DNA damage in comparison with T0 samples.

Table 3 % DNA damage and % DNA oxidative damage means (mean ± SD; N = 30) prior to EGCG consumption (T0) and after 90 days of 225 mg EGCG/daily capsule (T90) (mean ± SD; N = 30)

	% DNA damage mean ± std. dev	% DNA oxidative damage mean ± std. dev
T0	10.40 ± 11.08	13.33 ± 8.17
T90	19.77 ± 12.70	19.87 ± 5.65

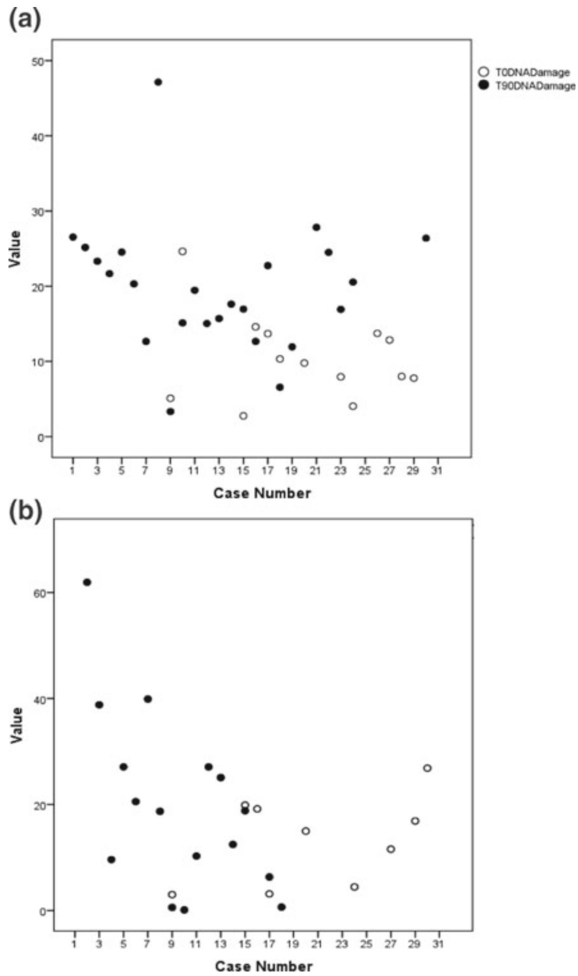

Fig. 2 Graphic representation of % DNA damage (A) and % DNA oxidative damage (B) of the T0 (N = 30) and T90 samples (N = 30) distribution in all analyzed individual samples from the volunteers enrolled in the study. White dots represent T0 samples and black dots T90 samples

5 Discussion

Currently, cardiovascular diseases and cancer are some of the most concerning diseases worldwide, with associated occupational risk factors as key players. In this context, the unquestionable and widespread human exposure to several compounds, including natural products with described health benefits, such as antioxidant properties, raises questions regarding its potential benefic effects for human health.

Green tea, one of the most consumed beverage in the world, has described antioxidant properties which include the ability to limit the amount of free radicals by scavenging ROS, upregulating basal levels of antioxidant enzymes, and increasing the activity of these antioxidant enzymes (Reygaert 2018). However, the pro-oxidant effects of green tea polyphenols have also been suggested as potential mechanisms for cancer (Lambert and Elias 2010) and cardiovascular diseases prevention associated with reduced total lipid levels and improved LDL to HDL ratio (Bhardwaj and Khanna 2013).

EGCG, the major polyphenol in green tea, has demonstrated antioxidant effects related to anticancer function, particularly associated with decreased cell proliferation and induction of apoptosis in colon carcinoma cells, inhibition of adhesion and invasion of hepatoma cells and downregulation of ROS levels (Min and Kwon 2014). EGCG has been used in human clinical trials, where 400 mg to 800 mg of EGCG intake, which result in peak serum concentrations in the range of 100 to 400 ng/mL, are considered safe doses (Chow et al. 2003a, b). Moreover, a recently published review of toxicological evidence from laboratory studies demonstrated that the liver is a target organ for EGCG, associated with levels and dosing conditions, which can present hepatotoxicity with associated alterations in liver function parameters (Hu et al. 2018).

In our interventional study, we did not observe any alteration in the individual's lipid profile or liver function parameters induced by the daily exposure to 225 mg of EGCG, which agrees with the previously described safe dosage threshold.

On the other hand, although previous studies have demonstrated that EGCG prevented DNA damage at low concentrations in different cells, it also acted as a pro-oxidant at higher concentrations (Johnson and Loo 2000). Additionally, under certain conditions, catechins may be unstable and undergo auto-oxidation and behave like pro-oxidants (Lambert and Elias 2010; Min and Kwon 2014). Studies in vitro showed that 10 μM EGCG increased DNA damage assessed by alkaline comet assay after 1 h and enhanced micronuclei formation after 24 h (Elbling et al. 2005). Results from Aydin et al. (2015) showed that above the concentrations of 0.01 μM EGCG a significant antioxidant capacity is observed and at all concentrations studied above 5 μM of EGCG significant DNA damage was reported (Aydin et al. 2015). However, within the concentrations of 0.01–10 μM EGCG significantly reduced oxidative DNA damage induced by H_2O_2 and at the concentration of 5 μM EGCG induced FPG sensitive sites indicating the increased oxidized purine base levels. Study from Kanadzu et al. (2006) reported that EGCG was inhibitory against DNA breakage stimulated or not by mutagens in lymphocytes at relatively lower concentrations, but increased DNA breakage in lymphocytes at higher concentrations, all experiments measured by comet assay. Considering these findings, it was suggested that the pro-oxidative effects of EGCG at high concentrations might resulted from the generation of radicals, and EGCG is both antioxidant and pro-oxidant. Nevertheless, it is important to emphasize that EGCG effects observed in vitro may not be the same as in vivo due to obvious complexity of living organisms (Kim et al. 2014).

Our results, regarding in vivo genotoxicity assessment, showed an increase of DNA damage % and oxidative DNA damage parameters from T0 to T90, which indicate a pro-oxidant effect of EGCG at the tested concentration. Although 225 mg is considered a low safe dose it is relevant to contemplate that in this study exposure was continued for 90 days, which is not taken into consideration by in vitro studies.

Furthermore, previous studies have described that pro-oxidant effects appear to be responsible for the induction of apoptosis in tumor cells (Furukawa et al. 2003) but may also induce endogenous antioxidant systems in normal tissues offer protection against carcinogenic insult (Lambert and Elias 2010). Depending on the source, antioxidant defense systems can be endogenous—antioxidant enzymes and non-enzymatic antioxidative system; and exogenous—classified depending to their origin as natural, nature-identical and synthetic (Hevelke et al. 2016). While EGCG is classified as a synthetic antioxidant, nature-identical antioxidants such as Vitamin E, a major lipid-soluble component in the cell antioxidant defense system, also have well described effects in oxidative stress management (Hevelke et al. 2016). Vitamin E, has been described as crucial for anti-inflammatory processes, inhibition of platelet aggregation, immune-enhancing activity associated with prevention and reversal of several disease pathology and complications, including cancer, ageing, arthritis and cataracts (Rizvi et al. 2014).

Here, the increase of vitamin E serum levels associated with increased DNA damage and oxidative DNA damage suggest that moderate/low concentrations of EGCG, can induce low level oxidative stress which may be beneficial cue for the body to initiate induction of protective anti-oxidant systems and boost immune responses (Kim et al., 2014).

Overall, EGCG continuous exposure to low concentrations (225 mg daily exposure for 90 days) endorse some level of oxidative stress that may lead to the induction of endogenous antioxidant systems (Lambert and Elias 2010) with no effects in lipid profile or liver function parameters in vivo.

6 Conclusions

In this study, we demonstrated that the daily consumption of low concentrations of EGCG (225 mg) does not affect lipid profile or liver function parameters in vivo in healthy volunteers, however it increases low level oxidative stress observed by DNA oxidative damage which may act as a beneficial cue for the body to initiate induction of protective antioxidant systems associated with vitamin E, and boost immune responses. Further research is crucial in order to understand the extent and potential effects of EGCG in oxidative stress, DNA damage and DNA oxidative damage and potential interactions with antioxidant defense systems, as well as its potential as an alternative to minimize occupational factors effects in the increased risk of cardiovascular diseases and cancer.

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Biomarkers of Effect and Biomarkers of Exposure Among Firefighters: Is There Any Correlation? A Review

Bela Barros, Marta Oliveira, and Simone Morais

Abstract *Background* Firefighting encompasses several health risks caused by exposure to toxic chemicals and due to the highly physical- and psychological demanding activities. Biomonitoring, based on biomarkers of effect and exposure, has been increasingly used to characterize the health status of firefighters and promote occupationally safer environments. *Objective* This study aims to identify possible correlations between biomarkers of exposure and effect among firefighters. *Method* Scientific databases were used to retrieve all the published information until December 2021. *Results* A total of eleven studies was found to explore the application of both types of biomarkers (exposure and effect). Chemicals such as polycyclic aromatic hydrocarbons, metals and other woodsmoke components, per- and polyfluoroalkyl substances, and flame retardants were biomonitored in blood, and urine. Generally, there were associations between these chemicals and altered biological mechanisms in blood and in urine including oxidative stress, inflammation, DNA damage, metabolic syndrome and thyroid hormone levels. However, overall, these findings, alone, are not sufficient to establish causality. Nevertheless, they are important starting points to address this problem and to stimulate the development of future studies, especially follow-up cohorts, which can gather more information and better confirm these associations.

Keywords Human biomonitoring · Health risks · Firefighting · Firemen · Occupational exposure

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1 Introduction

Natural disasters, such as forest fires, have dramatically increased their frequency (EC 2021). Firefighters are at the frontline of any type of fire combat, being exposed to a variety of health hazards. Depending on the vegetation burnt, wildland fires can release several chemicals into the atmosphere including a diverse proportion of volatile organic compounds (such as polycyclic aromatic hydrocarbons), nitrogen oxides, metals and metalloids, different fractions of particulate matter (e.g., PM_{10}—particles with an aerodynamic diameter less than 10 μm, $PM_{2.5}$—particles with an aerodynamic diameter less than 2.5 μm, ultrafine—particles with an aerodynamic diameter less than 0.1 μm), organic/elemental carbon, levoglucosan, etc. (Navarro et al. 2018). On the other hand, structural fire emissions largely depend on the type of burnt material and may release additional pollutants, namely, phthalates, phenols, flame retardants, metals and metalloids, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, polychlorinated biphenyls, polybrominated diphenyl ethers, perfluoroalkyl acids, among others pollutants (Fabian et al. 2014; Kirk and Logan 2015). Therefore, firefighting encompasses several stressful conditions combined with toxic occupational exposure, which can lead to the stimulation of pathological pathways and consequent increase of potential health risks (Barros et al. 2021, 2022). Altogether, the evidence gathered during the last years has been demonstrating short-term effects related with firefighting activities, namely eye, nose, and throat irritation, headaches, vomiting and the aggravation of respiratory diseases (e.g., asthma, sinusitis, and rhinitis) (Gianniou et al. 2018). In addition, prolonged exposures to fire emissions have shown to increase the risk of diseases development, mainly those related with immune function declines, lung, liver and cardiorespiratory diseases (Adetona et al. 2016). Furthermore, several reports have been indicating a higher incidence of lung, brain, bladder, breast, kidney, ureter, colorectal, testicular, prostate, and esophageal cancers as well as leukemia, multiple myeloma, non-Hodgkin's lymphoma, and benign neoplasms in firefighters (Barry et al. 2017; Glass et al. 2016).

Human biomonitoring is an important tool to assess the dose that is absorbed by firefighters during their exposure periods and also the consequent biological alterations that can be promoted due to such exposures (Zare Jeddi et al. 2021). Biomarkers are molecules that are measured in biological samples such as saliva, blood, urine, exhaled breath condensate, nails, hair, etc.. Biomarkers of exposure in blood reflect the absorbed concentration that is circulating throughout the human body. On the other hand, urine exposure biomarkers can be used to estimate the internal dose that was recently assimilated by the human organism and went through an enzymatic metabolization before excretion. Consequently, several biological samples can be used to monitor acute and long-term exposure depending on the persistence and nature of the chemicals that are being studied. In the case of biomarkers of exposure, the route of exposure is important to choose the most reliable matrix. Effect biomarkers are molecules that take part in specific biochemical or pathological pathways, which can reflect the current health status or disease risk (Nordberg 2010).

Independently of the route of exposure, the total absorbed dose of chemicals can trigger some changes in biomarkers of effect. The most significant effects can also reflect the main route, for example, if the exposure was mostly through the respiratory system, it is expected a higher impact on respiratory health biomarkers than on systemic ones, but influence on the latter cannot be excluded. Nevertheless, the complexity of human body response is reflected by the increased concentration of systemic biomarkers of effect even when the exposure is multiple sided (Barros et al. 2021). Biomarkers of effect have an inter- and intra-individual variability, which can limit the interpretation of the generated data. Therefore, when discussing the results related with effects, each individual general health (e.g., previous diagnosis), age, and other parameters (e.g., duration of exposure) must be taken into account. Moreover, the simultaneous use of several biomarkers of exposure and effect (including physiological responses) has drawn the attention of researchers as a more comprehensive health risk approach. Thus, in this study, we aim to discuss the recent findings regarding the association between biomarkers of exposure and effect in the context of firefighting activities.

2 Material and Methods

For the purpose of this study, ISI Web of Science, PubMed, and Science Direct databases were used to search for scientific information by combining at least two of the following keywords: “firefighters, biomarkers, biomonitoring, effect, exposure, correlation, association”. Only studies published from 2000 until December 2021 were considered reaching a total of 162 studies found. After duplicate elimination and abstract screening, studies that: (i) have solely explored relations between exposure metrics (e.g., pollutant concentration in the air, questionnaire) and one biomarker type; (ii) did not determine biomarkers of exposure and effect; and (iii) did not include firefighters as participants in the study were excluded. Only studies that had explored associations between biomarkers of effect and exposure in firefighters were selected. A total of 11 scientific studies were considered in this work. Since there was a wide heterogeneity (type of biomarkers, unities of concentration, among others) between the few studies that met the inclusion criteria, a proper meta-analysis could not be conducted.

2.1 Occupational Exposure

Firefighters’ health impacts are dependent on the type of firefighting. Even though structural fire emissions have higher concentration of persistent pollutant exposure due to the diversity and complexity of the burnt material, firefighters wear full personal protective equipment (PPE) with self-containing breathing apparatus, which significantly decreases smoke inhalation. Nevertheless, exposure is not null because even with full PPE wear, skin absorption, as well as secondary inhalation exposures, can still occur (Banks et al. 2021; Cherry et al. 2019). The fire station environment can be also contaminated via vehicle exhaust residues as well as off-gassing chemicals from PPE clothes and fire combat tools and vehicles (Kirk and Logan 2015). On the other hand, since wildland fires are unpredictable and rapidly spread throughout hectares of vegetation, the use of full PPE becomes unpractical during fire combat activities, which can result in a worse compliance to safety clothing code by firefighters (Oliveira et al. 2016). Therefore, wildland firefighters can face higher exposure via inhalation and dermal routes when compared with structural firefighting personal. The toxicity of the absorbed pollutants is highly dependent on the type and duration of firefighting as well as on the differences in personal protection used and the chemical composition of the emitted gaseous and particulate pollutants.

Figure 1 represents an overall demonstration of the biological mechanisms that are initiated and may promote the development of disease in a firefighting context and which occupational environment can contribute to trigger these mechanisms. Toxic compounds can be absorbed via inhalation, dermal contact and/or ingestion. Regardless of the route, these chemicals can form free radicals that stimulate the formation of reactive oxygen/nitrogen species, which can disrupt the redox homeostasis promoting oxidative stress (Barros et al. 2022). Further increase in oxidative stress can trigger a cascade of events such as inflammation and immune system activation which, in excess, can stimulate pathological pathways (Avenbuan and Zelikoff 2020). Several mechanisms are used by the human body to regulate cellular function and maintain homeostasis. Oxidation–reduction reactions have to occur, and their balance is required for correct cellular function. The disequilibrium in this redox metabolome caused either by endogenous metabolism (e.g., stress) or exogenously (exposome) results in oxidative stress. Mental and physical stress are associated with the fight-or-flight response that is an important endogenous mechanism of oxidative stress (De Rosa et al. 2019). Therefore, exposome embraces all external stimuli from lifestyle and exercise to air pollution exposure (Sies et al. 2017). Epidemiological studies have shown that firefighters can present acute exposure effects derived from prolonged occupational fire suppression (Gianniou et al. 2016, 2018). Cumulative exposure to fire emissions and vehicle exhaust (fire station garage) can be hazardous to firefighters´ health. Moreover, the higher career lengths can have also consequent chronic exposure over the years, thus increasing the risks of developing chronic disorders (Barry et al. 2017; Kondo et al. 2019; Soteriades et al. 2019). Moreover, some individuals are more resistant to toxic exposure than others, which influence the stimulation of oxidative stress and other pathological triggers. Thus, individual susceptibility is also a variable to consider when assessing health effects.

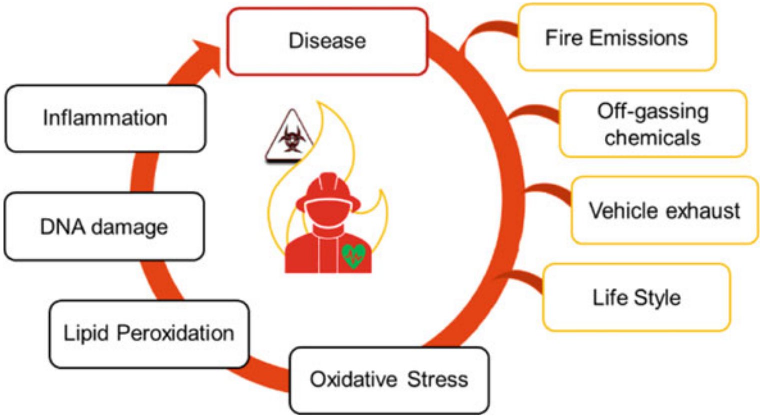

Fig. 1 Occupational exposure during firefighting and key biological mechanisms that may contribute to disease development in these workers

2.2 Correlation Between Biomarkers of Effect and Exposure

To our best knowledge, only eleven studies explored simultaneously biomarkers of exposure and of effect in the urine and blood of firefighters involved in firefighting activities. Table 1 gathers the available information by presenting the reported associations between both types of biomarkers.

Concerning organic pollutants' characterization, positive and significant correlations between the urinary levels of malondialdehyde (a biomarker of effect associated with early stages of oxidative stress) and cross-shift changes in urinary mutagenicity ($p = 0.0010$; a biomarker of mutagenic potential of chemicals in urine) and 1-hydroxypyrene ($p = 0.0001$; considered the biomarker of exposure to polycyclic aromatic hydrocarbons) were reported in the United States of America (USA) wildland firefighters exposed to prescribed burns, especially in those responsible for lighting fires (Adetona et al. 2019). Evidence is also supported by the study of Keir et al. (2017), that observed significant increases in the urinary levels of polycyclic aromatic hydrocarbon metabolites (2.9 to 5.3-fold) and urinary mutagenicity (4.3-fold) in Canadian firefighters participating in fire suppression (Table 1). Additionally, Andersen et al. (2018b) found a positive correlation between the urinary levels of the metabolite of pyrene and the DNA strand breaks determined in the blood of Danish trainees after a 3-day of live-firefighting exercises. Nevertheless, even when concentrations of biomarker of DNA damage related with the number of oxidative stress-related lesions on the DNA molecule in peripheral blood mononuclear cells of exposed firefighters were increased by 8.0% (comparatively with the control group), no correlation was observed with the urinary metabolite of pyrene (Table 1).

Levoglucosan has been identified as a wood smoke exposure biomarker (Bergauff et al. 2010; Hinwood et al. 2008; Naeher et al. 2013). Gaughan et al. (2014) observed a positive correlation between urinary levoglucosan and oxidative stress biomarkers

Table 1 Correlations found between biomarkers of exposure and effect that were explored by 11 studies in firefighters

Continent, Country	Type of exposure	Subjects		Biomarkers		Correlation	References
		n	Age	Exposure	Effect		
America, Canada	5-consecutive 24 h shifts typically spanning 12 days (structural firefighters)	Office Workers		Urinary PAH metabolites	Urinary mutagenicity, Clara Cell 16 (CC16) and isoprostane (8-iso-PGF2α) Creatinine-adjusted values	Post-exposure: Increase in urinary levels of PAHs metabolites ($p <$ 0.0001) and urinary mutagenicity (p $<$ 0.001), suggestive of association with occupational exposure Post-exposure: No significant difference in urinary CC16 and 8-iso-PGF2α	Keir et al. (2017)
		17	50 (28–62)				
		Firefighters					
		16	34 (25−50)				
America, USA	Occupational exposures during their work shifts at prescribed burns and on working days when prescribed burns were not conducted (January–July of 2015)	12 ($n =$ 67 samples)	33 ± 5.4	Urinary 1-hydroxypyrene (1-OHPYR, a PAH metabolite)	Urinary mutagenicity, malondialdehyde (MDA), 8-isoprostane Creatinine-adjusted values	Post-exposure: No significant differences occurred in urinary mutagenicity after exposure Positive associations between cross-work shift changes in urinary mutagenicity and MDA ($R^2 =$ 0.1677; $p = 0.0010$; $n = 67$), urinary mutagenicity and 1-OHPYR ($R^2 = 0.2132$; $p = 0.0001$; $n = 67$)	Adetona et al. (2019)
	Arizona Firefighters	Firefighters		Blood Polyfluoroalkyl substances	Blood Cardiometabolic markers, total cholesterol, and interleukin-6 (inflammation)	Significant negative associations among male firefighters between perfluorodecanoic acid and total cholesterol and perfluoroundecanoic acid and interleukin-6. (Data shown in forest plots without the corresponding r and p value)	Khalil et al. (2020)
		38	–				
		NHANES Survey					
		49	–				

(continued)

Table 1 (continued)

Continent, Country	Type of exposure	Subjects		Biomarkers		Correlation	References
		n	Age	Exposure	Effect		
	Incumbent firefighters recruited between 2016 and 2019	197	–	Blood Polyfluoroalkyl substances	Blood Epigenetic age and DNA methylation	Association found between: levels of linear perfluorooctane sulfonate and sum of branched perfluorooctanoate isomer with extrinsic epigenetic age acceleration (estimate increase 2.12; $p = 0.003$, 1.69; $p = 0.009$, respectively) Levels of linear perfluorooctanoate and perfluorohexane sulfonate with intrinsic epigenetic age acceleration (estimate increase 1.57; $p = 0.014$, 1.05; $p = 0.017$, respectively)	Goodrich et al. (2021)
	All Firefighters (2018–2019)	47	39.15 ± 9.35	Blood Polyfluoroalkyl substances	Blood Metabolic syndrome biomarkers: Triglycerides, High density lipoproteins, and fasting blood glucose	No significant association. For every $\log_{10}$ unit increase in serum levels of perfluorooctanoic acid, perfluorooctane sulfonic acid, perfluorononanoic Acid, perfluorohexane sulfonic acid there was a decrease in metabolic syndrome biomarkers by 46% (OR 0.54; 95% CI 0.85 to 3.43), 33% (OR 0.67; 95% CI 0.24 to 1.86), 65% (OR 0.35; 95% CI 0.05 to 2.35), and 23% (OR 0.77; 95% CI 0.25 to 2.71), respectively	Leary et al. (2020)
	Airport Firefighters (support the military base airport)	38	41.71 ± 7.57				

(continued)

Table 1 (continued)

Continent, Country	Type of exposure	Subjects		Biomarkers		Correlation	References
		n	Age	Exposure	Effect		
	Suburban Firefighters (crash and rescue, structural fires)	9	28.33 ± 8.63				
	Training sessions	38	29 ± 4.34	Urinary levoglucosan (woodsmoke exposure marker)	Urinary 8-iso-prostaglandin F2a (8-isoprostane) and 8-hydroxy-2'-deoxyguanosine (8-OHdG)	Higher levoglucosan levels positively associated with oxidative stress scores: for every twofold increase in $\log_{10}$ levoglucosan, mean 8-OHdG increased by $\log_{10}$ 0.14 μg/ml (estimate 0.41 (95% CI: 0.04, 0.79) and 8-isoprostane increased by $\log_{10}$ 0.16 ng/ml (estimate 0.52 (95% CI: 0.06, 0.97) Smoking history was not a confounder ("Yes": $p = 0.51$; "No": 0.64) for levoglucosan levels	Gaughan (2014)

(continued)

Table 1 (continued)

Continent, Country	Type of exposure	Subjects		Biomarkers		Correlation	References
		n	Age	Exposure	Effect		
	Firefighters and Fire station office workers from the Women Firefighters Biomonitoring Collaborative Cohort (2014–2015)	86	47.5 ± 4.6	Blood Flame retardants	Blood Thyroid Hormones: thyroxine (T_4) and thyroid-stimulating hormone (TSH) controlling for age and $\log_{10}$(creatinine)	Firefighters: a twofold increase of bis(1,3-dichloro-2-propyl)phosphate was significantly associated with a 2.88% decrease (95% CI: −5.28, −0.42) in T_4 Office workers: No significant associations between flame retardants and T_4 (decrease of 0.23%, 95% CI: −2.49, 3.03) Flame retardant levels were not associated with TSH levels	Trowbridge et al. (2022)
Europe, Portugal	Firefighting activities (overall fire exposure)	Total n = 171		Urinary 1-hydroxypyrene (1-OHPYR, a PAH metabolite) Creatinine adjusted values	Blood cells' DNA damage by comet assay	Positive Spearman's correlations were found between the sum of OHPAHs and the oxidative DNA damage of non-smoking firefighters; ($r = 0.382$ for control group, $r = 0.393$ for the non-smoker exposed; $p \leq 0.001$). Inconclusive data were obtained for subjects from the smoker exposed group	Oliveira et al. (2020)
		Non-Smoker Exposed					
		48	30 (21–52)				
		Smoker Exposed					
		30	32 (26–50)				
		Control					
		93	36 (22–55)				

(continued)

Table 1 (continued)

Continent, Country	Type of exposure	Subjects		Biomarkers		Correlation	References
		n	Age	Exposure	Effect		
Europe, Denmark	3 consecutive 24-h work shift days in December. Fire smoke exposure (yes/no): Day 1 (7/0) Day 2 (1/7) Day 3 (6/1) Subjects self-reported participation in fire extinction activities during their work-shift	Total Firefighters		Urinary 1-hydroxypyrene (1-OHPYR, a PAH metabolite) Creatinine adjusted values	Blood inflammation biomarkers: Intercellular Adhesion Molecule -1, Vascular Cell Adhesion Molecule-1, Serum Amyloid A, C-Reactive Protein, Interleukins (IL: IL-6 and IL-8) Blood DNA damage by comet assay	The work shift was not associated with increased levels of genotoxicity	Andersen et al. (2018a, b)
		22	51.7 ± 6.2 (39–59)				
		Work shift Day 1					
		7	50.9 ± 6.8				
		Work shift Day 2					
		8	51.9 ± 5.6				
		Work shift Day 3					

(continued)

Table 1 (continued)

Continent, Country	Type of exposure	Subjects		Biomarkers		Correlation	References
		n	Age	Exposure	Effect		
		7	52.4 ± 6.9				
	Firefighting drills (three exposure scenarios)	Firefighters		Urinary 1-hydroxypyrene (1-OHPYR, a PAH metabolite) Creatinine adjusted values	Blood inflammation biomarkers: Intercellular Adhesion Molecule -1, Vascular Cell Adhesion Molecule-1, Serum Amyloid A, C-Reactive Protein, Interleukins (IL: IL-6 and IL-8); Blood DNA damage by comet assay	The level of DNA strand breaks was positively associated with urinary excretion of 1-OHPYR (estimate increase: 0.6492 ± 0.1679; $p < 0.001$). A no significant association between 1-OHPYR and a decrease in FPG-sensitive sites [a] (estimate: −0.3656 ± 3.4941) Other biomarkers of effect were not increased after exposure or were below the limit of detection	Andersen et al. (2018a, b)
		43	21.1 ± 1.6				
Europe, Turkey	All (occupational exposure)	Firefighters		Urinary arsenic levels	Thiol/disulphide blood homeostasis parameters	A positive Spearman's correlation between urinary arsenic and disulphide ($r = 0.422$, $p < 0.001$), disulphide/native thiol % ratio ($r = 0.409$, $p < 0.001$)	Gündüzöz et al. (2018)
		100	36.5 ± 8.2				
		Unexposed (control)					
		50	37.2 ± 8.5				

CI Confidence interval; *NHANES* National Health and Nutrition Examination Survey; *OR* odds ratio; *PAH* Polycyclic Aromatic Hydrocarbons; *USA* United States of America. *a* FPG-sensitive sites are indicative of DNA oxidation which can be detected by DNA repair enzymes

(8-hydroxyguanine and 8-isprostane) in wildland USA firefighters during training sessions. For each two-fold increase in urine levels of levoglucosan, there was an increase in both $\log_{10}$ 8-hydroxyguanine and $\log_{10}$ 8-isoprostane urinary concentrations, 0.14 μg/mL and 0.16 ng/mL, respectively (Table 1). Moreover, a study reported a positive and significant correlation between the urinary levels of levoglucosan and the formation of intercellular reactive oxygen/nitrogen species in murine alveolar macrophage cells that were exposed to PM_{10} (Tuet et al. 2019). Additionally, wood smoke exposure can be associated with increases in urinary isoprostanes (Barregard et al. 2006). Therefore, these findings suggest a relationship between levoglucosan urine levels and oxidative stress, which could explain the correlation observed by Gaughan et al. (2014) in wildland firefighters. Nevertheless, it is important to consider the possible confounders such as grilled/smoked food consumption while analyzing urinary levoglucosan.

Regarding other pollutants, Gündüzöz et al. (2018) reported positive correlations between urinary concentrations of arsenic with two biomarkers of antioxidant activity, namely disulphide ($r = 0.422$; $p < 0.001$) and disulphide/native thiol ratio ($r = 0.409$; $p < 0.001$) in the blood of Turkish firefighters during a regular medical examination; increased levels of both biomarkers of effect suggest the occurrence of oxidative stress (Table 1). Per- and polyfluoroalkyl substances are persistent pollutants and firefighters can either be directly exposed to burning household materials or by using class B aqueous film forming foams, which are used for liquid fuel fires suppression (Goodrich et al. 2021). Goodrich et al. (2021) found an association between perfluorohexane sulfonate, perfluorooctanoate and the sum of branched isomers of perfluorooctane sulfonate in serum with accelerated epigenetic age (i.e., the biological age that reflects exposure and disease risks independently of the chronological age) of USA structural firefighters (Table 1). Moreover, branched perfluorooctanoate, linear perfluorooctane sulfonate, perfluorononanoate, perfluorodecanoate and perfluoroundecanoate were associated with locus-specific DNA methylation in those same firefighters. Epigenic changes can alter DNA expression patterns disrupting normal cell function, thus, these alterations are important precursors of disease development, especially cancer (Jeong et al. 2018). Leary et al. (2020) explored the association between metabolic syndrome blood biomarkers [fasting triglyceride level (>150 mg/dL), high-density lipoprotein (HDL: <40 mg/dL (men) and <50 mg/dL (women)), and blood sugar (>100 mg/dL)] and per- and polyfluoroalkyl substances exposure in USA firefighters. Logistic regression analysis did not show significant associations between per- and polyfluoroalkyl substances and metabolic syndrome biomarkers in both airport and urban USA firefighters (Table 1). Notably, Khalil et al. (2020) found a significant negative association between the levels of perfluorodecanoic and perfluoroundecanoic acids with values of total cholesterol and interleukin-6 (inflammation biomarker), respectively, in USA firefighters. However, per- and polyfluoroalkyl substances were not associated with carotid intima-medial thickness, a biomarker of cardiometabolic syndrome (Table 1). In other occupational and generally exposed populations, per- and polyfluoroalkyl substances have been linked with immune response alterations, respiratory disease, and prostate cancer (Khalil et al. 2020); thus, firefighters should also be biomonitored regarding per-and polyfluoroalkyl substances exposure and effects. Flame retardants, suspected to be endocrine-disruptors substances, have been identified in firefighting gear and fire station dust (Fent et al. 2020). Blood and urine samples from a group of women firefighters and fire station office workers were collected to explore the association between these pollutants and total thyroxine and thyroid-stimulating hormone (Trowbridge et al. 2022). The authors detected that, for each two-fold increase in bis(1,3-dichloro-2-propyl) phosphate levels in urine, there was an associated decrease of 2.88% in thyroxine serum levels in women firefighters, while no significant association was found among office workers (Table 1). These findings are a starting point to address the important contribution of occupational exposure to total chemical body burden and respective health effects in firefighters.

3 Conclusions

Firefighting is a hazardous occupational activity, which is being increasingly studied over the years. Given their health risks, firefighters should be frequently biomonitored to assure occupational environment safety. Overall, the combination of biomarkers of exposure and effect has brought some evidence towards association between firefighters exposure to fire emissions with early oxidative stress and oxidative DNA damage (Gaughan et al. 2014; Gündüzöz et al. 2018; Keir et al. 2017; Oliveira et al. 2020), urinary mutagenicity (Adetona et al. 2019; Keir et al. 2017), genotoxicity (Andersen et al. 2018a, b; Goodrich et al. 2021), metabolic syndrome biomarkers (Khalil et al. 2020; Leary et al. 2020), and endocrine system alterations (Trowbridge et al. 2022). Moreover, oxidative stress and DNA damage are important precursors of early health risks that contribute to the aggravation and/or development of several ailments including cardiovascular and respiratory diseases and cancer (Sies et al. 2017). However, information is still scarce, and more comprehensive studies in diverse firefighter occupational activities are needed to validate and complement these findings. In addition, some authors recently highlighted the potential of using emerging exposome studies to evaluate the dynamic response of individuals biological system due to multiple and cumulative exposures to physical, chemical, and psychological hazards at the same time (Bocato et al. 2019). This approach would strongly contribute to reduce the time and resources used in biomonitoring bringing the assessment of firefighters' occupational exposure to a level much closer to the real and effective exposure, thus, allowing the proposal of procedures and actions to promote firefighters' health. Despite the available evidence related with the correlations and associations between these two types of biomarkers, the causality of such observations cannot be draw from cross-sectional and case-report studies. Due to the human body complexity, causality is better tested in cohort studies, during a long-lasting period in which each firefighter is followed during several years. More studies are needed to understand if these findings are equally observed in other geographical areas and during/after different firefighting activities (wildland fire combat versus structural fire versus training exercises) and in fire station activities. It is crucial that more studies explore the correlations among different biomarkers of exposure and effect. This approach will allow a better characterization of firefighters' occupational exposure and associated health effects and, consequently, will shorten the current research gap related to occupational exposure and its health impacts among firefighters.

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Movement Analysis in Going Up and Down Stairs and the Aggravation of Patellofemoral Pain Syndrome at Work—An Observational Study

P. M. Pereira, J. Duarte, J. Santos Baptista, and J. Torres Costa

Abstract Patellofemoral pain syndrome (PFPS) is a musculoskeletal disorder in the anterior region of the knee, affecting people of different ages. When it is necessary to go up and down many stairs in a work context, there is a risk of increased wear on the knee joint and, consequently, PFPS. The main objective of this work was to identify the risk of contracting PFPS associated with the action of going up and down stairs in the workplace. An analysis of workers' movement on an oil platform without lifts was carried out in the circulation by stairs between the different floors. It has been found that leg movements made when going up and down stairs can be harmful to the knee joints. A recommendation was made to change the way workers go up and down stairs to reduce the overload on the joint knee and the risk of contracting or worsening PFPS.

Keywords Stairs · PFPS worsening · Patellofemoral pain · Knee joint · Prevention

1 Introduction

Patellofemoral Pain Syndrome (PFPS) is a musculoskeletal disorder that presents pain in the anterior region of the knee, retro or peripatellar. Symptoms worsen with movement up and down stairs and when performing squats (Crossley et al. 2016).

The main risk factor occurs during knee flexion, when the vertical line that passes through the anterior region of the tibia crosses the vertical line that passes through the toe's tips (of the same side) (Bolgla et al. 2018; Crossley et al. 2019; Fry et al. 2003; Pereira et al. 2020; 2022b, c; Powers et al. 2017). Another risk factor that can

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be pointed out is the difference in strength between the thigh and hip muscles (of the same side), which makes the syndrome symptomatic (Narici et al. 2021; Pereira et al. 2020; Scott et al. 2020; Søgaard and Sjøgaard 2017).

Depending on personal factors such as the degree of existing inflammation, PFPS can be classified as an MSD-3 or MSD-2 (Pereira et al. 2021). PFPS can be aggravated when the work requires walking up and down a high number of steps (Pereira et al. 2022b, c).

PFPS prevalence in the general population is about 22.7% (Smith et al. 2018). However, it may be higher in specific populations, e.g. 29.16% were found in professional dancers (Winslow and Yoder 1995), 34.6% in the automobile industry in Iran (Sharifian et al. 2020) and 30% in truck drivers from selective garbage collection in Portugal (Pereira et al. 2022a).

Few studies were found in the literature on PFPS in environments where workers recurrently use stairs (Pereira et al. 2022b, c). Examples of such situations are oil platforms, some of which do not have elevators.

Thus, considering the importance and scope of the problem, the objective of this work was to study movements with the risk of contracting or aggravating PFPS that occur when going up and down stairs in offshore oil platforms.

2 Materials and Methods

The study was carried out between September 16 and October 7, 2021, using the STROBE approach (Von Elm et al. 2007).

The methodological protocol was divided into three phases:

1. workplace evaluation,
2. worker's biomechanics movement evaluations, and
3. suggestions for movement improvement (to avoid the translocation of the anterior line of the tibia beyond the line of the toes of the same side).

2.1 Site Characterization

Data were collected on an oil platform between September 16 and October 7, 2021. The height difference between the lower production floor and the highest point of the platform, the "Hellideck", is approximately 47 m in height and 36 m in height to the top floor of the cabins. The distances from the water level are 17 m, 64 m and 56 m, respectively.

Considering a ceiling height of 3 m, the platform's total height corresponds to a 20-story building, considering a ceiling height of 3 m. The platform does not have elevators for moving people, only stairs.

2.2 Sample Characterization

The population on board was 129 workers during the evaluation period, and their average height was 1.76 m.

The test sample was chosen according to their height, matching the average population'. Three workers, males, healthy and without any symptomatology of PFPS, were included in the test. Their personal data, as well as occupational activity and time in function, are included in Table 1.

Table 1 Oil rig workers' data

Subject	Age	Gender	Height (cm)	Weight (kg)	BMI (kg/cm^2)	Previous history of PFPS or knee pain	Function	Time in function
#1	35	Male	176	94.0	30.34	No	HSE	8 years
#2	51	Male	176	95.5	30.83	No	Bosun	13 years
#3	59	Male	176	83.0	26.79	No	Bosun	28 years

BMI body mass index; *HSE* health, safety and environment technician

The number of steps taken daily by each platform worker was not quantified due to the diversity of the performed functions. However, it was considered a minimum movement of 20 flights of stairs, per person, per day among workers who work mostly inside. Working indoors means within the office and dormitory areas of the platform, with exposition to 4–5 floors of staircases.

This value was estimated considering the worker's cabin, the floor of the workplace and the daily meals eaten in the cafeteria. Each internal floor has 18 steps, equivalent to a minimum exposure of 360 steps per day.

2.3 Assessment of the Stairs

The stairs built on the platform are based on ISO 14122 (International Organization for Standardization 2016) standards and the Brazilian equivalent NR 12 (Técnicas 2019) (Fig. 1) (Rocha 2017). The steps were measured with a standardized tape measure.

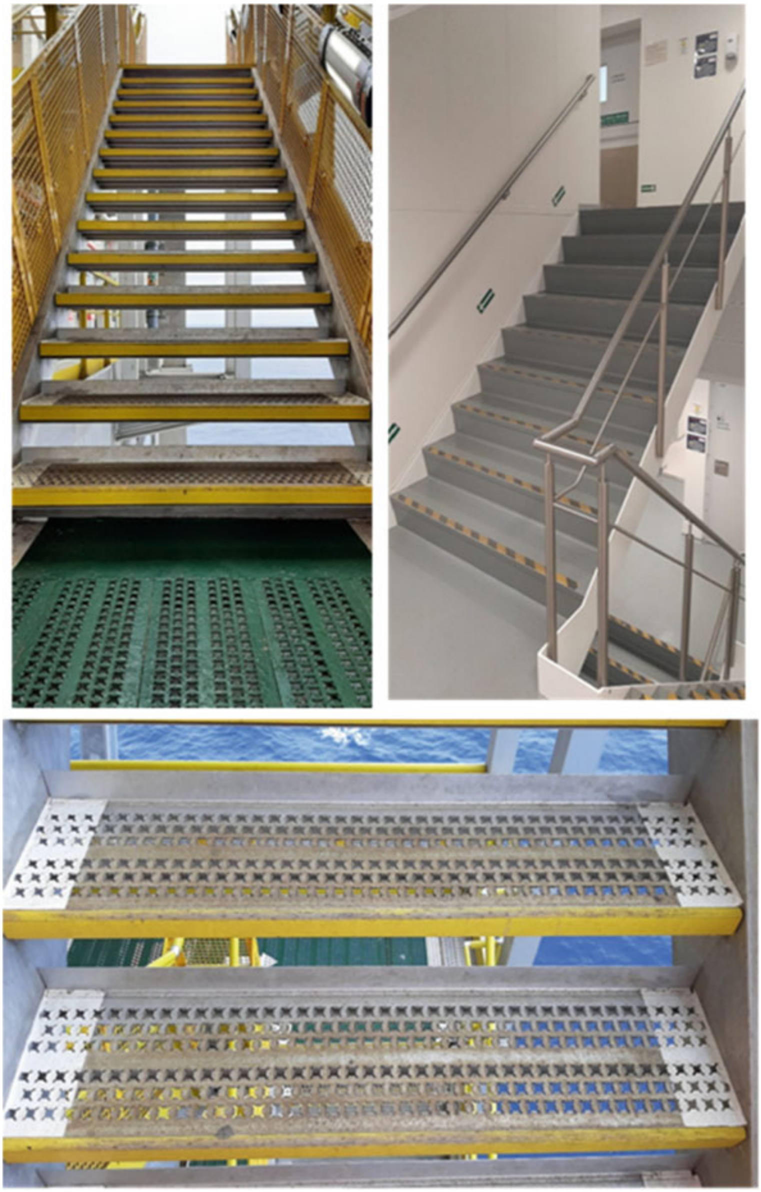

Fig. 1 Images of the external and internal stairs of the platform

2.4 Worker's Movement Assessment

The evaluation of the test sample subjects' movements while using the stairs was carried out. Due to the impossibility of obtaining lateral images on outside staircases, only movements on the inside staircases were considered.

The footage was obtained through filming with a CANON camera with a high dynamic range (HDR). The equipment was positioned perpendicular to the longitudinal plane of the ladder to obtain the lateral images and positioned parallel to the frontal plane of the ladder to obtain the frontal images of the workers. The camera remained static during the protocol. After receiving the footage, the analysis of the photos was performed on a computer.

The risk assessed was that of the tibial translation movement in the anterior plane in front of the ipsilateral fingers, as reported in the literature as harmful (Brechter and Powers 2002; Collins et al. 2013; Crossley et al. 2004; Fry et al. 2003; Lorenzetti et al. 2018; Pereira et al. 2022b; Powers et al. 2017; Schütz et al. 2014).

The movement analysis was directed to identifying PFPS, as described in the literature (Pereira et al. 2022b). Other methods for assessing lower limb movement were not used due to the no specificity of their evaluations (Pereira et al. 2022b, c).

2.5 Proposal to Change the Way of Going Up and Down Stairs

All platform population were asked to climb the stairs two at a time and descend laterally to protect the knee joint and prevent PFPS.

3 Results and Discussion

3.1 Results of Workplace Analysis

While assessing the existing stairs on the platform, it was determined that their construction complies with ISO 14122 standards and the Brazilian equivalent NR 12 (Fig. 1) (Rocha 2017). The steps of the exterior stairs are 18 cm high and 27 cm depth. The steps of the interior stairs are 21.5 cm high and 31.5 cm in depth.

3.2 Results of the Assessment of Workers' Movements

The movement and knee position were observed while ascending and descending the stairs (Figs. 2 and 3).

Fig. 2 The horizontal yellow line represents the risk associated with going up and down stairs

In this process, the translation of the anterior line of the tibia in relation to the ipsilateral line of one of the toes was identified.

According to the literature, such a movement justifies the implementation of prevention measures (Brechter and Powers 2002; Collins et al. 2013; Crossley et al. 2004; Fry et al. 2003; Neal et al. 2019; Pereira et al. 2022b; Powers et al. 2017; Willy et al. 2019).

3.3 PFPS Risk Prevention Proposal

The risk existence was evidenced when assessing the risk of worsening PFPS due to the need to go up and down stairs in the work environment (Fig. 2). Even though there is no standardization on oil platforms construction, many of these constructions have dimensions that can correspond to 20-story buildings.

Fig. 3 Climbing the stairs two at a time, side view

The result of the analysis of workers' movements showed that going up and down stairs is a factor that worsens PFPS due to the translocation of the anterior line of the tibia about the line of the toes on the same side (Bustos et al. 2021; Fry et al. 2003; McLaughlin et al. 1978; Pereira et al. 2020, 2022b; Powers et al. 2017).

Therefore, the main proposal for the two considered movements is given in Fig. 4.

- In the ascending movement, the steps must be climbed two by two to prevent the knee from advancing in relation to the toes (on the same side). The effort from this action must be supported by holding the handrail (Fig. 3).
- The descending movement must be carried out laterally, positioning the body at about a 45° angle with the stairs, one step at a time.

The suggestion of going up the steps two at a time is effective from the point of view of protection concerning the PFPS, as it prevents translocation of the knee in front of the line of the feet on the same side. Also, the lateral descent is effective compared to the frontal descent. In both solutions, protection of the patellofemoral joint occurs.

Fig. 4 Descent of stairs laterally front view

3.4 Limitation

The test sample is considered low. However, the three subjects were chosen due to their representativity of the general oil rig population. Personal risk factors such as obesity, overweight, and muscular strength capacity, were not evaluated since that fell out of scope for this work. However, these characteristics will be considered for future protocols.

Also, movement analysis, as well as the risk of worsening PFPS, focused on the use of inclined stairs. Although there are different types of stairs, these were the encountered type in the oil ring. It is important to consider that other staircase types present another type of biomechanics of movement and other associated risks concerning PFPS (Pereira et al. 2022c).

4 Conclusion

It was evidenced in these three workers that they are at risk of worsening or contracting PFPS due to adopted postures while performing the movement, as they go up and down a high number of stairs throughout the day, every day.

This risk can be aggravated if the movement is carried out through a frontal descent or a step-by-step ascent, as verified in the results found in accordance with the existing literature (Brechter and Powers 2002; Collins et al. 2013; Crossley et al. 2004; Fry et al. 2003; Lorenzetti et al. 2018; Pereira et al. 2022b; Powers et al. 2017; Schütz et al. 2014). Future work needs to consider other personal factors such as overweight and muscular strength capacity.

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Bioimpedance and Arterial Stiffness in Shift Workers: A Preliminary Case Study

Beatriz Azevedo, Joaquim Pereira, Hélder Simões, João Lima, and Telmo Pereira

Abstract *Background* Body composition has been associated with arterial stiffness as a marker of cardiovascular risk. The association between shift work and cardiovascular diseases is well known. *Objectives* To analyze the relationship between anthropometric parameters, body composition parameters obtained by bioimpedance, and arterial stiffness, in a sample of shift workers. *Materials and Methods* The study included 28 participants (14 shift group and 14 control group), equal from both genders, with a mean age of 34.7 ± 10.2 years, from a private company. Anthropometric measurements included waist and hip circumference, waist-to-height ratio (WHtR), and body mass index (BMI). Parameters derived from bioimpedance included body fat percentage (%BF), lean mass (LM, kg), bone mass (BM, kg), and visceral fat. Arterial Stiffness was measured by pulse wave velocity (PWV), estimated by oscillometry, using the Mobil-O-Graph device. *Results* No association was found between body composition and arterial stiffness in the studied sample. A moderate to high correlation was seen between blood pressure (BP) and all anthropometric parameters. *Conclusions* The present study did not confirm a positive association between shift work and an higher cardiovascular risk.

Keywords Arterial stiffness · Body composition · Bioimpedance · Cardiovascular diseases · Shift work

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1 Introduction

Cardiovascular Diseases (CVD) constitute one of the major non-communicable diseases, with great responsibility in mortality globally (Lozano et al. 2012), and the percentage of deaths due to these pathologies has undergone a significant increase, from 28.2% in 2000, to 31.4% in 2012 (McAloon et al. 2016). Thus, the identification of risk factors associated with CVD has become a truly relevant topic (Hernandez-Martinez et al. 2019). The cause of the vast majority of cardiovascular diseases can be attributed to risk factors, which include hypertension, diabetes mellitus, smoking, dyslipidemia, and alcohol consumption (Nascimento et al. 2014), as well as obesity and atherosclerosis. There is an increased risk of atherosclerosis in obese individuals (Li et al. 2017).

Currently, it is suspected that some occupational factors are also related to the development of cardiovascular diseases. Among them, work schedule management, namely shift work, has become one of the most relevant factors (Esquirol et al. 2011).

According to the Decree-Law No. 7/2009 of February 12. Diário da República No. 30/2009, Series I "shift work is considered to be any work organization in teams, in which workers successively occupy the same jobs at a given rate, including rotating, continuous or discontinuous, and may perform work at different times in a given period of days or weeks". According to the National Institute of Statistics, in the year 2019, 16.8% of the Portuguese employed population worked rotating hours.

Studies indicate that this type of working schedule alters the circadian rhythm of workers (Boivin and Boudreau 2015). This phenomenon may be responsible for inflammation (Aho et al. 2013), as well as multiple metabolic alterations (Ulhôa et al. 2015), thus increasing the risk of dyslipidemia (Karlsson et al. 2003), diabetes (Ika et al. 2013), and insulin resistance (Leproult et al. 2014). A reduction in melatonin secretion, justified by less contact with daily sunlight, may be associated with an increased risk of insulin resistance (Ulhôa et al. 2015).

In addition, there is a higher prevalence of increased blood pressure, obesity, physical inactivity, unbalanced diet, smoking, and excessive alcohol consumption among shift workers (Bekkers et al. 2015; Virtanen et al. 2012). It should be noted that shift work has been suggested as an independent risk factor for weight gain and obesity (Ulhôa et al. 2015).

A recent systematic review concluded that there is a 17% increase in CVD risk for shift workers compared with daytime workers. After the first five years of shift work, a 7.1% increase in the risk of cardiovascular events was witnessed for each additional five years of exposure (Torquati et al. 2018).

Since shift work has a proven association with multiple cardiovascular risk factors (Boivin and Boudreau 2014; Costa 2015; Aho et al. 2013; Ulhôa et al. 2015; Karlsson et al. 2003; Ika et al. 2013; Leproult et al. 2014; Bekkers et al. 2015; Virtanen et al. 2012), it is plausible to inquire about a possible association between it and increased arterial stiffness.

Arterial stiffness is a strong predictor of cardiovascular risk, especially for hypertension, and is characterized by a reduction in arterial wall elasticity (Mac Ananey et al. 2015). It affects the cardiovascular system through the constant blood flow distribution from the heart to the peripheral capillaries, with a devastating effect on the heart and microcirculation (Kim et al. 2018).

In clinical practice, arterial stiffness can be noninvasively estimated using three main methods: assessment of pulse wave velocity; analysis of the contour of the arterial pressure curve; and direct estimation of stiffness using measurements of the arterial diameter or luminal area and the distension pressure, measured at the site where the change in diameter occurs (London and Pannier 2010).

However, pulse wave velocity is accepted as the most accurate method for assessing arterial stiffness (Hernandez-Martinez et al. 2019; Li et al. 2017), as well as for assessing target organ damage (Li et al. 2017; Mac Ananey et al. 2015). The ease in determining pulse wave velocity, its reliability, as well as the large amount of evidence demonstrating its association with the occurrence of cardiovascular incidents, regardless of the presence of traditional risk factors, have made pulse wave velocity measurement the gold standard method (Reference Values for Arterial Stiffness' Collaboration 2010).

Body composition constitutes one of several factors that may accelerate the process of arterial stiffening in apparently healthy individuals (Caspersen et al. 1985). Body composition, which consists primarily of water, fat, protein, carbohydrates, various vitamins and minerals, is one of the most important indicators of health and fitness, so its determination is of clinically significant interest (Wells and Fewtrell 2006).

There is evidence that an increased BMI is associated with an increased pulse wave velocity and, consequently, increased arterial stiffness (Wildman et al. 2003). However, it is known that BMI assesses excess weight in relation to height, and not excess adipose tissue, i.e., it does not reflect body composition (Kim et al. 2018; Wykretowicz et al. 2007).

Thus, an individual can keep his or her BMI constant by showing a progressive increase in the ratio of fat mass to lean mass (Wykretowicz et al. 2007).

Other studies have proven that anthropometric parameters, such as waist circumference (WC), hip circumference (HC), and waist-to-height ratio (WHtR), are directly associated with AS (Recio-Rodriguez et al. 2012). Neck circumference is also associated with arterial stiffness (Fantin et al. 2017). Body composition assessment using the aforementioned simple parameters is considered by some authors to be a poor indication, since the percentage of muscle mass, protein, and lean tissue is not considered (Zeng et al. 2008).

The relationship between arterial stiffness and body composition has also been explored by acquiring measurements generated by bioimpedance. This method is based on the assumption that the human body has intracellular and extracellular fluids capable of electrical conduction (Wells and Fewtrell 2006; Willett et al. 2006).

Bioimpedance involves the administration of a weak alternating electric current, at one or several radio frequencies, through surface electrodes in order to characterize the conductivity or non-conductivity of tissues and fluids present in the body's constitution. The applied current flows at different speeds depending on the composition of the body. The current is well conducted by water-rich tissues, such as blood and muscle; and poorly conducted by fat or bone. The decrease in current–voltage is detected by electrodes and impedance is recorded (Mulasi et al. 2015).

Bioimpedance allows the acquisition of parameters such as body fat percentage, fat mass index, and lean mass index (Kyle et al. 2003). The association between arterial stiffness and obesity using anthropometric parameters or parameters derived from bioimpedance has been previously described (Browning et al. 2010). However, this relationship was not the subject of a lot of research in apparently healthy individuals. Furthermore, to the author's knowledge, there is no study that has focused its sample on a group of shift workers.

In summary, the present scientific article proposes to investigate the relationship between body composition, with the acquisition of simple (anthropometric) and complex parameters, and arterial stiffness, in a sample of shift workers. The knowledge of relationships between shift work and cardiovascular risk factors is extremely important since problems related to shift work can only be solved by manipulating these relationships since the primary source of exposure cannot be eliminated.

2 Materials and Methods

2.1 Study Design

This is a case study, carried out in a private company that had as its main objective the evaluation of the relationship of different anthropometric and body composition parameters, acquired through bioimpedance, with AS, in shift workers. A total of 28 adult subjects were evaluated during the month of May 2021.

The presence of a pacemaker or other device inside the body with the function of providing life support; pregnancy or suspected pregnancy; and the presence of metal plates were exclusion criteria, motivated using bioimpedance during the study.

Participants were personally approached and invited to participate after a brief explanation of the study in question. The evaluations were scheduled to accommodate the preferences of each individual and lasted approximately 15 min.

The experimental protocol was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (No. 89_CEPC2/2020)—Appendix 1—and informed consent was obtained from all individuals prior to their participation in the study. Materials and Methods should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail, while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Include any pre-registration codes.

2.2 *Statistical Variables*

2.2.1 Socio-demographic Data

All participants completed a questionnaire, comprising a variety of sociodemographic questions. Individuals were asked to report their date of birth, gender, marital status, level of education, as well as description of their employment status. The latter allowed the constitution of two study groups, according to the type of working schedule, i.e., rigid schedule (control group) versus shift work regime.

The participants were also questioned about their medical history, with emphasis on the search for personal and/or family history of cardiovascular diseases, as well as about their smoking, alcohol consumption, and physical exercise habits.

For statistical analysis purposes, the intake of 1–2 drinks per day was considered regular, light to moderate consumption of alcoholic beverages (O'Keefe et al. 2014). Regular physical exercise was considered to be practiced when the individual stated that he/she performed some type of physical activity at least 3 times a week, at moderate to high intensity, with an average duration of 40 min per session (Eckel et al. 2014).

Adherence to the Mediterranean dietary pattern was assessed using the PREDIMED instrument. A score above 10 points is indicative of good adherence to the Mediterranean diet.

2.2.2 Body Composition Assessment

A Bioimpedance scale (Tanita, Tokyo, Japan) was used to measure body weight, percentage of fat mass, lean mass, bone mass, and visceral fat. Other parameters were obtained, namely total body water, metabolic index and metabolic age. With this device, the individuals were evaluated with their clothes on and without shoes, and the measurements were taken while standing, by contact between two electrodes and the sole of both feet, according to the manufacturer's instructions.

Anthropometric measurements were collected, using a tape, with the individual in an upright position. WC was measured at the site of smallest circumference, between the lower costal margin and the iliac crest. The HC was obtained at the level of the maximum protrusion of the buttocks. Both measurements were made twice, and the average value obtained was used for evaluation purposes.

The BMI was calculated by dividing the value of body weight (kg) by the square of the height (m^2). The WHtR resulted from dividing the WC value (cm) by the height value (cm). The height considered was the one that appears on the participant's citizen card.

2.2.3 Pulse Wave Velocity (PWV) Assessment

Pulse wave velocity was estimated by oscillometry, using the Mobil-O-Graph (model NBP-24 NG), an ambulatory blood pressure monitoring system, in order to assess arterial stiffness. The Mobil-O-Graph is a valid instrument for clinical use (Browning et al. 2010).

The brachial artery blood pressure (bBP) measurement provides systolic BP (bSBP), diastolic BP (bDBP), mean BP (bMBP), in addition to pulse pressure (bPP) and heart rate (HR). After the conventional oscillometric BP measurement, the pulse waves are recorded, using the brachial cuff at the level of the bDBP, for approximately 10 s. After the digitization, the algorithm is applied. First, the pressure waves are checked for reasonableness; then all waves are compared in order to identify possible artifacts; finally, an aortic pulse wave is generated (Weber et al. 2011). After quality verification, the main parameters derived from the pulse wave analysis are obtained, including the PWV, which is estimated from the aortic pulse wave reconstruction, considering the age of the individual (Weber et al. 2011; Papaioannou et al. 2013).

PWV was measured while the participants were seated, in silence, with a cuff placed on the arm—the arm being properly supported—at the level of the brachial artery and with the palm facing upwards. A single measurement was taken. The suggested reference value for healthy individuals should be less than 10 m/s (Reference Values for Arterial Stiffness' Collaboration 2010).

All evaluations that did not meet the quality criteria provided by the device's own software were repeated.

2.3 Statistical Analysis

The data obtained from the participants in the sample were computerized and processed using IBM SPSS Statistics, version 25.

Simple descriptive statistics were used to characterize the sample. Regarding comparative statistics, variables were compared using the t-student test and the Mann–Whitney test for independent variables. Groups were compared using Pearson's chi-square test.

Bivariate correlations (Pearson's Correlation) were applied to assess the association between continuous variables.

Results are presented as mean $\pm$ standard deviation or as percentage (n). Differences were considered statistically significant for $p \leq 0.05$.

3 Results

The present study included 28 individuals: 14 men (50%) and 14 women (50%), aged 24–56 years, with a mean age of 34.71 ± 10.15 years. The BMI ranged from 19.7 to 40.2 kg/m^2, with a mean of 26.11 ± 4.99 kg/m^2.

The sample was divided into two groups according to the work schedule: the study group included 14 individuals working on shift work; the control group included the same number of individuals (n = 14) working on a rigid schedule. No statistically significant differences were found between the two groups with regard to the variables considered (Table 1).

Cardiovascular risk factors (obesity, smoking, excessive coffee and alcohol consumption, history of cardiovascular disease, physical inactivity) were analyzed separately. The prevalence of the risk factors studied is similar in both groups considered, and no statistically significant differences were found in any of the parameters.

In order to better understand the participants eating habits, adherence to the Mediterranean dietary pattern was studied using the PREDIMED instrument. Of the 28 individuals studied, 42.9% (n = 12) showed good adherence to the Mediterranean Diet. Although there was less adherence in the study group (35.7%) than in the control group (50%), no statistically significant differences were found between the two groups ($p = 0.704$).

The results corresponding to the statistical treatment of the hemodynamic data obtained for each of the groups studied are summarized in Table 2.

After analysis, it is verified that there are no statistically significant differences between groups in any of the variables considered.

Table 1 Characteristics of the study sample

Parameters		Total (n = 28)	Shift group (n = 14)	Control group (n = 14)	*p*-value
Age (years)		34.71 ± 10.15	34.21 ± 10.36	35.21 ± 10.29	0.635
Gender	Male % (n)	50 (14)	25 (7)	25 (7)	1.00
	Female % (n)	50 (14)	25 (7)	25 (7)	
Weight (kg)		76.95 ± 15.52	76.79 ± 15.82	77.1 ± 15.80	0.946
Height (cm)		171.36 ± 9.11	170.36 ± 10.02	172.36 ± 8.35	0.571
BMI (kg/m^2)		26.11 ± 4.99	26.34 ± 5.26	25.88 ± 4.89	0.804
WC		86.64 ± 14.33	86.43 ± 15.09	86.86 ± 14.10	0.910
HC		104.46 ± 9.36	103.93 ± 10.03	105.0 ± 8.99	0.701
WHtR		0.51 ± 0.08	0.51 ± 0.09	0.50 ± 0.08	0.874

Data are presented as mean ± standard deviation or as percentage (n). *BMI* body mass index; *WC* waist circumference; *HC* hip circumference; *WHtR* waist-to-height ratio

Table 2 Comparison of the hemodynamic results obtained in the two groups

Parameters	Shift group (n = 14)	Control group (n = 14)	*p*-value
SBP (mmHg)	127.36 ± 18.07	127.21 ± 15.32	0.910
DBP (mmHg)	77.14 ± 17.61	78.21 ± 13.04	0.946
MBP (mmHg)	100.14 ± 16.51	100.64 ± 13.62	0.734
PP (mmHg)	50.21 ± 12.57	49.00 ± 8.03	0.946
HR (bpm)	76.00 ± 12.59	72.64 ± 10.87	0.511
cSBP (mmHg)	117.14 ± 17.45	117.36 ± 13.865	0.982
cDBP (mmHg)	78.71 ± 17.97	79.79 ± 12.68	0.946
cPP (mmHg)	38.43 ± 10.04	37.57 ± 8.00	0.946
Augmentation pressure	1.32 ± 0.13	1.32 ± 0.14	0.667
Systolic volume (ml)	68.77 ± 12.97	71.48 ± 17.71	0.946
Cardiac output (l/min)	5.13 ± 0.79	5.10 ± 1.00	0.734
TVR (s/mmHg/ml)	1.19 ± 0.20	1.21 ± 0.22	0.734
Cardiac index (l/min/m^2)	2.72 ± 0.39	2.68 ± 0.48	0.667

Data are presented as mean ± standard deviation. *SBP* systolic blood pressure; *DBP* diastolic blood pressure; *MBP* mean arterial pressure; *PP* pulse pressure; *HR* heart rate; *cPBP* central systolic blood pressure; *cDBP* central diastolic blood pressure; *cPP* central pulse pressure; *TVR* total vascular resistance

The PWV, a relevant parameter in the study of AS, varied between 5 and 9 m/s, with a mean value of 6.01 m/s. The difference found was not statistically significant when the arterial stiffness parameters themselves were considered (Table 3).

Of all the study subjects (n = 28), 9 had a higher than desired %FM according to their sex and age. The number of individuals included in each subdivision was similar for both study groups. Table 4 shows the remaining data acquired by bioimpedance.

The results obtained were similar for the two study groups, concluding that there was no statistical significance.

Table 3 Arterial stiffness results

Parameters	Shift group (n = 14)	Control group (n = 14)	*p*-value
Augmentation pressure (mmHg)	7.79 ± 3.62	9.21 ± 6.46	0.734
Reflection coefficient (%)	64.43 ± 4.72	63.29 ± 7.47	0.769
Augmentation index (%)	21.07 ± 12.33	21.86 ± 13.46	0.769
PWV (m/s)	5.96 ± 0.99	6.06 ± 1.20	0.910

Data are presented as mean ± standard deviation. *PWV* pulse wave velocity

Table 4 Comparison of body composition results obtained in the two groups

Parameters	Shift group (n = 14)	Control group (n = 14)	*p*-value
FM (%)	24.12 ± 10.08	24.73 ± 10.40	0.769
LM (kg)	55.37 ± 11.83	54.34 ± 10.51	0.982
BM (kg)	2.91 ± 0.58	2.86 ± 0.50	0.804
Visceral fat	5.21 ± 3.87	5.86 ± 4.17	0.874
Caloric index	1733.21 ± 356.23	1702.00 ± 317.10	0.910
Metabolic age (years)	31.07 ± 15.52	33.36 ± 16.91	0.804

Data are presented as mean ± standard deviation. *FM* fat mass; *MM* lean mass; *BM* bone mass

It was tried to analyze the existence of correlations between hemodynamic and arterial stiffness parameters acquired and anthropometric and body composition parameters. Bivariate associations are shown in Table 5.

Pearson's correlation revealed significant associations, ranging from moderate ($0.40 \leq R < 0.70$) to high ($0.70 \leq R < 0.90$) correlations. Noteworthy are the correlations found between SBP, MBP, cSBP; and all anthropometric and body composition variables studied, with emphasis on waist circumference (Fig. 1). No correlation was found between the latter and PWV.

Finally, a possible correlation between the number of years of shift work and hemodynamic parameters was investigated, and no association of a relevant character was found (data not shown).

4 Discussion

The aim of the present study was to evaluate a possible association between different anthropometric and body composition parameters and arterial stiffness in a sample of shift workers. The findings indicate that there is no association between AS and the parameters under study.

BMI has been studied for multiple years as an independent predictor of cardiovascular risk (Lavie et al. 2009; Mandviwala et al. 2016), but data from the present study failed to show a correlation between this index and arterial stiffness. This is in line with findings of other authors (Wyckretowicz et al. 2007), who had previously concluded that BMI was not a very useful tool in predicting obesity-associated changes in AS. This may be justified by the fact that BMI does not consider the amount of fat mass, having been developed to quantify weight and not to function as an index of obesity (Pietrobelli et al. 1998) besides being unable to differentiate FM from LM. It is also known that weight loss and, consequently, a change in BMI do not necessarily correspond to fat loss (O'Keefe et al. 2014). Other studies, however, continue to advocate the use of this index because it is the easiest and most commonly accepted measure of obesity (Litwin 2008), considering that although a BMI-based

Table 5 Bivariate correlations between the variables under study

		BMI	WC	HC	WHtR	Caloric index	Metabolic index	FM	Visceral fat	BM	LM
SBP (mmHg)	R	0.686	0.703	0.675	0.689	0.495	0.528	0.404	0.573	0.478	0.462
	P-value	0.000	0.000	0.000	0.000	0.007	0.004	0.033	0.001	0.010	0.013
DBP (mmHg)	R	0.550	0.661	0.623	0.661	0.270	0.561	0.463	0.573	0.257	0.246
	P-value	0.002	0.000	0.000	0.000	0.164	0.002	0.013	0.001	0.187	0.207
MBP (mmHg)	R	0.651	0.722	0.683	0.715	0.397	0.578	0.464	0.607	0.380	0.366
	P-value	0.000	0.000	0.000	0.000	0.037	0.001	0.013	0.001	0.046	0.055
PP (mmHg)	R	0.281	0.144	0.155	0.123	0.388	0.013	−0.040	0.067	0.381	0.372
	P-value	0.148	0.465	0.431	0.533	0.041	0.947	0.839	0.736	0.046	0.052
cSBP (mmHg)	R	0.675	0.703	0.683	0.676	0.510	0.521	0.391	0.555	0.492	0.475
	P-value	0.000	0.000	0.000	0.000	0.006	0.004	0.040	0.002	0.008	0.011
cDBP (mmHg)	R	0.545	0.651	0.618	0.651	0.273	0.541	0.453	0.560	0.260	0.249
	P-value	0.003	0.000	0.000	0.000	0.160	0.003	0.015	0.002	0.182	0.202
cPP (mmHg)	R	0.238	0.105	0.127	0.058	0.416	−0.023	−0.099	0.003	0.408	0.398
	P-value	0.223	0.595	0.520	0.768	0.028	0.906	0.618	0.987	0.031	0.036
SV (ml)	R	0.088	0.167	0.029	0.052	0.438	0.011	−0.235	-0.010	0.423	0.439
	P-value	0.658	0.396	0.882	0.764	0.020	0.955	0.229	0.959	0.025	0.019
CO (l/min)	R	0.300	0.380	0.198	0.300	0.483	0.114	−0.027	0.217	0.447	0.464
	P-value	0.120	0.046	0.311	0.122	0.009	0.562	0.890	0.268	0.017	0.013

BMI body mass index; *WC* waist circumference; *HC* hip circumference; *WHtR* waist-to-height ratio; *FM* fat mass; *BM* bone mass; *LM* lean mass; *SBP* systolic blood pressure; *DBP* diastolic blood pressure; *MBP* mean arterial pressure; *PP* pulse pressure; *cSBP* central systolic blood pressure; *cDBP* central diastolic blood pressure; *cPP* central pulse pressure; *SV* systolic volume; *CO* cardiac output

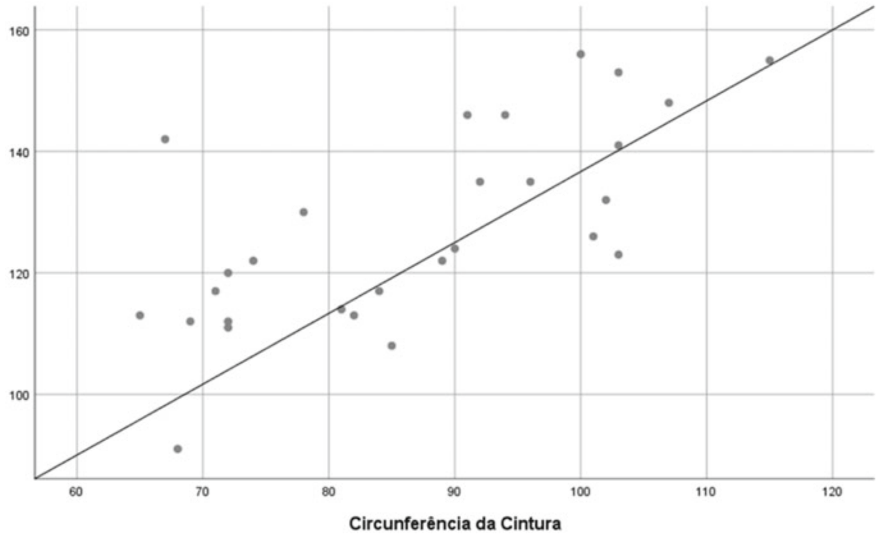

Fig. 1 Correlation between systolic blood pressure and waist circumference (R = 0.703; $p < 0.001$)

estimate of FM for a single individual may be imprecise, it corresponds well across groups and different categories of body fat (Flegal et al. 2009).

In a study, carried out by Recio-Rodriguez et al. (2012), WHtR and WC showed a more important correlation than BMI and %FM with arterial stiffness, assessed using PWV. Later, Zhang et al. (2017), corroborated these same findings, stating that WHtR and WC were superior to BMI in identifying arterial stiffness, in both sexes. The utility of waist circumference as an indicator of cardiovascular risk, associated with pulse wave velocity, had previously been proven (Ko et al. 2010; Czernichow et al. 2005). Neck circumference, not evaluated in this article, has also shown a positive association with arterial stiffness (Fantin et al. 2017).

Although the present study has not been able to prove this association, there are multiple investigations that support the use of anthropometric parameters as predictors of cardiovascular risk (Litwin 2008; Flegal et al. 2009; Recio-Rodriguez et al. 2012; Zhang et al. 2017; Ko et al. 2010; Czernichow et al. 2005; Fantin et al. 2017).

Given the existing controversy, although BMI is a validated method in obesity assessment, widely used in studies, it may be important to implement other methods, which are based on the quantification of body fat.

There are several methods that allow the assessment of body composition, and electrical bioimpedance is one of the methods that has come to prominence, with more and more studies seeking its validation (Mulasi et al. 2015). According to previous research, the percentage of fat mass is closely associated with several cardiovascular risk factors (Spiegelman et al. 1992). Thus, changes in %FM can be used as early indicators of increased risk (Leproult et al. 2014). A study in Chinese subjects (Zeng et al. 2008) found data consistent with a strong correlation between fat mass index and cardiovascular function, which led the authors to argue that this index better reflected cardiac function and arterial compliance than other commonly used indices such as BMI. Similarly, Wyckretowicz et al. (2007) had a year earlier observed clear associations between AS parameters and body fat content.

More recently, Hernandez-Martinez et al. (2019) pointed to the lean mass index as a valuable predictor of AS. Other studies have also found a strong relationship between LM and cardiovascular risk parameters (Gracia-Marco et al. 2016; Julius et al. 2002).

The authors tried to find physiological mechanisms that could explain the relationship between lean mass and cardiovascular risk. It has been suggested that a greater amount of LM may lead to a greater circulating blood volume, thus increasing the left ventricular systolic volume and, consequently, the cardiac output (Gracia-Marco et al. 2016). As a consequence of these changes, ventricular hypertrophy and enlargement may result, in all similar to what could be found in obese individuals (Gracia-Marco et al. 2016; Ortega et al. 2016).

Based on previous studies, shift workers were expected to have an increased prevalence of several cardiovascular risk factors (Buchvold et al. 2015). A positive association between BMI and shift work has been proven (Buchvold et al. 2015; Rabanipour et al. 2019). This may be because the disruption of circadian rhythms alters the metabolism, reducing baseline energy consumption and increasing the blood glucose level, resulting in an increased risk for obesity. In addition, modification of meal timing and quality also affects this same risk (Lowden et al. 2010). The results obtained by us contrast with this information, since no association was found between obesity parameters and shift work.

With regard to alcohol consumption, the present study found a higher prevalence of regular drinking by shift workers when compared to rigid schedule workers, which is not consistent with the findings of Buchvold et al. (2015). In turn, a study conducted in the same year had concluded that individuals who switched from working rigid hours, to shift work amplified their alcohol consumption (Bekkers et al. 2015).

No association was found between shift work and smoking, exercise or caffeine consumption. These findings are supported by the results obtained by Buchvold et al. (2015) and by Bekkers et al. (2015).

In the present study, the number of years of shift work was not statistically associated with any of the hemodynamic parameters studied. This finding is in contrast to the evidence found by Wang et al. (2018), who revealed that a dose–response relationship exists between the duration of shift work and increased risk of morbidity and mortality caused by cardiovascular diseases. A second study, previously mentioned, reinforced this conclusion, stating, however, that this association is only present after the first 5 years of exposure to shift work (Fantin et al. 2017).

Although no correlations were found between shift work and the parameters under study, the correlation between blood pressure and anthropometric parameters, should be highlighted. Cruz et al. (2019) found that in a population of children, WC was a highly predictive measure of increased blood pressure. Similarly, other authors have indicated that central adiposity, as assessed by anthropometric measures, could be a determinant of BP and hypertension in a group of Indian adults (Taing et al. 2016).

Overall, these results suggest that blood pressure may be predominantly associated with abdominal adiposity. Increased blood pressure may result from oxidative stress, inflammation, or physical compression of the kidneys by excess abdominal fat, particularly visceral fat (Hall et al. 2015).

This study has several limitations. First, the sample size was small, so the number of participants may have conditioned the results obtained, as well as the detection of differences between the two study groups. Second, information regarding medical history, as well as personal habits, was acquired through a questionnaire, filled out by the participants themselves, which may have created difficulty in obtaining correct information. In addition, the assessment of arterial stiffness was performed using the Mobil-O-Graph device. Recently, it was concluded that the algorithm used by this device, to estimate the PWV from the oscillometric data obtained, adds little to the information provided by age and systolic blood pressure (Schwartz et al. 2019). Finally, body composition variables were derived from electrical bioimpedance, a method that is not yet considered the gold standard for body composition assessment (Ward 2019).

However, it is crucial to note that a considerable amount of hemodynamic and body composition parameters was considered, in a sex-balanced sample. This research provides information regarding arterial stiffness in shift workers, a subgroup that had been the subject of little investigation to date.

5 Conclusions

The present study did not confirm a positive association between shift work and an higher cardiovascular risk. However, new studies should be conducted in order to identify possible relationships between these variables.

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Physiological Monitoring Systems for Fatigue Detection Within Firefighters: A Brief Systematic Review

Pedro Pratas, Denisse Bustos, J. C. Guedes, J. Mendes, J. Santos Baptista, and M. Vaz

Abstract Firefighters' fatigue can negatively impact safety, production, and health. During firefighting, the risks are extreme, and firefighters' health status is commonly neglected. A wearable sensor capable of predicting fatigue levels would have a substantial positive impact on the health and organisation of the teams. This review aims to collect information regards usage conditions and the development of wearable sensors at the occupational level. It also presents a proposed design for a wearable sensor that firefighters can use. This review is based on articles that reference the use of wearable sensors on an occupational level and the development of those systems. The studies show few wearable sensors used in high-intensity activities, although many can be used in other environments. The methodology suggested for the proposed design needs further investigation and adjustments. The final system must be capable of measuring heart rate, respiratory rate and body temperature. It should also send the firefighter GPS localisation and alerts of falling detection.

Keywords Wearable · Firefighters · Physiological · Wireless · Internet of things

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1 Introduction

During firefighting, firefighters are exposed to multiple hazards to human health, severely impacting performance and health (Groot et al. 2019). A way to monitor health status is through fatigue. Fatigue can be an unpleasant symptom that brings sensations ranging from tiredness to exhaustion, interfering with an individual's ability to act and perceive (Ream and Richardson 1996). Furthermore, it can be considered a risk factor that negatively impacts safety, production, and health (Thomas et al. 2019). Physiological parameters such as heart rate, physical activity and core temperature can be good predictors of fatigue and health state, as they present alterations when submitted to environmental, metabolic, and neuropsychiatric stressors (Bustos et al. 2021a).

A wearable sensor capable of collecting those vital signs, processing them, and sending the firefighters' health status to the command could prevent numerous injuries and help make a better combat strategy. This system would alert firefighters when their vital signs are abnormal and they should withdraw. Implementing this system in every firefighter during long combat would make it easier for the command to manage the teams, decreasing the risks of bad health status.

The development of this system must obey rules and legal issues that must be considered. Also, there are technical problems to overcome, such as the guarantee of uninterrupted communications between every participant, the well-placed sensors, and the best choice of equipment. All these problems must be discussed and studied, and all the decisions must be based on the most up-to-date scientific knowledge. The main goal of the present review is to find relevant information regarding the development of wearable systems capable of real-time non-invasive measurement of vital signs (such as heart rate, respiratory rate and core body temperature), including the communication approaches during firefighting duties.

2 Methods

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement guidelines (Page et al. 2021).

As eligibility criteria, this work only includes published articles and articles in press focusing on systems that firefighters could use. That means it was necessary to guarantee that the systems could perform in extreme physical conditions. There were only considered research developed within working age and no sedentary workers. Only articles written in English were considered. The research was performed within four electronic databases: SCOPUS, Web of Science, Academic Search Ultimate and INSPEC. There were only included articles from January 2017 until January 2022. The decision to only include articles published only in the past five years is based on the technological breakthrough that occurred in the past five years. Accordingly to Ometov et al. (2021), in the past five years, the search for wearable monitorisation systems has increased significative. Also, the pandemic situation lived on the past three years increased the need for health monitoring patients remotely.

As search strategy, the review focuses on developing wearable systems and their potential applications in occupational settings. With this aim, three groups of keywords were selected. The first one refers to the main goal, a wearable system; therefore, "wearable" was needed to be included. This first group was only applied to the title of the articles. The second group refers to the vital signs that must be collected: "Heart", "Breathing", "Respiratory", "Temperature", and "Vital signs". The third group selected the field that needed to be studied, the occupational settings with "Occupational" and "Safety" and the engineering with "IoT" and "Internet of things". The following query was adapted for each database, and the keywords from the groups were combined as follows: TITLE(wearable) AND TITLE/KEYWORS/ABSTRACT ((Heart) OR (Breathing) OR (Respiratory) OR (Temperature) OR ("Vital signs")) AND TITLE/KEYWORS/ABSTRACT ((Occupational) OR (Safety) OR (IoT) OR ("Internet of things")).

The management of collected articles was made through a customised Excel table. Selected papers from each database were exported for screening. Both title and abstract were first examined. Then, with the established selection criteria, full-text papers were retrieved and assessed.

Records themselves were managed with the *EndNote* software. In each database, after the combination of keywords was inserted, the following exclusion criteria were applied through search filters:

- Date: Articles published between January 2017 and January 2022.
- Type of articles: Articles and Articles in Press.
- Source type: Journal.
- Language: English.

The decision for choosing those exclusion criteria was to have a better sample of the articles and to have the ones that better fit the topic. Duplicated articles were removed at this point. Papers that fulfil the following criterion were also excluded:

- Focus on the development of hardware.
- Focus on legal issues.
- Systems are not able to be applied within an active working-age population.
- System design for specific diseases. Except for COVID-19.

After all non-relevant papers were excluded, full texts were analysed to collect information of interest. This information was organised in a specifically designed Excel spreadsheet and included: Study general information: authors, publication year; Vital signs analysed; Signal processing methods; Communication; Development of the system; Vital signs sensors; System validation.

In addition to the previous information, microprocessors and sensors information was collected when the authors developed the system entirely.

To understand best the principles beyond the development of a wearable system. Five main topics needed to be approached.

1. Which methods are the best for measuring the vital signs?
2. How can the system be developed and which sensors and microprocessors should be used?
3. How to process the signal measured by the sensors?
4. How do transmit the results out of the system?
5. How do validate the system and the accuracy of the results?

The results and discussion will be presented in the previous order.

3 Results

The selection of studies was summarised in the PRISMA flow diagram, Fig. 1.

The articles were separated into five groups; those groups are not exclusive. Eight articles focus on the signals' processing, six focus on communication, 16 on development, eight about the practices used to measure vital signs and three refer to validation methods. Table 1 clarifies and details each group and which articles belong to each group.

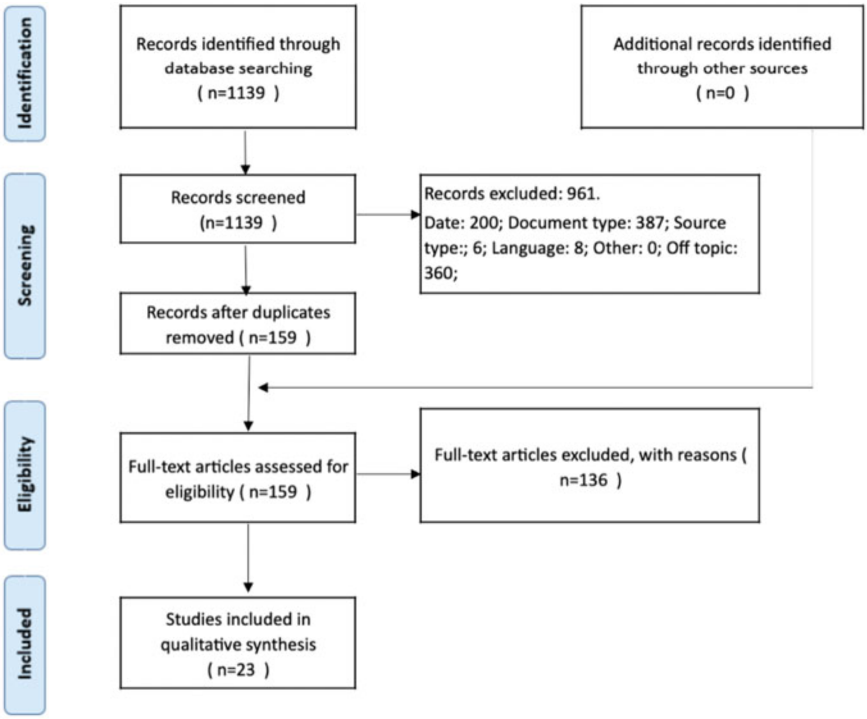

Fig. 1 PRISMA flow diagram

Table 1 Articles categorisation by groups

Group	References
Signal processing methods	Dosinas et al. (2017), El Attaoui et al. (2020), Hooshmand et al. (2017), Li et al. (2021a, b), Liu et al. (2019), Manas et al. (2019), Ozkan et al. (2020), Sakphrom et al. (2021)
Communications	Sakphrom et al. (2021), Batista et al. (2019), Fan et al. (2018), Jain et al. (2020), Paulraj et al. (2021), Wu and Chen (2021), Wu et al. (2020), Yuntao and Lianda (2020)
Developed systems	El Attaoui et al. (2020), Li et al. (2021a), Manas et al. (2019), Sakphrom et al. (2021), Batista et al. (2019), Fan et al. (2018), Paulraj et al. (2021) Abro et al. (2018), Ahmed Zeeshan et al. (2019), Al Bassam et al. (2021), Hyndavi et al. (2020), Kassem et al. (2021), Khatami et al. (2021), Kodali et al. (2018)
Vital signs measurement methods	Dosinas et al. (2017), Li et al. (2021b), Sakphrom et al. (2021), Yuntao and Lianda (2020), Al Bassam et al. (2021), Khatami et al. (2021), Balasubramaniyam et al. (2019), Mukhopadhyay et al. (2018), Roossien et al. (2020)
Validation	Li et al. (2021a), Manas et al. (2019), Sakphrom et al. (2021)

There are plenty of methods to measure vital signs, being the ones addressing breathing rate are the least common. Heart rate (HR) can be calculated through electrocardiogram (ECG) or photoplethysmography (PPG). Six articles mention the first method (El Attaoui et al. 2020; Li et al. 2021a; Liu et al. 2019; Ozkan et al. 2020; Paulraj et al. 2020; Kassem et al. 2021), and seven articles mention the second (Manas et al. 2019; Sakphrom et al. 2021; Batista et al. 2019; Jain et al. 2020; Al Bassam et al. 2021; Hyndavi et al. 2020; Kodali et al. 2018). Respiratory rate (RR) can be measured through flexible sensors (two articles) (Khatami et al. 2021; Balasubramaniyam et al. 2019), piezoresistive sensors (two article) (Khatami et al. 2021; Mukhopadhyay et al. 2018), respiratory inductive plethysmography (RIP) (one article) (Dosinas et al. 2017) or cardiopulmonary sound (two articles) (Yuntao and Lianda 2020; Al Bassam et al. 2021). Core temperature can be measured by in-ear thermometers (one article) (Roossien et al. 2020) or estimations based on body or environmental temperature (one article) (Manas et al. 2019).

The development of wearable sensors to measure physiological signals is based on light and cheap components. Table 2 makes a resume of used microcontrollers and sensors. It also gives information regarding the usage conditions of the system.

Signal processing can be done by hardware or software and most often is preferred a combination of both methods. Hardware signal processing is used to eliminate noise. Software signal processing is used to study and decode understandable values. The values that reach the microcontroller are analogue, and it is needed to understand what that range means in the units that are being studied. To present the information out of the system, these can be transmitted wireless, using WiFi, radio, or other convenient technology. The studies suggested five technologies:

Table 2 Summary of sensors used and microprocessors (continues on next page)

Usage condition	Sensors				Microprocessor	References
	HR	RR	Temperature	Other		
Coal miners	PPG—PulseSensor	–	–	Temperature and humidity—DHT 11 Gas detecting—MQ2 Pressure and depth—BMP180	Arduino Mega	Abro et al. (2018)
Industrial applications	–	–	–	Gas sensor—LPG Gas detecting—MQ2 Temperature—LM35	Arduino UNO	Ahmed Zeeshan et al. (2019)
Daily's use of potentially infected patients with COVID-19	PPG—Sparkfun pulse oximeter and heart rate sensor	The microphone of Arduino nano BLE	Body—Dallas temperature sensor (DS18B20)	SpO_2—Sparkfun pulse oximeter and heart rate sensor	Arduino MKR 1400	Al Bassam et al. (2021)
Daily use	PPG—PulseSensor	–	Body—LilyPad temperature	Gyroscope, magnetometer and accelerometer—Flora LSM9DS0	Circuit playground express (CPX)	Batista et al. (2019)
Hospital patients	ECG—AD8232 sensor	–	–	–	Arduino LilyPad	El Attaoui et al. (2020)
Walking	–	–	Body—BME680 Bosh Sensortec	UV sensor—si1145	ATmega328P	Fan et al. (2018)
Daily use. Not tested fully	PPG—PulseSensor	–	Ambient—NTC thermistor	Pressure sensor GPS-GMS—SIM808 module	Arduino UNO	Hyndavi et al. (2020)
On duty soldiers	PPG—MAX30100	–	Body/Surround—LM35	SpO_2—MAAX30100 GPS—skm52 GPS module	ATmega328P	Jain et al. (2020)

(continued)

Table 2 (continued)

Usage condition	Sensors				Microprocessor	References
	HR	RR	Temperature	Other		
Resting, walking and running	ECG—ADS1292R	–	Body—MAX30205	SpO_2—AFE4400	Raspberry Pi 3	Kassem et al. (2021)
Relaxed test	–	Flex sensor—FSL 0555 Force sensitive resister—FSR402	–	–	ESP32	Khatami et al. (2021)
Industrial workers	PPG—PulseSensor	–	Body/Surround—LM35	Gas sensor—MQ7 Humidity and surrounding temperature—DHT-11 Accelerometer—ADXL335	ESP32	Kodali et al. (2018)
Tests were done at rest and motion	ECG—TI's ADS1292	–	Body—LMT70	Motion—MPU6050	MAS-EXP430F5529	Li et al. (2021a)
Daily use	PPG—Shelley and Shelley	–	Body—LM35	Accelerometer—ADXL335	Arduino UNO	Manas et al. (2019)
Hospital patients	ECG—AD8232 sensor	–	Body—LM35	Sweat rate—Galvanic skin Accelerometer—ADXL345 Blood pressure—PulseSensor	Arduino UNO	Paulraj et al. (2021)

(continued)

Table 2 (continued)

Usage condition	Sensors				Microprocessor	References
	HR	RR	Temperature	Other		
Admitted patients	PPG—MAX30102	–	Body—GY-906	Blood pressure—MAX-30102	ESP32	Sakphrom et al. (2021)

- Global System for Mobile (GSM) this technology uses a mobile network to transmit data (one article) (Batista et al. 2019);
- Long-Range (LoRa) technology, which is widely used to send small information over long distances (two articles) (Fan et al. 2018; Jain et al. 2020);
- WiFi commonly used in domestic environments (three articles) (Sakphrom et al. 2021; Paulraj et al. 2021; Wu et al. 2020);
- Radio communication (one article) (Wu and Chen 2021);
- ZigBee, this technology is similar to WiFi, but the implementation of mesh networks is more straightforward, making this technology a great solution for transmitting over medium-long distances (one article) (Yuntao and Lianda 2020).

Other possible wireless technologies are not relevant to transferring information like Bluetooth. However, it is used to share information to a cellphone close to the system, and the next GSM sends the data over long distances.

The validation of the systems is usually not done. However, some studies compare medical equipment results (Li et al. 2021a; Sakphrom et al. 2021). By comparing the results, the accuracy and feasibility of the system are verified. The sensors also need to be calibrated. Only one study mentions a calibration method of LM35 temperature sensor (Manas et al. 2019).

4 Discussion

4.1 Vital Signs Measurement Methods

Three vital signs are the most relevant to monitoring firefighters' fatigue on duty: heart rate, respiratory or breathing rate, and core temperature (Bustos et al. 2021a). However, there are some constraints regarding those parameters.

Heart Rate

ECG and PPG are two main methods to measure heart rate (Sakphrom et al. 2021). Among those two, ECG is probably the most important. Yet PPG is often available in low-cost wearable systems, such as smartwatches and wristbands. On the other hand, comprehension algorithms were never applied to PPG signals, unlike ECG signals (Hooshmand et al. 2017).

A PPG can be obtained by using a pulse oximeter. This device illuminates the skin and measures changes in light absorption. The results show the changes in blood flow and are synchronised with the heartbeat. In theory, any body part can be used to measure heart rate through PPG, although it is most commonly used in fingertips and earlobes (Manas et al. 2019). Movements can be constrained by a gripping device in the fingers or earlobes during some activities (Sakphrom et al. 2021), especially during firefighting. Another disadvantage of this system is that the position significantly impacts the results. A move from the preferred position may lead to less accurate pulse measurements (Sakphrom et al. 2021).

An ECG measures the electrical signal generated by the heart in each cycle (Sakphrom et al. 2021). This method can be used with different configurations. Liu et al. (2019) used a 12 derivation ECG SmartVes. However, 3-leads ECG is mainly used (El Attaoui et al. 2020; Paulraj et al. 2021; Kassem et al. 2021). Like the PPG, the ECG also has their disadvantages. Conventional ECG measurement electrodes need to be attached to the body with conductive gel. This gel may be toxic and cause skin irritation (Ozkan et al. 2020). In addition, the constraints in having electrodes attached to the chest may not be comfortable (Sakphrom et al. 2021).

At the moment, there are several pieces of equipment on the market for heart rate measurements. Although many of them only work in closed systems, those signals are hard to read. Nevertheless, research was done to verify the compatibility between commercial sensors and the developed system. Through this research, it is clear that Polar heart rate monitors are the best in the market and that those measurements are well seen in the scientific community. This conclusion is based on the number of articles that use Polar sensors, and brief research among the competitors' sensors was made to compare them. Table A1 from the paper presented by Bustos et al. (2021b) shows the number of articles in occupational studies that use each system.

As mentioned early, ECG signals are more reliable than PPG, and Polar ECG sensors are incredibly comfortable and easy to use.

Respiratory or Breathing Rate

Measuring respiratory rate is probably the hardest vital sign. Several papers have described methods to perform this measure, although most of them cannot be applied to high physical demands (Khatami et al. 2021).

The methods used to get respiratory rate can be summarised and organised accordingly to the equipment used (Mukhopadhyay et al. 2018). The most used are flexible chips and sensors, yet piezoresistive sensors are becoming more often (Balasubramaniyam et al. 2019). Dosinas et al. (2017) use a RIP to measure respiratory rate. This method uses an inductive sensor.

Flex sensors are variable resistors that increase their resistance as the angle of bend increases (Balasubramaniyam et al. 2019). The flex sensor detects the changes in the abdomen movement when a person breathes. The sensor must be placed in the subject's abdomen to get the best results. The positioning and protection of the sensors are the main constraints in this solution (Khatami et al. 2021; Balasubramaniyam et al. 2019).

Force sensing resistors are piezoresistive sensors that, as flex sensors, function as a variable resistance. The operation mode is similar to flex sensors (Khatami et al. 2021). The force applied to the sensor varies with each breath, and it is possible to get the respiratory rate. These devices can be placed in the chest or stomach of individuals (Mukhopadhyay et al. 2018).

The RIP method proposed by Dosinas et al. (2017) uses an expandable belt in which attached insulated wires are disposed of in a sine wave pattern. During each breath, the length of the belt varies and the self-inductance of the coils changes.

Detecting the coils' self-inductance variations gives the rib cage and abdomen variations. Through this data, it is possible to calculate the respiratory rate. This method is sensitive to body moves and posture changes (Dosinas et al. 2017).

All the proposed methods have constraints regarding usage. Any system was made for high-demand physical efforts, being the Balasubramaniyam is the more versatile one, applied and tested for daily use (Balasubramaniyam et al. 2019). The system proposed by Khatami et al. (2021) and Mukhopadhyay et al. (2018) were tested in relaxed or low activities. According to Dosinas et al. (2017) no information regarding the intensity of the tests is available.

Respiratory rate is the hardest to get. It has many problems associated with the measure, such as the capability to ignore possible cycle counts due to body movements and the system's robustness to ensure safe use at the occupational level, preventing damage and keeping the comfort (Dosinas et al. 2017).

The easiest to apply and most reliable and robust methods are through flexible or force resistive sensors (Khatami et al. 2021). Also, Vanegas et al. (2019) presented complete instructions to assemble and implement a respiratory rate sensor. However, the RIP sensor from Dosinas et al. (2017) is a more elegant solution.

Core/Body Temperature

It is crucial to have the subject's temperature estimate fatigue levels, which is the *gold standard* for core temperature assessment. The best method to measure core temperature is using temperature sensor pills; however, it is also expensive. This method is also considered invasive, and it is difficult to determine the pill's location on the gastrointestinal tract. Moreover, temperature sensor pills must be taken 4–6 h before the measures, which is impractical for firefighters (Roossien et al. 2020).

Body temperature is often chosen because it is more accessible to implement and cheaper, and there are numerous sensors to measure body temperature. Body temperature can be measured through imaging processes like infrared scanners or direct measures like the Dallas Temperature Sensor DS18B20. Infrared scanners can be affected by ambient and external factors (Al Bassam et al. 2021). During firefighting, ambient factors can cause high measurement errors.

Accordingly, ISO 9886 in-ear temperature is a great way to estimate core temperature. Although this method is very susceptible to radiation, tests were done on firefighters performing their job. The disappointing results revealed an invalid method for measuring core temperature (Roossien et al. 2020).

Core temperature is tough to get during firefighting. Besides being an intrusive method and many participants refuse to use it, it is impossible to know when they need to be on duty. Temperature sensor pills are costly and need to be calibrated before every usage (Roossien et al. 2020; Falcone et al. 2021).

The best method to estimate core temperature is in-ear temperature, but this method is an invalid method during firefighting. Other estimations for core temperature use body temperature measured from different body parts. The resume of some estimates is shown on (Falcone et al. 2021).

4.2 Developed Systems

Many articles refer to the development of wearable systems capable of measuring vital signs. Although many of them present constraints regarding the usage conditions and the vital signs that can be measured. The sensors and microprocessors used are also relevant to the analysis. Other optional sensors can also be interesting to consider. Table 2 organises the information collected in the articles regarding the systems' usage conditions, the sensors used, and the microcontrollers.

There are few studies regarding the development of wearable systems capable of being used during high physical demands. Yet it can be helpful to understand the capabilities of those systems and select the sensors needed for our study.

The articles collected verified that Arduino boards are the most used (nine articles), ESP-32 board is also used in some studies (three articles), and Raspberry Pi 3 is used in one study. To select a microcontroller is needed to compare the features of each one: Dimensions, weight, integrated sensors, connectivity and communication hardware, processing speed, power consumption, voltage, and available digital/analogue pins.

To develop a system, it is necessary to study the sensors to use and choose the best option based on the knowledge of what parameters the system needs to collect. This study focuses on heart rate, respiratory rate, core temperature, and motion analysis. Therefore, are those sensors that are going to be discussed.

Heart rate sensors are the most common. This measurement can be done by a PPG sensor or an ECG sensor. PPG sensors are often, and the most used is PulseSensor. Other sensors like SparkFun Pulse Oximeter and Heart Rate or Pulse Oximeter MAX30100 can also be used. ECG sensors are seldom used, and most of them use three leads, which can be uncomfortable to use during firefighting. However, an option is not reported on the selected articles, and it can be used. Polar ECG sensors are the most reliable heart rate sensors on the market. They are used in several medical studies and can be used during high-intensity activities. It is possible to read Polar ECG signals through an Arduino board, ESP-32 or Raspberry Pi using a proper adapter.

Respiratory rate sensors without breathing masks are rarely sold on the market. As so, it is needed to study possible systems. The use of flexible or force-sensitive resistors is the best choice. On this topic, the point is to verify and analyse the components. Some characteristics need to be clear to choose the sensors, like dimensions and range. The usual temperature sensor is the LM35. However, other sensors can be used, like the LilyPad, the NTC Thermistor, the LMT70 GY-906, BME680 from Bosch Sensortec, or the Dallas Temperature Sensor DS18B20.

The accelerometers or gyroscopes are the preferred sensors to analyse activity levels. Those sensors can be attached or already installed on the microcontroller board. Flora LSM9DS0, ADXL335, or MPU6050 are alternatives to connect to the board. Motion detection and route analyses can also be done by GPS positioning. This method also has some limitations, being the primary loss connection of satellite.

4.3 Signal Processing Methods

There are two main steps to processing and analysing data captured from sensors. The first one is to get rid of noise and amplify the signals, and the second is to understand the analogue reads and translate them to understandable units. Ozkan et al. (2020) used an instrumentation amplifier and three operational amplifiers to process ECG analogue signals. This amplifies the ECG signal, reduces the noise, generates a virtual ground for analogue signals, acts as an antialias filter before sampling, and performs the analogue-to-digital operation. The software processing algorithms depend on the sensors' signals. To calculate HR, it detects the number of R waves per minute. The ECG signal is differentiated to determine the peak value of the R wave (Ozkan et al. 2020).

In another study, it was added a median filter to process the ECG data. First, the baseline drift was removed and after, the signal needed to pass through a low-pass filter. The algorithm finds the two consecutive peak voltages index and calculates HR (Li et al. 2021a). The bandpass filters were applied to eliminate noise outside the typical ECG signal band (i.e., 0.5–100 Hz). ECG samples are passed through a digital low-pass filter. To calculate the HR is used the method described by Li et al. (2021a) and Ozkan et al. (2020).

PPG is usually processed through a high-pass filter followed by a low-pass filter. This way, unwanted direct current signals are removed (Manas et al. 2019). After filtering the sensor signals, it is necessary to calculate the HR. Selected studies all follow the same logic, finding two consecutive peaks and measuring the time difference between them.

There is only one paper that studies a respiratory sensor's processing methods. More than some filters are needed to process the signals that came from the RIP sensor. The respiratory signal processing circuit proposed by Dosinas et al. (2017) comprises the inductive sensor made to the occasion, a variable frequency oscillator, a respiratory signal demodulator, a bandpass filter, and an amplifier. The oscillator generates a signal that varies accordingly to the inductance changes produced by the inductive sensor. This signal is characterised by being an oscillator signal that alters the frequency. The demodulator and filter together transform the frequency changes into a pulse signal. The bandpass filter cuts off noise beyond the considered frequency (Dosinas et al. 2017).

4.4 Communications

During firefighting, environmental conditions are extreme. Not only regarding physical effort and high temperatures but also regarding difficult terrain conditions and lack of communication. Many times, mobile and radio signals are off.

There are alternatives for wireless transmissions. Radio Frequency technology, Bluetooth technology, Global System for Mobile Communication technology, and

WiFi technology are all possible solutions already used to transmit medical information to soldiers on the battlefield. However, there are disadvantages to those technologies, like high power consumption, short-range, high cost, disconnecting problems, and poor encryption (Jain et al. 2020).

Each technology has its advantages. LoRa technology can be an excellent choice for long-range, although this technology is a point-to-point communication. ZigBee can also be a possible option, this communication was a shorter range, but it is possible to make a mesh network capable of transmitting information for vast areas. These two have the disadvantage of low data rates. WiFi is very power consuming and has a short range. Bluetooth is only viable to close communications (10 m maximum) (Jain et al. 2020).

ZigBee can function with three different configurations—Star Topology, Three Topology and Mesh Topology (Yuntao and Lianda 2020). Using Mesh Topology makes it possible to create a network capable of transmitting information in a long range.

4.5 Validation

System validation is seldom done. However, there are different methods regarding the sensor and its usage when it is done. For example, respiratory rate systems' warranty is frequently made by comparing RR measured by the system and RR measured manually (Khatami et al. 2021). HR systems can be validated using other equipment, like the standard medical equipment (IOS Smart Watch) (Sakphrom et al. 2021). Or using a simulator and comparing the data generated by the simulator and the signals measured (Li et al. 2021a).

It is also important to calibrate the sensors. However, only one paper makes a brief reference to the method used. Manas et al. (2019) explain the calibration method used for the LM35 temperature sensor.

5 Conclusion

This review tried to resume and analyse possible solutions to develop a wearable system that firefighters could use to detect fatigue. The foremost vital signs used to estimate fatigue are heart rate, respiratory rate and core temperature. Heart rate and core temperature can be measured easily and precisely, even during high-intensity activities. Body movements significantly influence respiratory rate measurements and make them less accurate for high-intensity workouts.

The overall systems need to have some signal processing methods, the most used are hardware applied, like low-pass, high-pass or bandpass filters, but it is also required to analyse the signal through software. The most used algorithm is the ECG wave and the process of translating the wave into beats per minute.

Communication is the most challenging barrier to overcome. During firefighting, environmental conditions are extreme, and many wireless technologies are out of signal. This review concluded that LoRa and ZigBee are the two technologies that can lead to better results. These two can transmit information in vast areas using low power.

Conflict of Interest The authors declare that they have no conflict of interest.

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State of the Art in Occupational Safety and Health

Emissions from Vehicle Fires: A Literature Review of Levels of Exposure During Firefighting Activities

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Abstract *Objective* This chapter aims to review the available literature related to firefighters' exposure to health-relevant pollutants during firefighting of vehicle fires. *Background* Despite the increased number of vehicle fires, few studies assessed the compounds emitted and their potential health risks to firefighting forces. *Method* A literature review based on PRISMA methodology was performed regarding the characterization of vehicle fire emissions and associated firefighters' exposure to the pollutants released during fires. *Results* Available literature characterized emissions during training fire events and so far, only one study evaluated the emissions from an emergency fire event. Increased levels of particulate matter, mainly the fine/ultrafine fractions, carbon monoxide (3–4 ppm inside the passenger compartment), and total volatile organic compounds (1.5–722.4 ppm; 3.16–502.7 mg/m^3) were reported during vehicle fires. More specifically, benzene (0.38–60 mg/m^3), styrene (0.45–314 mg/m^3), methane (0.8–110.0 ppm), butanol (81.8–181.6 ppm), and naphthalene (0.170–1.200 mg/m^3 at the cabin compartment) were also present in fire emissions. Despite scarce, evidence highlighted the contribution of vehicle fire emissions to firefighters' occupational exposure. *Conclusion* Further studies should be conducted to provide a more detailed characterization of vehicle fires emissions and associated firefighters' exposure, thus moving the scientific knowledge forward in order to promote firefighters' safety and health.

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1 Introduction

Firefighting activities are classified as possible carcinogens to human by the International Agency for Research on Cancer (IARC) (International Agency for Research on Cancer 2010a). Also, the occupational exposure as firefighter is under evaluation by IARC. Evidence demonstrates firefighters' exposure to pollutants released from fires with associated health risks (Barros et al. 2021; Engelsman et al. 2020; Hwang et al. 2021; Soteriades et al. 2019). Forest and structural fires are among the most characterized types of fires; limited information is available about vehicle fires.

A total of 189,500 highway vehicle fires were reported in 2019 in the United States of America (USA). This number represents an increment of 4.4% when compared with the previous year (2018) (Statista 2021). Between 2014 and 2016, an estimated 171,500 highway vehicle fires occurred in the USA (about 13% of the total number of fires), representing an annual average of 345 deaths, 1300 injuries, and $1.1 billion in property damages (United States Fire Administration 2018). Between 2020 and 2021, it was registered 17,517 vehicle fire incidents in United Kingdom (United Kingdom Government 2021), being registered a decrease in this type of fire events since 2018 in Europe (European Union Agency for Railways 2021). Data from the occurrence of vehicle fires in European countries remain limited due to the inexistence of a database or regular annual reports.

Fire emissions, including those from vehicle fires, release particulate matter (PM), carbon monoxide (CO), several volatile and semivolatile organic compounds (VOCs), including polycyclic aromatic hydrocarbons (PAHs), among other pollutants (Truchot et al. 2018). Vehicle fires, namely the burning of automobiles, trucks, among other motor vehicles, are a common type of urban fires, being a considerable source of toxic compounds due to their composition with different synthetic materials (e.g., rubber, tires, oil, batteries, foam, steel, electronic devices, etc.) and the presence of fuel (except in electrical cars). The development of the car industry encompasses the continuous introduction of new materials, technologies, and plastic-related products that strongly contribute to the complexity and toxicity of emissions during vehicle fire events (Evans and Fent 2015). Firefighters report regular participation in vehicle fires however, the knowledge concerning the composition of fire emissions, levels of exposure, and associated potential health risks remains limited. Vehicle fires predominantly occur outdoors, being that burning in an open and well-ventilated space and strongly contributes to reducing the intensity and duration of the fire event when compared with the burning of vehicles inside a building, e.g., a garage (Fent and Evans 2011). Structural firefighters use personal protective equipment (PPE) with the self-contained breathing apparatus (SCBA) during firefighting of urban fires, including vehicle fires. However, firefighters tend to (partially/totally) remove the SCBA when the fire is under control, including during the overhaul phase

(Fent and Evans 2011), thus contributing to an enhanced exposition to the emitted toxic compounds.

This chapter aims to compile the available literature related to firefighters' (ambient/personal air) exposure to vehicle fire emissions during firefighting activities. Information related to potential risks for human health is also briefly presented. Despite scarcity, evidence reports the release of some health-relevant pollutants, e.g., PM, CO, VOCs, and PAHs from vehicles' burning, thus contributing to firefighters' occupational exposure.

2 Material and Methods

Information related to firefighters' occupational exposure to chemical contaminants released during vehicle fires was searched up to December 2021. The literature search was conducted in different databases, Scopus, PubMed, Science Direct, Scielo, and ISI Web of Knowledge with the combination of at least two of the following keywords: vehicle fire, automobile fire, firefighting, firefighters' exposure, PM, CO, VOCs, and PAHs; the Boolean symbol "AND" was always used between keywords to make the search broader and more complete (e.g., "vehicle fire AND firefighting AND CO", "firefighters' exposure AND vehicle fire", etc.). A PRISMA methodology was applied to the search, taking into consideration the following inclusion criteria: (i) to be original work and (ii) to assess the characterization of firefighters' exposure to fire emissions during vehicle fires (Fig. 1). All the eligible studies were abstract screened after the elimination of duplicates. Overall, a total of ten studies were selected for this study. Five reports assessed the characterization of firefighters' occupational exposure to vehicle fire emissions while five studies described the characterization of vehicle fire emissions.

3 Results and Discussion

The selected ten studies characterized the emission of PM (n = 4), CO (n = 6), VOCs (n = 6), and PAHs (n = 3) during vehicle firefighting activities.

3.1 Particulate Matter

PM is a heterogeneous mixture of solid particles and liquid droplets suspended in the air that vary in size, shape, and origin. PM is classified according to its aerodynamic diameter as coarse (particles with an aerodynamic diameter higher than 2.5 μm), fine (particles with an aerodynamic diameter lower than 2.5 μm), and ultrafine (particles

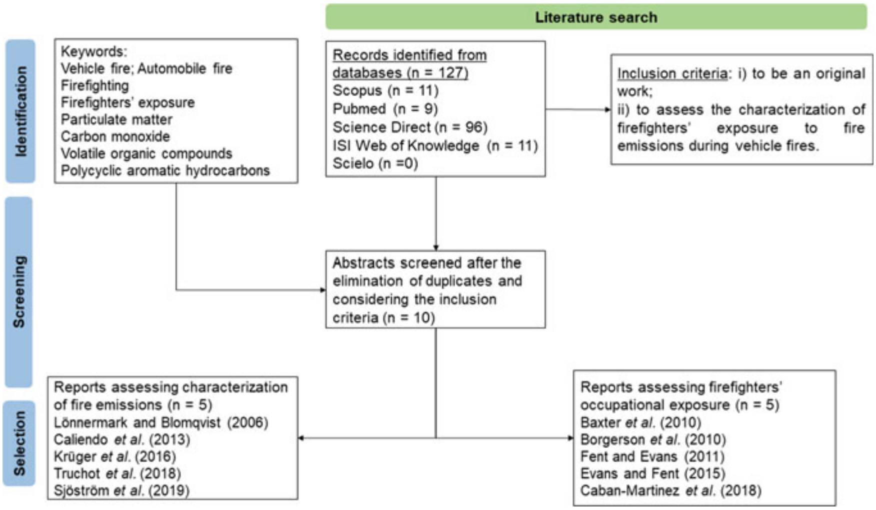

Fig. 1 Flow diagram based on PRISMA methodology applied

with less than 0.1 µm of aerodynamic diameter) particles (World Health Organization 2006).

Lönnermark and Blomqvist (2006) investigated the emission of hazardous chemical compounds during 3 experimental vehicle fires with a duration of up to 3 min. Those authors reported the environmental contamination (air and water) with fine and ultrafine particles. The collected PM was analysed regarding its content in different inorganic compounds, e.g., zinc (50,300 mg/kg of combustible material consumed), lead (12,800 mg/kg), chlorine (39,000 mg/kg) and bromine (4000 mg/kg), which demonstrated the emission of toxic compounds during vehicle fires (Lönnermark and Blomqvist 2006). So far, a total of 3 studies assessed the levels of PM emitted during experimental and training vehicle fires (Table 1).

Evans and Fent (2015) assessed the levels of respirable PM on the personal air of firefighters during 6 training exercises (up to 15 min of exposure) and concluded that PM exposure was mainly influenced by the position of firefighters relative to the burning vehicle and the wind direction. Veering plumes contributed to the highest PM concentrations observed during the ignition/approach and knockdown phases (Evans and Fent 2015). The highest PM concentrations were observed inside the passenger cabin fire, which highlights that exposure to PM can persist during the overhaul phase, when firefighters might (partially/totally) remove their SCBA. It was also found that the passenger compartment fire emitted higher concentrations of respirable PM than the engine fire (Table 1). Evans and Fent (2015) support these results with different experimental tests, including the use of higher fuel loads, more extensive fires, and longer suppressions periods. Borgerson et al. (2011) used particle impactors to measure firefighters' exposure during overhaul activities (Table 1). The

Table 1 Levels (mean ± SD, range) of PM during vehicle fires

Sample	Fires (duration)	Units	Concentrations	Reference
Personal air	6 training exercises (15 min)	mg/m^3 10^3 particles/cm^3	Engine fire Respirable PM: 0.22–0.53 Cabin fire Respirable PM: 0.13–5.9 Engine fire: 53–56 Cabin fire: 89–324	Evans and Fent (2015)
Ambient air	2 experimental fires (10 min)	particles/cm^3	Passenger compartment 1.96×10^4 Engine compartment 6.73×10^4	Borgerson et al. (2011)
Personal air	1 experimental fire (30 min)	particles/cm^3	$1.96 \pm 0.62 \times 10^4$	Baxter et al. (2010)

authors described that 99% of the ambient PM presented less than 1 μm of diameter (87.8–91.4% ranging from 0.01–0.11 μm; 8.6–12.1% ranging between 0.11 and 1.0 μm) (Borgerson et al. 2011), which was consistent with previous studies performed at residential fires (Borgerson et al. 2010). More specifically, inside the passenger compartment, the predominant PM fractions were those ranging from 0.93 to 3.5 μm (47.6%) and those with an aerodynamic diameter superior to 9.8 μm (22.8%) (Borgerson et al. 2011). Baxter et al. (2010) also described similar findings during 1 experimental fire with 91% of total PM (1.96×10^4 particles/cm^3) ranging from 0.01 to 0.11 μm and remaining 9% of PM varying between 0.11 and 1.0 μm. The occupational exposure limit for respirable particles, i.e., "inert" dust that can include some PM4 and larger particles, set by the Occupational Health and Safety Administration (OSHA), for an 8 h working day, is 5 mg/m^3 (Occupational Safety and Health Administration 2017). Fine and ultrafine particles can reach the deepest regions of lungs and even cross the alveolar surface membranes, being translocated into epithelial tissue, interstitial, pulmonary endothelium, or secondary organs (Navarro et al. 2021). Regular exposure to PM, mainly to fine/ultrafine particles, is associated with the aggravation/development of respiratory (e.g., allergies, sinusitis, and asthma) and cardiovascular (e.g., ischemic heart disease, heart failure, and ischemic/thrombotic stroke) diseases and cancer, contributing to higher rates of morbidity and mortality (Miri et al. 2018; Yang et al. 2019).

3.2 Carbon Monoxide

CO is a toxic gas that results from the incomplete burning of various materials and fuels, being also formed during fire events. The study from Lönnermark and Blomqvist (2006) also presented the levels of CO and carbon dioxide (CO_2) emissions during a vehicle fire. The authors reported a 60 g/kg of combustible material consumed for CO and 2400 g/kg for CO_2. Caliendo et al. (2013) performed a training exercise in a bi-directional road tunnel, with 4 different types of vehicles, to simulate the effects of vehicle fire emissions in a closed space. The monitored CO and CO_2 levels ranged from 11 (petrol tanker cab) to 150 g/kg of combustible material consumed (heavy goods vehicle) and from 2000 (bus) to 3000 g/kg of combustible material consumed (heavy goods vehicle), respectively (Caliendo et al. 2013). Both studies described approximated results for the emissions of CO and CO_2 during vehicle fires (Caliendo et al. 2013; Lönnermark and Blomqvist 2006). More recently, Truchot et al. (2018) also evaluated the factors that conditionate car emissions during experimental fire events and observed that CO_2 emissions represented the highest component in ambient air (96.5–97.3%) followed by CO (1.94–2.29%) (Truchot et al. 2018). Krüger et al. (2016) investigated the smoke development inside a passenger cabin during a vehicle fire and monitored the concentrations of CO and CO_2. After 5 min of fire, hazardous levels of CO (469 ppm) were registered with mean CO_2 values of 1940 ppm; maximum concentrations were observed after 9 min of fire (CO of 17,200 ppm and CO_2 of 97,006 ppm) (Krüger et al. 2016). So far, only 2 studies described the levels of firefighters' exposure to CO during vehicle fires (Borgerson et al. 2011; Caban-Martinez et al. 2018). Based on the reported results, both studies presented similar levels of CO inside the passenger compartment fire (values ranged between 3 and 4 ppm). As expected, levels of CO inside the passenger area were lower than the values achieved during an engine compartment fire (23.7–491.9 ppm), mostly due to the presence of fuel and oil in the engine compartment (Borgerson et al. 2011). Additionally, it was reported that personal air presented lower levels of CO than ambient air samples, since the monitored vehicle fires occurred in an exterior well ventilated area, which significantly reduce firefighters' exposure (Borgerson et al. 2011). According to OSHA, the occupational exposure limit for CO during 8 h of work is 50 ppm while National Institute for Occupational Safety and Health (NIOSH) proposed a limit of 35 ppm for a daily 10 h shift (National Institute for Occupational Safety and Health 2014; Occupational Safety and Health Administration 2017). Taking these values into consideration, Borgerson et al. (2011) reported CO levels superior to those exposure limits; however potential health effects are not expected, since the exposure during vehicle firefighting lasted less than 30 min. Regular exposure to CO promotes acute toxicity due to the formation of carboxyhemoglobin in the blood, which reduces/prevents the oxygen transport to vital organs (Gill and Britz-McKibbin 2020). Symptoms of CO poisoning are dependent on the length and levels of exposure and might include headaches, neurologic symptoms, confusion, and unconsciousness. A continued exposure to CO can cause arrhythmias, exacerbation of chest pain, severe heart ischemia (inadequate oxygenation) and it may end up with fatal arrhythmias (International Association of Firefighters 2022).

3.3 Volatile and Semi Volatile Organic Compounds

VOCs consist in a wide variety of gaseous organic pollutants that are directly emitted from biogenic and anthropogenic sources or they can be formed in the atmosphere (Mozaffar and Zhang 2020). Several VOCs are released during vehicles fires (Fent et al. 2020; Sjöström et al. 2019). Lönnermark and Blomqvist (2006) reported a total amount of VOCs of 8.5 g/kg of combustible material consumed, being benzene (3.0 g/kg of combustible material consumed) the predominant compound. More recently, Krüger et al. (2016) also assessed the levels of VOCs inside a passenger cabin fire and found ethylene (2117 ppm), benzene (1206 ppm), methane (854 ppm), and acetylene (828 ppm) as the compounds with the highest concentrations. Concerning firefighters' exposure to VOCs during vehicle firefighting activities, a total of 3 studies were found (Table 2). Overall, levels of total VOCs ranged between 1.5 and 722.4 ppm and from 3.16 to 502.7 mg/m^3, being benzene (0.38–60 mg/m^3), styrene (0.45–314 mg/m^3), methane (0.8–110.0 ppm), and butanol (81.8–181.6 ppm) the predominant compounds (Table 2). Analysing the information retrieved from the 3 studies, superior levels of total VOCs were obtained from the engine compartment fire (4.3–389.6 ppm) compared to the passenger compartment (2.5–107.3 ppm), due to the materials present on engine compartment (e.g., fuel/oil) (Borgerson et al. 2011). Comparing the results obtained by Caban-Martinez et al. (2018), similar levels were measured during an emergency fire event. The benzene (gas phase) maximum time-weighted average exposure limit is 1 ppm for an 8-h work shift and the maximum short-term exposure limit is 5 ppm for any 15-min period (Occupational Safety and Health Administration 2017). So far, only 1 study determined the levels of benzene and the reported values did not exceed the available occupational exposure limits (Fent and Evans 2011).

PAHs comprise a large group of VOCs with 2 or more fused aromatic rings arranged in different configurations (Kamal et al. 2015; Kim et al. 2013). There are 16 PAHs included in the list of priority pollutants, namely naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, benzo(g,h,i)perylene, and indeno(1,2,3-c,d)pyrene (United States Environmental Protection Agency 2005). Benzo(a)pyrene (BaP), a well-known carcinogen to humans (International Agency for Research on Cancer 2010), is frequently found on airborne fire emissions (Oliveira et al. 2017). Previously, Lönnermark and Blomqvist (2006) reported emissions of total PAHs of 1.1 g/kg of combustible material consumed during experimental vehicle fires.

Truchot et al. (2018) also found PAH emissions ranging from 0.37 to 0.45% of the total fire emissions. Regarding vehicle fires, only 1 study assessed the levels of naphthalene during 3 training exercises (Table 2). Following the same tendency

Table 2 Levels (mean, range) of VOCs and PAHs during vehicle fires

Sample	Fires (duration)	Units	Concentrations	Reference
Ambient air	2 training exercises and 1 emergency fire event	ppm	Total VOCs: (1.5–10) Total VOCs: 1.5 Total VOCs: (5–10)	Caban-Martinez et al. (2018)
Personal air	3 training exercises (10 min)	mg/m^3	Engine fire 1,3-butadiene (0.40[b]–4.8[c]); 1,2,4-trimethylbenzene (0.070[a]–4.2[b]); Acetone (0.40[a] –3.8[c]); Acetonitrile (0.12[b]–0.70[c]); Acrylonitrile (<0.026[b]–0.77[c]); Benzene (1.6[b]–11[c]); Chloromethane (0.17[b]–1.2[c]); Dichlorodifluoromethane (2.4[b]–48[c]); Ethylbenzene (0.15[a]–2.2[b]); *m,p,o*-xylenes (0.35[a]–9.1[b]); Propene (0.91[b]–11[c]); Styrene (0.83[a]–3.3[b]); Toluene (1.4[a]–9.3[b]) Naphthalene: (0.930–2.400) Cabin fire 1,3-butadiene (0.049[c]–6.8[a]); 1,2,4-trimethylbenzene (0.10[c]–0.70[b]); Acetone (0.30[c]–12[a]); Acetonitrile (0.034[c]–14[a]); Acrylonitrile (0.066[c]–27[a]); Benzene (0.38[c]–60[a]); Chloromethane (0.046[c]–11[a]); Dichlorodifluoromethane (0.0059[c] – < 0.087[a]); Ethylbenzene (0.12[c]–1.4[a]); *m,p,o*-xylenes (0.45[c]–2.7[b]); Propene (0.16[c]–18[a]); Styrene (0.45[c]–314[a]); Toluene (0.95[c]–10[a]) Naphthalene: (0.170–1.200) Total VOCs: 3.16–502.7	Fent and Evans (2011)

(continued)

Table 2 (continued)

Sample	Fires (duration)	Units	Concentrations	Reference
Ambient air	2 training exercises (10 min)	ppm	Passenger compartment Acetylene: 0.1; 0.5 Difluoroethane: 0.3; 0.2 Ethylene: 0.1; 8.5 Methane: 0.8; 15.5 Methanol: 1.2; 0.8; Butanol: 81.8 Total VOCs: 2.5–107.3 Engine compartment Acetylene: 0.3; 17.9 Difluoroethane: 0.5; Ethylene: 0.7; 75.4 Methane: 3.1; 110.0 Methanol: 0.2; 4.2; Butanol: 181.6 Total VOCs: 4.3–389.6	Borgerson et al. (2011)

[a]Start-up; [b]Knockdown; [c]Overhaul

as reported by other authors, concentrations of naphthalene were increased in the engine compartment (0.930–2.400 mg/m^3) than in the cabin burned area (0.170–1.200 mg/m^3) (Fent and Evans 2011). This study highlighted the need to include other PAHs in future studies assessing emissions from vehicle fires. According to OSHA, naphthalene exposure limit is 50 mg/m^3 (Occupational Safety and Health Administration 2017). The values reported by Fent and Evans (2011) did not exceed the exposure limit for naphthalene during the 10 min of training exercise. Exposure to VOCs may cause nose and throat irritation and may contribute to the development/aggravation of respiratory diseases (e.g., asthma, acute and chronic respiratory diseases) (Cheng et al. 2019). Small quantities of VOCs can condense on the skin and, thus, be available for biological uptake. Exposure to VOCs also promotes skin diseases, including cancer, and it has been related with leukaemia, brain cancer, as well as with nervous and endocrine system diseases (Cheng et al. 2019).

Despite scarce, available studies demonstrate the presence of hazardous pollutants in the emissions of vehicles fires, highlighting for firefighters' exposure and potential health risks for firefighting forces. Moreover, different authors emphasized the need to use a complete PPE, including SCBA, during the entire firefighting activity even during overhaul. Moreover, Caban-Martinez et al. (2018) also suggested the use of VOCs-filtering half face mask to minimize firefighters' exposure.

4 Conclusions

Despite the enhanced incidence of vehicle fires and the toxicity of compounds emitted during the burning of vehicles, ten studies reported the characterization of vehicle fire emissions and firefighters' occupational exposure. Also, only one study described firefighters' occupational exposure to emissions from an emergency fire event while the remaining studies characterized emissions during training fire events. Evidence suggests firefighters' exposure to respirable PM, CO, and VOCs emitted during vehicle fires. Considering the results summarized in the literature with the characterization of vehicles´ fire emissions, firefighting contributes to firefighters' occupational exposure and associated health burden. However, available information is more focused on the characterization of vehicle fire emissions rather than firefighters' occupational exposure. Therefore, there is an urgent need to better characterize emissions released from vehicle fires, and the contribution of these fires to firefighters' exposure during firefighting and associated potential health risks. Despite the reduced time of exposure during vehicle fires (e.g., comparing to wildland fires) and favourable climatic conditions (e.g., wind and ambient temperature) that contribute to reduce the impact of exposure, some authors emphasized the importance of wearing protective respiratory equipment during all the stages of a vehicle fire, including during the overhaul.

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Fire Safety with the Application of BIM for Historic Buildings: Systematic Review

Milena Campinho, Adeeb Sidani, and João Santos Baptista

Abstract Historic Building Information Modelling (HBIM) is characterised by the potential to manage and disseminate information about the built heritage. This review aims to investigate the recent tools and technologies carried out so far against fire in historic buildings. From the research in five databases, Scopus, Web of Science, INSPEC, Academic Search Ultimate and Current Contents Connect, from 2016 to 2021, 91 articles were initially selected, and after critical analysis, 25 relevant studies were collected for this review. The results indicate that few approaches were developed to evaluate the use of BIM in the analysis of fire safety in historic buildings, the relevant articles collected involving this theme were limited to presenting a methodology for adequate performance evaluation, as well as to configuring a procedure for interoperability between programs, moreover, to a mechanism to assist evacuation without significant changes in structure. However, when only the relationship between fire safety and historical building is evaluated, the results indicate a more significant number of studies that can be grouped into different approaches: Proposals of New Measures, Update on Implemented Measures, Evaluation of Fire Protection and Fire-Resistant Material. The results show that there are several methods to assess and improve the buildings protection against fire and the implementation of HBIM is an important tool which will improve the understanding of the past, the present and provide the tools for the safe future of historic buildings.

Keywords Historic buildings · Old buildings · Fire safety · Building information modelling (BIM) · Historic building information modelling (HBIM) · Evacuation

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1 Introduction

The fire protection project of a historic building represents a challenge due to the need to achieve an adequate level of safety in a building with many design restrictions (Torero 2019). Significant risk levels affect the built heritage due to its fundamental characteristics, presence of different hazards and high exposure (Bernardini et al. 2016). It is essential to define a methodology based on an integrated digital design procedure to protect the historical heritage, aiming to manage fire safety (Frosini et al. 2016). The use of Building Information Modelling (BIM), in particular the Historical Construction Information Modeling (H-BIM) approach, for fire safety purposes has been studied many times based on improper principles (Torero 2019). The "proper" evacuation of the building depends mainly on the perception of the spaces of the individuals, the architectural layout, and the presence of adequate signalling systems (Bernardini et al. 2016). One possibility for fire prevention analysis would be interoperability between HBIM models and open-source software (Frosini et al. 2016).

Research shows several studies related to fire safety in historic buildings, fundamental to enable the correct use of BIM or HBIM tools for the safe future of built heritage. To maintain the safety of the historic building, it is necessary to add active firefighting equipment (Chang et al. 2021). The combination of UFSM (Urban Fire Spread Model) results with Fire Dynamics Simulator (FDS) can help analyse the risk factors of input data and contribute to the improvement of cultural heritage building protection technology (Huang 2020). Implementing complementary security measures can help mitigate negative impacts and limit costs, such as an automatic entry flow control system for people in the building (Caliendo et al. 2020). To reduce catastrophic risks in buildings, a risk reduction programme is intended to implement standards, regulations and resolution of imperfections of standards (Shakib et al. 2018).

The preservation of historic buildings depends on a use compatible with their structural capacities and regular maintenance (Vijay and Gadde 2021). One of the critical factors in achieving robust fire safety in historic buildings is updating physical fire protection measures (Kincaid 2018). The optimisation of the functional purpose of renovated spaces in historical buildings allows the implementation of fire protection without further modifications to the original structures (Iringová and Idunk 2017). Most original historic buildings are not suitable for occupancy if we consider hygiene, static, thermal and fire protection (Iringová and Vandličková 2019). In addition, to increase the building's performance, it is essential to conduct analyses to determine fire resistance, such as historical systems of wooden arch floors submitted to different exposures to fire (Garcia-Castillo et al. 2021). The development of sustainable building materials, such as artificial pozzolans, increases the resistance of restoration mortars at high temperatures, decreases damage to historic buildings during the fire and contributes to cultural sustainability (Demircan et al. 2021).

However, no comprehensive review was identified to promote the integration and optimisation of heritage information constructed through HBIM to ensure fire safety in historic buildings. Thus, a literature review is proposed to identify knowledge gaps and validate the need for continuity and deepening of future research that can contribute to better understanding the past and the present and provide the tools for the safe future of historic buildings.

2 Methodology

Five electronic databases were used to develop this review: Scopus, Web of Science, INSPEC, Academic Search Ultimate and Current Contents Connect. The search was divided into two phases. In the first phase, the keywords were combined as follows: ("Historic Buildings" OR "Old Buildings") and "Fire Safety" AND (BIM OR HBIM). Due to the low number of articles obtained, a second search phase was considered. The authors decided to eliminate the keywords BIM and HBIM initially used, as follows: ("Historic Buildings" or "Old Buildings") and "Fire Safety". As a result, the number of articles found in the second search was 240, much higher than the seven articles found in the first phase. The search targeted fields were Title, summary and keywords for Scopus. Title and summary were applied to INSPEC and Academic Research. At the same time, the search of the keywords was for topics on the Web of Science and Current Content Connect. For the selection of studies, a screening process was carried out based on the following parameters: year of publication defined from 2016 to the present—we chose the last five years to have the latest data/methodologies, type of document of research articles of source type of peer-reviewed journals, and language of articles written in English—see Table 1. Then, the results were analysed, the studies related to the research theme were selected, and the duplicate records were eliminated.

The eligible studies were classified into four categories according to the article's content: (1) proposals of new measures, (2) updates on implemented measures, (3) evaluation of fire protection and (4) resistance of the material to fire. This process was carried out using a customised table to collect information of interest that mainly involved: references and country, objectives, methodology, results and limitations, target groups, equipment, evaluation method and its limitations.

3 Characteristics of the Selected Studies

3.1 Selected Studies

Through the searches in the databases, 247 articles were initially collected. Using the filters provided by each database (Table 1), restrictions were applied that resulted

Table 1 Data base search summary

Database	Filtros da Pesquisa 1
Scopus	(TITLE-ABS-KEY (“Historic* Buildings” OR “Old Buildings”) AND “Fire Safety” AND (BIMORHBIM)) AND (LIMIT-TO (PUBYEAR, 2021) ORLIMIT-TO (PUBYEAR, 2019) ORLIMIT-TO (PUBYEAR, 2018) ORLIMIT-TO (PUBYEAR, 2017) ORLIMIT-TO (PUBYEAR, 2016)) AND (LIMIT-TO (DOCTYPE, “ar”) ORLIMIT-TO (DOCTYPE, “cp”) ORLIMIT-TO (DOCTYPE, “ch”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”) ORLIMIT-TO (SRCTYPE, “p”) ORLIMIT-TO (SRCTYPE, “k”))
Web of science	((TS = (“Historic* Buildings” OR “Old Buildings”)) AND TS = (“Fire Safety”)) AND TS = (BIM OR HBIM)
INSPEC	(((“Historic* Buildings” OR “Old Buildings”) AND “Fire Safety” AND (BIM OR HBIM)) WN KY)
Academic search ultimate	AB (“Historic* Buildings” OR “Old Buildings”) AND AB “Fire Safety” AND AB (BIM OR HBIM)
Current contents connect	TOPIC: ((“Historic* Buildings” OR “Old Buildings”)) AND TOPIC: (“Fire Safety”) AND TOPIC: (BIM OR HBIM)
DATABASE	FILTROS DA PESQUISA 2
Scopus	(TITLE-ABS-KEY (“Historic* Buildings” OR “Old Buildings”) AND “Fire Safety”) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”))
Web of science	((TS = (“Historic* Buildings” OR “Old Buildings”)) AND TS = (“Fire Safety”)) and 2016 or 2017 or 2018 or 2019 or 2020 or 2021 (Publication year) and article (Document Type) and English (Languages)
INSPEC	(((“Historic* Buildings” OR “Old Buildings”) AND “Fire Safety”) WN KY) + (({ja} OR {ca}) WN DT) AND ({English} WN LA) AND ((2020 OR 2019 OR 2018 OR 2017 OR 2016) WN YR)
Academic search ultimate	AB (“Historic* Buildings” OR “Old Buildings”) AND AB “Fire Safety” Publication Date: 20160101-20211231
Current contents connect	((“Historic* Buildings” OR “Old Buildings”)) AND TOPIC: (“Fire Safety”) Limited For: Publication Year: (2020 OR 2019 OR 2018 OR 2017 OR 2016) AND Document Type: (ARTICLE)

in the rejection of 194 articles, as follows: year of publication defined from 2016 to the present—118 exclusions, type of research paper document—34, type of source of peer-reviewed journals—0 exclusions, the language of written articles in English, 4, and relationship with the theme—38 exclusions. Among the 53 articles selected, 28 were duplicated, leaving 25 relevant articles for analysis in the current review.

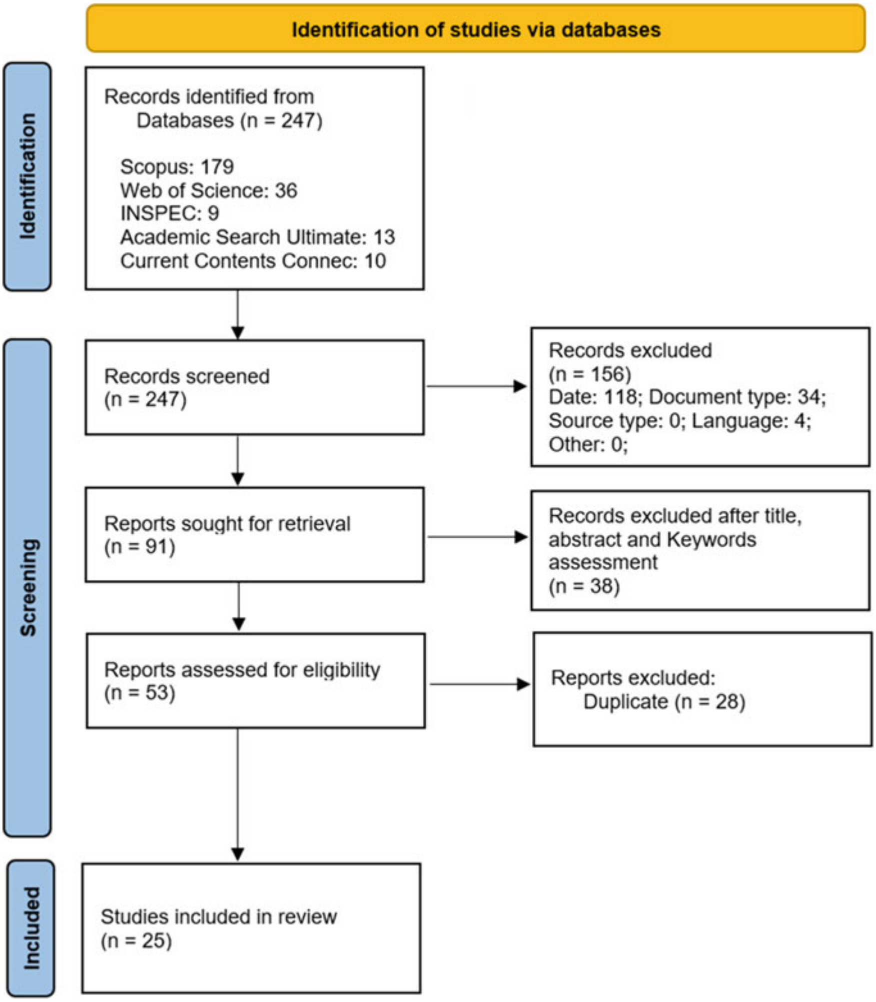

Fig. 1 Search summary, based on PRISMA's flow diagram

In Fig. 1, it is possible to overview the numbers of each stage of the methodology applied in the study.

3.2 *Characteristics of the Included Studies*

Among the 25 selected articles, in 2016 and 2021 the number of studies involving fire safety and historical building was six and five articles, respectively. However, the introduction of BIM or HBIM was addressed the most in 2016, two articles. Figure 2

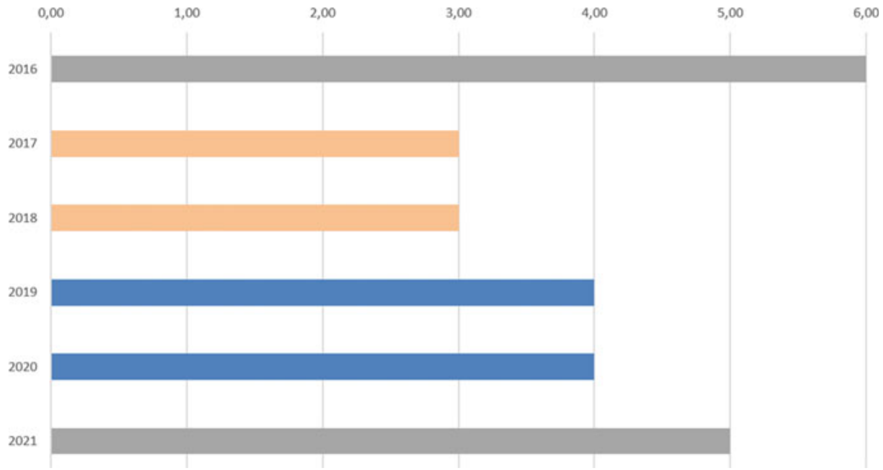

Fig. 2 Selected articles group per year (2016 until 2021)

shows the evolution of studies using this theme over the years, where it is clear that despite a downward trend of this approach between 2017 and 2018, 3 articles each year, research grows again from 2019 with four articles and five articles in 2021.

Despite the diversity of the topics of the 25 selected articles, four research areas could be identified. Among these, ten studies included presented proposals of new measures for fire safety in historic buildings. Three articles targeted updated information on measures already implemented. Four studies evaluated fire protection in specific cases. Finally, eight articles addressed issues related to fire resistance. A more representative quantity is observed among the areas involving proposals of new measures and resistance of the material to fire, as illustrated in Fig. 3.

Table 2 represents the articles grouped per their fields of study identifying the target groups, the type of case study, equipment used, and the indicators analysed of the selected studies. Among the 25 analysed articles, only five authors did not use any assessment method to test or validate their proposals, as illustrated in Fig. 4. These studies are all related to the fire resistance material field of study.

Among the ten articles in the research area that present proposals of new measures, the most common indicators are related to the evacuation of buildings in three (Bernardini et al. 2016; Caliendo et al. 2020; D'Orazio et al. 2016) studies and the spread of fire in two (Chang et al. 2021; Tung et al. 2020). In these ten cases, the software chosen consisted of most cases in SDS—Fire Dynamics Simulator (Torero 2019; Chang et al. 2021; Tung et al. 2020).

In the case of the eight articles related to the material's resistance to fire, despite the different indicators analysed, the most common studies are related to wood (Garcia-Castillo et al. 2021; Log 2016; Chorlton and Gales 2019) or masonry (Daware and Naser 2021; Demircan et al. 2021; Shao and Shao 2018). In these eight cases, the target group mainly consisted of the time (except Log 2016) in specialists, and most of them (Daware and Naser 2021; Demircan et al. 2021; Król 2016; Siligardi et al.

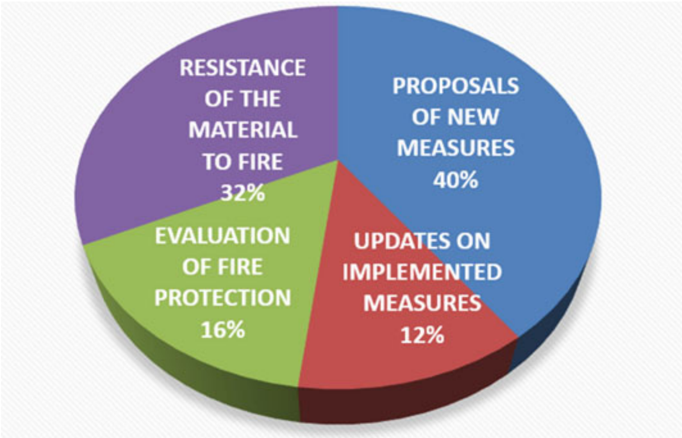

Fig. 3 Classification of articles based on the field of study

2017; Chorlton and Gales 2019) did not use the Case Study analysis method to test their proposals.

Among the seven articles related to updating information on measures already implemented (Kincaid 2018, 2019; Vijay and Gadde 2021) and evaluation of fire protection of specific cases (Iringová and Idunk 2017; Takács and Szikra 2017; Iringová and Vandličková 2019; Quapp and Holschemacher 2020).

3.3 Results Quality

After the screening process described earlier resulted in the exclusion of 156 articles, as shown in Table 1, 38 other studies were excluded because they did not present any relation with the objectives of the current review. All selected articles had their abstracts and conclusions read. After discarding the 28 duplicated articles, relevant articles full text was read, following a critical analysis and identifying their main contributions and limitations. Despite the weaknesses observed in some articles, mostly related to the structure of texts, the selected studies, in general, were considered fit in terms of quality, mainly because they presented relevant results. Most of the selected studies have at least one citation, between 1 and 33 citations, which indicates the quality of the articles.

Table 2 Characteristics of the studies grouped by their field of study

Study field	Target groups	Case study	Equipment	Indicators	References
1. Proposals of new measures	Owner, design	Educational building		Critical vision	Torero (2019)
	Owner, design, user	Theater/Museum/Cultural building	FDS + EVAC	Evacuation time	Bernardini et al. (2016)
	Design	Educational building	Model checking	Traditional and automated analysis	Frosini et al. (2016)
	Owner, design, user	Religious building	FDS	Banks on fire	Chang et al. (2021)
	Design	Castel/Palace	UFSM FDS	Risk factors	Huang (2020)
	Owner, design	Residential/Multiuse building	FDS	Fire growth and spread	Tung et al. (2020)
	Owner, design, user	Theater/Museum/Cultural building	CFD	People flow control	Caliendo et al. (2020)
	Owner, design	Religious building	SRA	Customisation of parameters	Naziris et al. (2016)
	Owner, design, user	Theater/Museum/Cultural building	CWS	Evacuation speed and time	D'Orazio et al. (2016)
	Owner, design	Residential/Multiuse building		Scenario, structure, installations, maintenance, propagation, and management	Shakib et al. (2018)
2. Update of measures	Owner, design	Residential/Multiuse building		Local rescue, lack of water and valuable artifacts	Kincaid (2019)
	Owner, design	Residential/Multiuse building		Materials, causes, history, codes and measures, with visual evaluation	Vijay and Gadde (2021)
	Owner, design	Castel/Palace			Kincaid (2018)
3. Fire protection assessment	Design, user	Theater/Museum/Cultural building		Static analysis and evaluation of fire resistance	Iringová and Idunk (2017)

(continued)

Table 2 (continued)

Study field	Target groups	Case study	Equipment	Indicators	References
	Owner, design, user	Residential/Multiuse building	CFD	Exposure to temperature and its evolution	Takács and Szikra (2017)
	Owner, design	Residential/Multiuse building		Physical, structural and layout determinants	Iringová and Vandličková (2019)
	Owner, design, user	Theater/Museum/Cultural building		Capacity load and safety	Quapp and Holschemacher (2020)
4. Material fire resistance	Design	Residential/Multiuse building	SAFIR	Vain, wood bending and fire exposures	Garcia-Castillo et al. (2021)
	Design	–		Mechanical and thermal properties	Daware and Naser (2021)
	Design	–	DRX e MEV	Compressive and bending resistance	Demircan et al. (2021)
	Owner, design, user	Residential/Multiuse building		FMC	Log (2016)
	Design	–	CFD	Fire resistance	Król (2016)
	Design	Religious building	FDS	ISO834 temperature–time curve	Shao and Shao (2018)
	Design	–		Microstructural development, diffraction and flammability analyses	Siligardi et al. (2017)
	Design	–		Carbonisation, ignition time and flame propagation	Chorlton and Gales (2019)

4 Discussion

The current systematic review focused on analysing fire tools and methodologies in historic buildings, with the primary objective of updating the studies carried out so far. In the analysis of the first research results, there was no strong link between the use of BIM/HBIM and fire safety in historic buildings. The main focus of the initial research, only 03 studies were found (Torero 2019; Bernardini et al. 2016; Frosini et al. 2016). Thus, the authors decided to eliminate BIM and HBIM, using

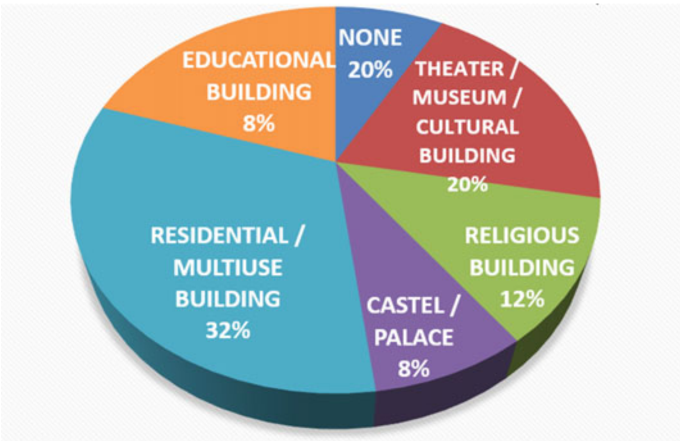

Fig. 4 Classification of articles based on the case study

the primary term "fire safety" only "historic buildings" (including "old buildings"), which resulted in more than 22 articles relevant to an investigation. The 25 selected articles were categorised into four studies with the same research objectives, as shown in Fig. 3. The following can be highlighted.

4.1 Group 1—Proposals for Improvements for Fire Safety in Historic Buildings

Among the ten articles in this research area, the most common indicators are related to the evacuation of buildings in three studies (Bernardini et al. 2016; Caliendo et al. 2020; D'Orazio et al. 2016) and the spread of fire in two studies (Chang et al. 2021; Tung et al. 2020)—see Table 2.

4.1.1 Evacuation of Buildings

The results revealed the evacuation of buildings as one of the most considered approaches to improvement proposals. Introducing low-impact components into the environment and an algorithm to assess possible overcrowding phenomena and identify the best evacuation routes can make up an Intelligent Evacuation Guidance System (Bernardini et al. 2016). To prevent an overcrowded museum, simulations verified the effectiveness of a noninvasive supplemental countermeasure based on an automatic system of control of the entry flow of people into the building (Caliendo et al. 2020). A system for evacuation guidance based on photoluminescent materials (PLM) has also been tested and approved, involving more than 100 people in smoke and darkness conditions (D'Orazio et al. 2016). The three proposals presented bring more solutions to achieve the evacuation of buildings to achieve better efficiency.

4.1.2 Fire Spread

Another approach considered more than once among the articles that presented proposals for improvements was related to the propagation of fire, and in both studies (Chang et al. 2021; Tung et al. 2020), the Software FDS—Fire Dynamics Simulator was used. To ensure that churches can be used in safer conditions, it is necessary to add active firefighting equipment initiated in wooden seats, for example (Chang et al. 2021). Numerical simulations that mimic the fire scenario compared to experiments in historical wood buildings on a real scale present development trends during fire spread (Tung et al. 2020). The perfecting of analysis tools related to the propagation of fire should be a continuous process and follow the development of new technologies because the result allows directing the interventions necessary to obtain greater safety more efficiently.

4.1.3 Other Results

Several studies propose features to improve the risk analysis process in historic buildings to achieve better fire safety. Appropriate tools to establish a proper performance assessment can result in minimal and rational changes that meet security goals while achieving other restoration goals (Torero 2019). To facilitate the process of analysis, design and fire management in historic buildings, automated procedures based on HBIM processes need to achieve interoperability with security software (Frosini et al. 2016). The use of parallel processing, combining the results of UFSM with SDS, improves the accuracy of fire risk models for cultural heritage buildings (Huang 2020). A tool based on heuristic meta optimisation can generate viable fund allocation solutions for different budget scenarios related to improving fire safety in historic buildings (Naziris et al. 2016). A risk reduction programme in an old building should assess different perspectives of progressive fire-induced collapse (Shakib et al. 2018).

4.2 Group 2—Updating Already Existing Measures

The three articles with research objectives related to this area (Kincaid 2018, 2019; Vijay and Gadde 2021) aim to include a broader target group, such as specialists, owners or users—see Table 2.

Not all historic buildings have many resources to apply to emergency planning, but even limited resources used with care can have a positive impact (Kincaid 2019). The preservation of historic buildings depends on use compatible with their structural and regular maintenance capabilities (Vijay and Gadde 2021). One of the critical factors in achieving robust fire safety is updating physical protection measures (Kincaid 2018). The measures already implemented are references to the new proposals, and updating this information is essential for both owners and specialists.

4.3 Group 3—Fire Protection Assessment

Among the four articles in this research area (Iringová and Idunk 2017; Takács and Szikra 2017; Iringová and Vandličková 2019; Quapp and Holschemacher 2020)—See Table 2, two points are worth mentioning and are related to each other: only one study used equipment to analyse their indicators (Takács and Szikra 2017), and all studies were focused on broader target groups including owners, users or specialists. A general assessment of the proposed systems for specific cases allows users and owners to familiarise themselves with the level of fire protection obtained in various buildings.

The optimisation of the planned function and its extension in the building allows the implementation of fire protection without further modifications to the original structures (Iringová and Idunk 2017). The protection cannot be omitted from the pillars until a certain height but can be left out in the carrying structure of the cover slab since the cover slab will not be in the flame zone of a possible fire show (Takács and Szikra 2017). Additional fireproof coatings must ensure Fire-resistance of the original structures if the extension in a cover space is made in places with low and medium fire load (Iringová and Vandličková 2019). Safety regulations and the protection of the historical structure should not be antagonistic but rather collaborate to preserve cultural heritage (Quapp and Holschemacher 2020).

4.4 Group 4—Resistance of Fire Material

In the case of the eight articles in this field (Garcia-Castillo et al. 2021; Daware and Naser 2021; Demircan et al. 2021; Log 2016; Król 2016; Shao and Shao 2018; Siligardi et al. 2017; Chorlton and Gales 2019), despite the different indicators analyzed, the most common studies are related to wood (Garcia-Castillo et al. 2021; Log 2016; Chorlton and Gales 2019) or masonry (Daware and Naser 2021; Demircan et al. 2021; Shao and Shao 2018). In these eight studies, the target groups mainly were specialists, except for (Log 2016), Table 2, and most of the articles (Daware and Naser 2021; Demircan et al. 2021; Król 2016; Siligardi et al. 2017; Chorlton and Gales 2019) did not use the Case Studies or assessment method to test their proposals.

4.4.1 Wood

Historical buildings do not always meet the requirements established by the standards and, therefore, the performance of analyses such as fire resistance of historical systems of wooden arched flooring is essential to ensure the preservation of architectural heritage (Garcia-Castillo et al. 2021). To reduce the likelihood of a fire outbreak, it can be predicted, for example, an increased risk associated with low CMF in inhabited wooden houses during winter (Log 2016). Historic wood chars at a rate up to 20% faster than contemporary wood, successful heritage conservation efforts by leaving wood exposed and on-site become possible once the wood performance is understood and other fire safety engineering strategies are in place (Chorlton and Gales 2019).

4.4.2 Masonry

Modern and updated temperature-dependent material models facilitate the design of new masonry constructions or the analysis of existing ones, including historic buildings (Daware and Naser 2021).

Mortars produced based on hydraulic lime have their mechanical properties affected when exposed to high temperatures. For the integrity of historic buildings, it would be more appropriate to use flyash (FA)—30% and granulated blast slag (GBFS)—15% (Demircan et al. 2021). In a fire in historic buildings, the cracks of the damaged, exposed side of the brick walls or the ineffectiveness and cracks of the fireproof material used are responsible for the expansion of smoke and combustion (Shao and Shao 2018).

4.4.3 Other Results

To properly evaluate the safety of steel beam floors with beams hidden in the thickness of the slab, it is necessary to treat each design case individually when assessing the fire conditions due to significant discrepancies found in final results (Król 2016).

The fibre-reinforced aerogel is a state-of-the-art, fire-resistant material suitable for replacing traditional ones such as rock wool, especially for retrofit and renovation of historic buildings, where interior insulation may be the only alternative (Siligardi et al. 2017).

4.5 Future Research Perspectives

The different studies addressed in this review evidenced the research trends on areas involving measures of improvement and resistance of fire material. While research on fire safety in historic buildings has been evolving, limitations were found in the number of approaches related to the use of BIM or HBIM. Some studies have highlighted the need to improve interoperability with fire safety software, use parallel processing, and create extensions of analysis tools to improve the accuracy of your simulations and reduce the margin of error. In addition, most investigations performed their analyses through a case study, which showed that using larger samples might also be the focus of future research.

Finally, there is a tendency for studies involving improvement measures and resistance of fire material to promote fire safety in historic buildings. Future prospects should explore the potential for management and dissemination of information through the use of BIM or HBIM and in larger samples during real-life operations.

Limitations
The possible deletion of some articles due to the non-compliance with some criteria applied, such as English language and search publication, may have left out data sources. In addition, given the variety among the studies, it was necessary to perform a statistical analysis combining the research areas for a clearer understanding of the results. The definition of these may have disregarded specific points relevant to some articles.

5 Conclusions

About the possibility of obtaining the information about the building and managing it, in a single location, with different disciplines, there are many advantages in using HBIM in historic buildings. However, no articles were explicitly found focusing on the application of HBIM for fire safety in historic buildings. Despite the various approaches found for fire safety, most studies focused on material improvements and fire resistance. Moreover, including the trend of growth of these approaches in recent years, the results allow us to validate the need for continuity and deepening on the theme, to promote the integration and optimisation of information of the heritage built through the use of HBIM to understand the past, present better and provide the tools for the safe future of historic buildings.

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Environmental and Occupational Safety and Hygiene KPI in the Mining Industry—A Short Review

J. Duarte, J. Castelo Branco, Fernanda Rodrigues, and J. Santos Baptista

Abstract In a technologically enhanced world brought by Industry 4.0, a great bulk of information can be drawn from the industrial processes. Nowadays, the question is what to do with information and how to manage it, rather than how to collect it. In this sense, Key Performance Indicators might be the answer. Mining is the industry where a more profound change can be seen but, at the same time, remains in the top three most hazardous. Therefore, the objective of this short review was to find evidence of occupational safety and hygiene and environment key performance indicators in the mining industry. The Preferred reporting items for systematic reviews and meta-analyses guidelines were used to conduct the research. A table was built to help collect the needed information from the included papers: indicator, description, valuation, measurement method, and potential indicator limitation. By applying the statement, 109 records were identified, of which 14 were found eligible and included in the study. The articles were screened, and key performance indicators' description, valuation, measurement method, and limitation were collected. Over 150 indicators were identified, most of them lagging, which means that little to no control can be made in the design process. The trend shows that more effort should be put into leading indicators as these might be useful to control the process upstream.

Keywords Key performance indicators · Mining · Maintenance · Safety

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1 Introduction

The emergence of Industry 4.0 allowed the smooth transition from manual processes to the digital working setting (Li et al. 2017). The technological leap led to an increased rate of available information almost from one day to the other, which, in its turn, pressured companies to achieve higher production rates to raise their competitiveness level (Bueno et al. 2020). In an increasingly complex environment, the information needs to be accessible, easy to read, and simple to optimise the decision process (Jena et al. 2020). Furthermore, the key players of today's business are not the same as they used to be, and the list is long: employees, contractors, suppliers, customers, shareholders, trade unions, creditors, insurers, local authorities, local communities, and governments all have its expectations and, foremost needs to be met (Pitz et al. 2016; Yarahmadi et al. 2020). Key Performance Indicators (KPI) in this context are self-explanatory as they provide simple metrics to track the performance of a given process in a specific area. Regarding the type of action, KPIs can be divided into lagging or leading indicators. Therefore, lagging indicators that measure the outcome of a process are useless in terms of prediction, while leading indicators can provide information regarding what to expect while monitoring a process (Parmenter 2015).

In an industry with a considerable negative historical passive, a more significant effort is required to keep pace. The concepts of green mining, sustainable development, circular economy and intelligent mining intersect and interconnect, shaping the new paths and mining methods (Barnewold and Lottermoser 2020; Ghisellini et al. 2016; Ginevra et al. 2022; Kusi-Sarpong et al. 2015). Even so, its operations reflect great water and energy consumption, not to mention the disturbance of land and natural habitats, most of the time leaving permanent scars on the landscape (Samba et al. 2022). The impacts on society and the environment receive special attention when the issue is exploitation (Ranängen and Lindman 2017). Furthermore, due to its complex challenges, this industry still contributes to the overall rate of occupational accidents worldwide (Takala 2019).

Putting all this together, how can KPIs support the decision-making process in the extractive industry to improve its practice? The objective of this short review was to find evidence within the literature on KPIs in the fields of occupational safety and hygiene, and environment that could help address this question.

2 Methodology

The Preferred reporting items for systematic reviews and meta-analyses statement (PRISMA) guidelines were used to conduct the research (Moher et al. 2009; Page et al. 2021).

The search was performed by introducing the selected keywords into the "Keywords/Abstract/Article title" (and similar) search fields in Scopus, INSPEC, and

Science Direct, "Title/Topic" in Web of Science, and "Title/Abstract" in Dimensions. The authors considered that these five multidisciplinary databases were enough to cover the possible spectrum for the research. Additionally, the fields had to be adapted to provide comparable data and allow the reproducibility of work. The Boolean expression summarising the combinations is [(KPI OR "key performance indicator") AND ("mining industry" OR "open pit" OR "open cast" OR "extractive industry" OR quarry)]. This expression was broad enough not to exclude any information on an initial phase due to the lack of publishing material with specific keywords related to the topic under study.

Additionally, no date filter was applied since "key performance indicators" is a relatively recent concept in this industry. The exclusion criteria were (1) Type of document—any article other than research articles, (2) Source type—any article published elsewhere than peer-reviewed journals, and (3) Language—articles published in any language other than English. Still, in the screening phase of PRISMA, the articles' titles and abstract were sought out to determine potential relevance to this short review. All the records were managed with Mendeley software, where the duplicate files were removed. To be included in the research, the focus of the remaining articles had to be on occupational safety or health or environment (OSHE). An excel table was built to help collect and assess the information pertinent to the study: indicator, description, valuation, measurement method, and potential indicator limitation. Any missing information regarding the prior mentioned parameters was not a criterion for excluding any work. After, the references of the eligible papers were screened to find additional records. Moreover, according to the snowballing technique, other workers from the referenced authors were also screened with that intent (Wohlin and Claes 2014).

The research was carried out in June 2021 and updated in January 2022.

3 Results and Discussion

3.1 Research Results

Over 100 articles were identified in the initial stages of the research, from which six were removed according to the exclusion criteria. Of the remaining, 21 were excluded because they were not for this short review, leading to the importation of 82 records to Mendeley software. Only 29 articles were left after this process. Putting these against the eligibility criterion, despite being all related to the mining industry, the majority (22 out of 29) focused on other fields other than occupational safety, hygiene, and environment (OSHE), such as financial, transport, equipment performance, production, product quality, and social (employability, career development, among others). Whenever a link was found between the topics mentioned above and the primary research areas (OSHE), the paper was also included for maintenance and sustainability-related articles. The snowballing technique (Wohlin and Claes 2014) added more than seven papers to the research. Overall, 14 papers met the defined criteria. The summary of the research is found in Fig. 1.

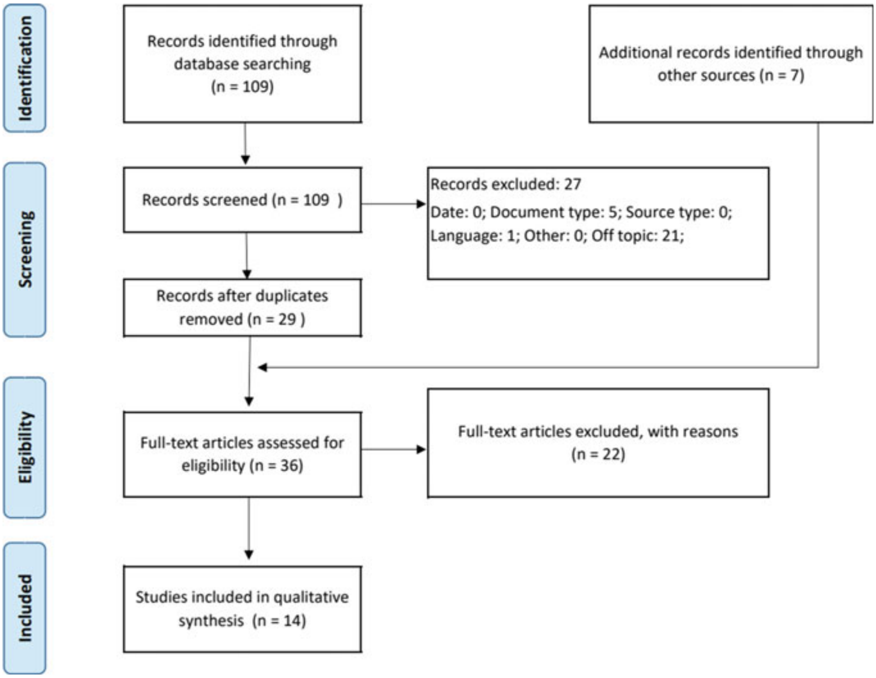

Fig. 1 Research summary based on PRISMA statement

3.2 *Studies' Analysis*

The eligible studies were published between 2004 and 2021, with the geographic distribution shaped in Fig. 2. South Africa stands out with four studies (Dougall and Mmola 2015; Nel et al. 2018; Pitz et al. 2016; Sorensen 2012) which may be explained due to the country's presence in the mining exploitation scenario. The remaining papers show a high context dispersion. No particular assertion can be drawn from the map analysis concerning the included studies.

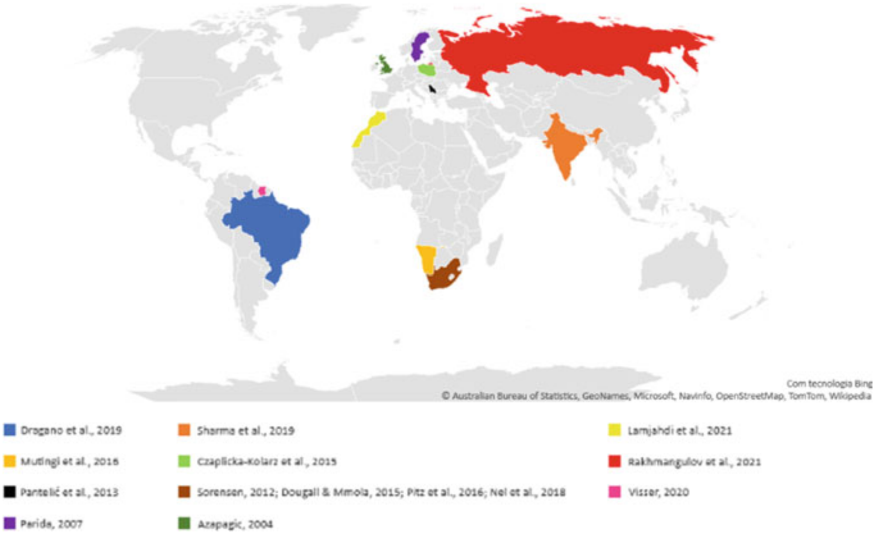

Fig. 2 Studies' distribution per country

Having an interest in the topics of OSHE, the studies were classified according to the subject: Occupational Safety, Occupational Hygiene, and/or Environment, Table 1. Even though the analysed KPIs were related to maintenance or sustainability in some cases, according to its description, it was possible to accommodate them into the categories above, as stated in Sect. 3.1. After, the focus was paid to KPI-related information such as description, valuation, measurement method, and limitation, also summarised in Table 1. Generally speaking, the data collection was not straightforward. Each study was screened to build a database of KPIs. However, most of the available information had to be interpreted and worked out. None of the 14 studies reported any limitations in the indicators. Only three provided measurement methods (Czaplicka-Kolarz et al. 2015; Dragano et al. 2019; Pantelić et al. 2013); of those, one (Dragano et al. 2019) added valuation to its rationale. Four studies evaluated their KPI (Azapagic 2004; Dougall and Mmola 2015; Nel et al. 2018; Visser 2020). This means that possible reproducibility in other contexts would be very hard to obtain. Nonetheless, it would be simpler to perceive measurement methods from the valuation results than the other way around, as little to no foundation is provided.

Further KPI description is provided in four out of the 14 papers (Azapagic 2004; Dougall and Mmola 2015; Dragano et al. 2019; Sharma et al. 2019), whereas this piece of information most of the time could be deducible from the actual indicator name.

In the field of occupational safety, three general areas were identified (Table 2): occupational safety management, maintenance issues and operation, in a total of 11 studies (Azapagic 2004; Dougall and Mmola 2015; Dragano et al. 2019; Lamjahdi et al. 2021; Mutingi et al. 2016; Pantelić et al. 2013; Parida 2007; Rakhmangulov et al. 2021; Sharma et al. 2019; Sorensen 2012; Visser 2020).

Table 1 Studies' overall classification

Study	Topic			Key performance indicator(s)			
	Occupational safety	Occup. hygiene	Environment	Description	Valuation	Measurement method	Limitation
Azapagic (2004)	No	No	Yes	Yes	Yes	No	No
Parida (2007)	Yes	No	Yes	No	No	No	No
Sorensen (2012)	Yes	No	Yes	No	No	No	No
Pantelić et al. (2013)	Yes	No	No	No	No	Yes	No
Czaplicka-Kolarz et al. (2015)	No	No	Yes	No	No	Yes	No
Dougall and Mmola (2015)	Yes	No	Yes	Yes	Yes	No	No
Mutingi et al. (2016)	Yes	No	No	No	No	No	No
Pitz et al. (2016)	No	No	Yes	No	No	No	No
Nel et al. (2018)	No	Yes	No	No	Yes	No	No
Dragano et al. (2019)	Yes	No	No	Yes	Yes	Yes	No
Sharma et al. (2019)	Yes	No	No	Yes	No	No	No
Visser (2020)	Yes	No	Yes	No	Yes	No	No
Lamjahdi et al. (2021)	Yes	No	Yes	No	No	No	No
Rakhmangulov et al. (2021)	Yes	No	Yes	No	No	No	No

Table 2 Occupational safety key performance indicators

Subject	KPI	Study
Management	Absence-hours related to health and safety	Azapagic (2004), Lamjahdi et al. (2021)
	Accidents number	Parida (2007)
	Complaints related to health and safety	Parida (2007)
	Fatality frequency rate	Dougall and Mmola (2015)
	Incident rate per out	Dougall and Mmola (2015)
	Incidents number	Parida (2007)
	Injury rate	Lamjahdi et al. (2021)
	Lost time incident frequency rate	Dougall and Mmola (2015)
	Lost time injury frequency rate	Dougall and Mmola (2015)
	Lost-time accidents	Azapagic (2004)
	Number of fatalities at work	Azapagic (2004)
	Safety audits score	Mutingi et al. (2016)
	Training and education	Azapagic (2004), Sorensen (2012)
Maintenance	Machine inspections	Pantelić et al. (2013)
	Mean time between failures	Sharma et al. (2019), Visser (2020)
	Mean time between repairs	Sharma et al. (2019)
	Mean time for preventive maintenance	Sharma et al. (2019)
	Number of equipment failures per day/week/month/year	Dougall and Mmola (2015)
	Planned maintenance tasks	Parida (2007)
	Preventive maintenance	Mutingi et al. (2016)
	Scheduled downtime	Visser (2020)
	Total minutes lost per shift due to breaks	Mutingi et al. (2016)
Operation	Bench height	Rakhmangulov et al. (2021)
	Berm slope angle	Rakhmangulov et al. (2021)
	Berm width	Rakhmangulov et al. (2021)
	Specific priming	Dragano et al. (2019)

By the analysis of Table 2, it is possible to conclude that most KPIs are lagging indicators. Exceptions are made for the three production parameters from the study of Rakhmangulov et al. (2021) that can be used in the design phase of the exploitation, therefore contributing to improved safety on top of production. This shortlist can also be added to planned maintenance tasks, scheduled downtime, and preventive maintenance to prevent accidents. Machine inspections can also have a significant impact on avoiding workers' injury or, at least, operation stopping times. Nonetheless, the costs will build up in exacerbated maintenance without adding value to the safety issue. Maintenance actions should be carefully planned to optimise the relation between operation, safety, and costs in the continuous improvement optic. In this sense, information collected along the equipment life cycle can and should be used to plan maintenance schedules and provide precious intel to understand and, if possible, prevent future failure (Sharma et al. 2019).

On the other hand, the number of failures (regardless of frequency) minutes lost per shift, among others, might indicate safety hazards or, at least, equipment issues; nonetheless, at the time of measurement, it can only contribute to future process optimisation. The same happens for the safety management indicators found within the literature. Incidents and accidents analysis might provide the grounds for a safety action plan, but occupational safety and health should always be at the source. Therefore, from Table 1, the only leading indicator that can be drawn is training and education. Workers' formation should continuously be assessed at the end of the training and periodically after the formation. The participatory training of workers can help prevent accidents and injuries at the workplace (Onder and Mutlu 2017; Yu et al. 2017).

Only one of the studies referred to occupational hygiene parameters (Nel et al. 2018) related to ventilation. In underground mining, this operation poses one of the highest costs. It is also a tremendous occupational health and safety issue (Jha and Tukkaraja 2020). In the light of Industry 4.0, the authors simulated different scenarios to determine the one with the highest safety compliance, improved production, and lowest operational costs. The KPIs identified were wet-bulb temperatures, air volumetric flow, air mass flow, and air pressure. This case study led to significant results as the total energy cost saving at the end of the 18-month trial was around 0.7 million dollars. However, none of the used parameters were leading indicators, despite providing enough information to optimise the process.

Finally, regarding the environment (and sustainability), nine studies covered diverse KPIs, being the most significant summarised in Table 3 (Azapagic 2004; Czaplicka-Kolarz et al. 2015; Dougall and Mmola 2015; Lamjahdi et al. 2021; Parida 2007; Pitz et al. 2016; Rakhmangulov et al. 2021; Sorensen 2012; Visser 2020). This table left out KPIs that were not measurable such as policies and overall descriptions.

Azapagic (2004) raises several environmental issues at the proposal's core: biodiversity loss, overall emissions, energy and water use, land use, resource availability and use, solid waste and widespread environmental impacts. The author reports that this proposal is "not dissimilar to the GRI reporting". The Global Reporting Initiative, best known as GRI, are widely recognised guideline providing information on companies' social, environmental and economic impacts (Global Reporting Initiative 2006). However, these standards are more appropriate for big companies than small-scale businesses; therefore, their application is not always upfront. Pitz et al. (2016) also make a strong point in biodiversity parameters, particularly concerning the impacts of noise, lighting, dust emission and overall quarry activities on fauna and flora present at quarries. The authors took European Union biodiversity policies, addressed the different stakeholders' interests, gathered that knowledge, and proposed a framework. However, all these pointers have in common that they are, again, lagging indicators. Despite providing enough information to analyse, assess and adapt overall future performance in terms of process optimisation, they do not do much in real-time control of the operation.

Overall, the KPIs provided in Table 3 are measurable units despite lagging. The eco-efficiency indicator deserves a reference as an innovative method to correlate economic and environmental efficiency in the coal mining industry (Czaplicka-Kolarz et al. 2015).

Table 3 Environmental key performance indicators

KPI	Study
Carbon footprint	Dougall and Mmola (2015)
Eco-efficiency indicator	Czaplicka-Kolarz et al. (2015)
Emissions of particles	Azapagic (2004)
Emissions of acid gases	Azapagic (2004)
Emissions of CO_2	Azapagic (2004)
Emissions of greenhouse gases	Azapagic (2004)
Emissions of ozone-depleting substances	Azapagic (2004)
Energy from renewable sources	Azapagic (2004), Rakhmangulov et al. (2021)
Number of environmentally protected or sensitive sites	Azapagic (2004)
Number of habitats in the quarry	Pitz et al. (2016)
Number of planted trees	Azapagic (2004)
Number of rehabilitated sites	Azapagic (2004)
Number of protected species in the quarry	Pitz et al. (2016)
Percentage of recycled and reused water	Azapagic (2004)
Percentage of resources extracted	Azapagic (2004)
Total amount of chemicals used	Azapagic (2004)
Total amount of land disturbed	Sorensen (2012)
Total emissions	Sorensen (2012)
Total energy consumption	Dougall and Mmola (2015), Lamjahdi et al. (2021), Sorensen (2012)
Total number of environmental accidents	Azapagic (2004)
Total number of external complaints related to noise, road dirt and dust, visual impact, and other nuisance	Azapagic (2004), Parida (2007)
Total volume of tailings	Azapagic (2004), Sorensen (2012)
Total volume of water discharged into waterways	Azapagic (2004)
Total waste extracted	Azapagic (2004), Dougall and Mmola (2015), Rakhmangulov et al. (2021), Visser (2020)
Total water use	Azapagic (2004), Dougall and Mmola (2015), Lamjahdi et al. (2021), Rakhmangulov et al. (2021), Sorensen (2012)

3.3 Limitations

Despite the plethora of available information on KPI use in the extractive industry context, the OSHE field does not occupy a significant niche. For this reason, only 14 papers were included in this research.

Additionally, due to the nature of the studies, the information had to be worked (interpreted) around the main objective, which could possible introduced bias in results. Most of this short review findings derive from Azapagic (2004) study, which turned out to be the most significant article in this scope.

4 Conclusions

The literature review screening identified 14 papers in the scope of occupational safety, hygiene, and environment in the mining industry context. Most of the critical performance indicators classified in the three key performance areas were lagging indicators, which means that the measurements are performed downstream of the process. This translates into little to no operation/system control (regardless of critical performance area), although this type of indicator is generally the most adequate to perform economic analysis.

Recovering the question raised in the introduction on how KPIs can support the extractive industry's decision-making process to improve its practice, the answer is quite disappointing. The data collection led to more than 150 identified indicators, of which only a handful could help address this issue through more training, adequate design of operation and scheduled maintenance. This shows that more effort should be put into using leading indicators as these measure processes rather than the outcome. Nonetheless, it is essential to remember that selecting the fittest key performance indicators to a given problem is a multi-criteria decision process that does not always have a single answer.

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Artificial Intelligence Marvelous Approach for Occupational Health and Safety Applications in an Industrial Ventilation Field: A Short-systematic Review

Teerayut Sa-ngiamsak, Tomi Zlatar, and Anamai Thetkathuek

Abstract The evolution of technology in twenty-first century particularly in the era of industrial 4.0 had brought an artificial intelligence (AI) and its subset machine learning (ML) into the real-world applications. This study was conducted to present a short review on the artificial intelligence approach for occupational health and safety applications focusing in an industrial ventilation. The searches were performed over 3 available electronics data bases including ScienceDirect, SCOPUS and Sprinker-Link. There were 503 articles found in total; combined with 18 articles, relevant to the topic, sought and selected from the search engines. Only 7 were considered meeting with the inclusion criteria. The study showed that there were three major categories, if considering base on types of dataset and data acquisition, which consisted of computer vision, various sensors and the historical dataset. Each category was unique to its own implementation depending on difference in an individual feature of interests. The ML application showed efficient performance and looming for the bright prospects in the present and near future.

Keywords Artificial intelligence · Machine learning · Occupational health and safety · Industrial ventilation

1 Introduction

The starting era of the twenty-first century had come with a big leaf of technological development in considerably every sector, particularly in computer and electronics. The industrial 4.0 revolution or largely conceived as smartization of manufacturing industry is a digital transformation of manufacturing/production (Diez-Olivan et al.

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2019; Rattan et al. 2022). It had enhanced industrial process by integrating an interconnection of all involved resources with the digital information efficiently (Aiello et al. 2022).

Artificial intelligence (AI) is a computing technology that had gained a momentum of interest since then. It is a smart tool that capable of doing the tasks requiring the intelligence competency such as visual perception, speech recognition, and decision-making under uncertainty, which normally only human can (Gillath et al. 2021).

Machine learning (ML) is a subset of the AI that works by mimicking human brain via a learning to model patterns using mathematical statistics (Rattan et al. 2022). In recent days, applications of ML had been seen in considerably every sector and being implemented in many real-world applications (Verma and Verma 2021).

Occupational health and safety is among them that involves broad kind of those and had also been adopting this technology intensively. For example, it had been applied in occupational accident analysis (Sarkar and Maiti 2020), accident prediction in construction (Koc et al. 2022), workers safety in agriculture (Aiello et al. 2022), a vision-based occupational health and safety monitoring of construction site workers (Zhang et al. 2020), the primary prevention of work-related musculoskeletal disorders (Chan et al. 2022) and so.

Ventilation system whether a general or local exhaust is also essentially associated with considerably all kind of occupational activities. Its quality largely affects occupants' health and safety, particularly in an industrial sector where a number of workers, toxic materials and polluted environments are located together. Anyways, so far, the study about them utilizing AI/ML in this particular sector had been rarely found, especially the summation of the kinds in this field.

This study aimed to provide a brief summary of the published literatures regarding the artificial intelligence applications outlying the tendencies of their utilizations in an industrial ventilation for occupational health and safety purposes, whether in the present or the near future.

2 Materials and Methods

2.1 Search Strategy

This systematic review was conducted in compliance with PRISMA statement (PLoS_Medicine 2009). The literature searches were carried out during February 2022. The searches were achieved from three available and widely accepted electronic databases, including: ScienceDirect, SCOPUS and Springer_Link. The selected key-words for the search included: "Artificial-intelligent", "Industrial ventilation", "Occupational-health", "Occupational-Safety". All was applied across three databases using a search term of: [Artificial-intelligent] AND [Industrial ventilation] AND [Occupational-Safety].

In addition, search engines including google and google scholar also played another role in this literature search. It was achieved through searching and selecting ones that met the keywords and search term, as well as the tracking-back searches from those relevant articles' reference lists. The considerable eligible articles were only from the full publishing formats. In other ways, insufficient information configurations, such as abstracts published in conference or workshop proceedings, were not included.

2.2 Screening and Eligibility Criteria

The searches were done with no restriction of the publication year, in order that this would increase the chance of finding as many relevant articles as possible, regarding the topic being studied is very new and rare. After the duplication removal, all remaining articles were then screened based on several criteria. Those that corresponded to the following would be dismissed:

- Clearly unrelated to the studied topic
- Review articles or encyclopedia
- Inaccessible for the full-text articles
- Studies that involved ventilation system but no AI/ML or studies that involved AI/ML but no ventilation system.

The remaining articles would be considered eligible if they met the following criteria:

- Studies that involved AI/ML with ventilation system and those must be associated or linking to the occupational health and safety application.

3 Results

3.1 Study Selection

After screening and eligibility processes, only 7 articles were considered exactly relevant to the studied topic. The summarized details of all studies' selection and inclusion criteria could be demonstrated in Fig. 1.

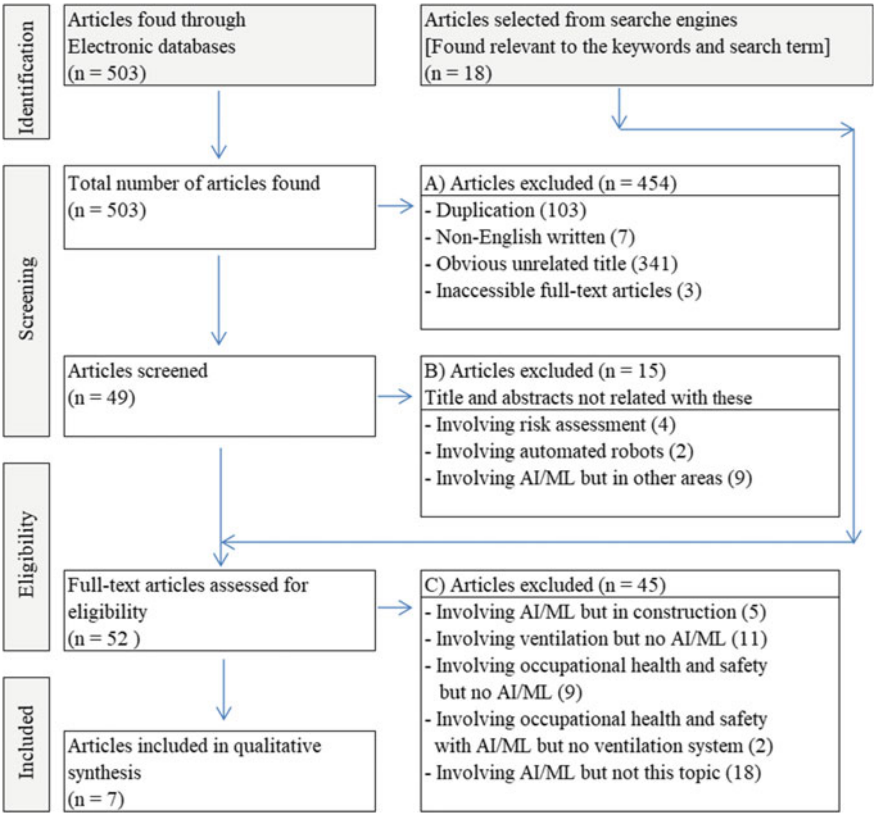

Fig. 1 Details of studies selections and inclusion criteria

3.2 Machine Learning Applications in an Industrial Ventilation Related Field

There were seven studies in total found directly related to the study topic. Both general and local exhaust ventilation took part in this novel technique. All briefly relevant information was summarized in Table 1.

Paige Wenbin Tien and the team (2020) conducted the research on machine learning applying deep learning technique (Faster R-CNN) and video camera to detect and recognize the feature of interest for this study, which was the window's conditions whether being manually opened or closed. This was very crucial in managing and adjusting the HVAC system to cope with these changing conditions in term of thermal comfort and energy consumption (Paige et al. 2020).

This kind of process, via capturing the feature of interest, with either live-streaming camera or image camera or commonly known as a computer vision technique was also found in many others across this study. Wang and the team (2020) did

Table 1 Found studies of artificial intelligence approach for occupational health and safety application in an industrial ventilation (7 studies)

No	Article title	Ventilation systems	Data acquisition devices	Data processing techniques	Types of ML	Features of interest	Practical applications
1	A computer vision deep learning method for the detection and recognition of manual window openings for effective operations of HVAC systems in buildings (Paige et al. 2020)	General Ventilation (HVAC)	Video camera (in real time)	Computer vision (Real-time processing)	Deep learning (Faster R-CNN)	Recognizing the closed or opened windows	To use vision-based deep learning in detection and recognition of the window being opened or closed by the occupants. This was achieved in real-time with an accuracy of the recognition, alerting the HVAC systems in minimizing any energy wastage to help maintain the indoor thermal comfort
2	Machine vision for natural gas methane emissions detection using an infrared camera (Wang et al. 2020)	Local Exhaust ventilation (Focusing on the emission from the stack)	Infrared Camera (FLIR GF-320) (in real time)	Computer vision in the practice of infrared video capture (Real-time processing)	Deep learning (CNN)	Leaking methane gas in the practice of infrared video capture over the stack's top	To use vision-based deep learning in detection and recognition of the methane leaking over the top of the stack, in real time. It was done using the infrared video capture and with the overall accuracy up to 95%. This enabled the decision making automatically for immediate troubleshooting without any human operators involved

(continued)

Table 1 (continued)

No	Article title	Ventilation systems	Data acquisition devices	Data processing techniques	Types of ML	Features of interest	Practical applications
3	Detection of indoor air pollution on wet or moist walls using thermal image processing technique (Khamisan, Ghazali and Ching 2015)	General Ventilation	Thermal imaging camera (taken photograph)	Computer vision (Thermal images)	Image processing technique in Matlab 2010a using classification technique	Leaking pollution was detected via purple spots. This illustrated the wet or moisture on the wall in the image	To use thermal image camera to detect, recognize and identify the leakage of wet or moisture that could cause indoor air pollution. This technique worked via using the divergence in color regarding the difference in thermal level in the environment
4	Deep Neural Network Based Ambient Airflow Control through Spatial Learning (Kim et al. 2020)	General Ventilation (Air conditioner)	Video camera (in real time)	Computer vision (Real-time processing)	Deep learning (DNN)	Recognizing and identifying the living spaces and the real-time location where the human body was detected	To use vision-based deep learning in detection and recognition of the human body living in the area and smartly direct the air flow from the air conditioner to that being detected. The study showed that less than 5 degrees of error occurred in the air flow adjustment and 19.8% faster for the targeted temperature reach and up to 25.7% power consumption save obtained

(continued)

Table 1 (continued)

No	Article title	Ventilation systems	Data acquisition devices	Data processing techniques	Types of ML	Features of interest	Practical applications
5	A single shot multibox detector based on welding operation method for biometrics recognition in smart cities (Lu et al. 2020)	Proposed for Local Exhaust ventilation and Protective Personal Equipment (PPE) detection	Video camera (in real time)	Computer vision (Real-time processing)	Deep learning (Faster R-CNN)	Detecting and recognizing PPE (welding safety gloves) and point of operation for the welding spot where the hand is holding the welding torch	To use vision-based deep learning in detection and recognition of the moving hand with PPE (welding safety gloves) of the operators in real time. The study pointed to the advantage on the PPE wearing inspection and monitoring. Accordingly, with this capability of tracking the movement of the welding spot, it could imply to the potential in ventilation system such as the competence of tracking and sucking off the welding fume across the welding line
6	Pollutant Recognition Based on Supervised Machine Learning for Indoor Air Quality Monitoring Systems (Mad Saad et al. 2017)	General ventilation	Various types of Sensor module including: CO_2, CO, VOCs, O_3, NO_2, O_2, Humidity, Temperature, PM10	Supervised data set that consisted of 5 sources of pollutions including: combustion activity, chemical present, fragrance present, food and beverage present and ambient air	3 Supervised machine learning algorithms including: multilayer perceptron (MLP), K-nearest neighbor (KNN) and linear discrimination analysis (LDA)	Detecting and recognizing the presence of 5 experimental sources of the pollutions through the supervised data set obtained from the tested sensor modules	To use machine learning based on supervised data set to detect, recognize and identify the sources of indoor air pollution automatically. The study showed the accuracy of classification rate up to 100% for each of all 5 samples and surprisingly it could predict the presence of two mixed samples at once. This could reduce human workload and enhance the more efficient troubleshooting for the developing conditions, for example: regulate the air flow or its distribution or even raise the alarm in case of emergency

(continued)

Table 1 (continued)

No	Article title	Ventilation systems	Data acquisition devices	Data processing techniques	Types of ML	Features of interest	Practical applications
7	Applying machine learning techniques to mine ventilation control systems (Kashnikov and Levin 2017)	General ventilation	–	A training set consisting of historical data of the ventilation operating system	Neural networks for the regulator adjustments using regression analysis	Based on historic dataset projecting to the demand for the air change rate during the mining operation, shift-by-shift and day-by-day	To use machine learning in predicting of the required air flow or air change rate. As a result, it could adjust the venting regulators to be in accordance with different situations which altered shift-by-shift and day-by-day. If comparing with the traditional mine ventilation that supplies a constant volume of air using an assumption of the maximal demand during each planning period, this approach could help reduce energy consumption while still meet the efficiency and safety requirements

ML Machine Learning

the study, but instead of using the conventional video camera, he utilized an infrared video camera to detect and recognize the live emission of the toxic methane gas from the top of the ventilation stack via applying a deep learning (CNN) technique (Wang et al. 2020). This is reasonable enough for the use of the infrared video camera, regarding the methane gas itself is invisible, moreover giving no colour and odder (National Library of Medicine (NIH) 2022).

Khamisan and the team (2015) applied machine learning via classification technique to detect and recognize the leakage of wet or moisture that could cause the indoor air pollution. But in this case, the thermal images taken from the infrared camera were utilized as the dataset for the ML's decision making (Khamisan et al. 2015). Sunghak Kim and the team (2020) adopted the machine learning using deep learning (DNN) technique to detect and recognize human body living in the ventilated area. By acknowledging the occupant's location, the general ventilation (air conditioning) could smartly direct the air flow to that particular living sector (Kimet al. 2020).

The last found study using the computer vision technique was conducted by Hongzhi Lu and the team (2020); they adopted machine learning using deep learning (Faster R-CNN) in detecting, recognizing and tracking the welding point using live-streaming video camera, in which torch shapes and groves were also included in the real-time analyzing. It was tested on 3 well-known different types of welding including: SMAW (shielded metal arc welding), GMAW (gas metal arc welding) and TIG (tungsten inert gas) with heigh accuracy rate (Lu et al. 2020).

Another two studies involved no camera, capturing the feature of interest (computer vision techniques), at all. Shaharil Mad Saad and the team (2017) applied 3 supervised machine learning algorithms including: multilayer perceptron (MLP), K-nearest neighbour (KNN) and linear discrimination analysis (LDA) to detect and recognize different sources of indoor air pollution automatically (Mad Saad et al. 2017). Several types of sensors were used to collect necessary information linking to the pollution types being in focus including combustion activity, chemical present, fragrance present, food and beverage present, ambient air and with the 100% accuracy results.

The last one, found in this study, Kashnikov and Lev-in (2017) utilized none of the active data collecting devices, but utilized historic related dataset instead. It was used in the prediction of an airflow redistribution for the ventilation control system used in the mine industry. They used a regression model based on neural networks in the machine learning algorithm (Kashnikov and Levin 2017).

4 Discussion

Machine learning showed its innovative and marvelous values in various kinds of utilization. The algorithm that enables this complex process, just like a human's decision making, is based on predictive statistics such as CNN, DNN, regression and these kinds, which require a set of training sample, known as training data.

Only in this short review, focusing solely on an industrial ventilation related field, those included articles had all overview contents covering both general and local exhaust ventilation. If considering based on types of dataset and data acquisition, it could be classified roughly into 3 categories including: computer vision related dataset, various sensors related dataset and the historical related dataset. Each came with its own unique function, which could provide users the smart and optimal choices enhancing ventilation system efficiency.

The computer vision was the most popular method found in this review. Up to 5 over 7 or about 71.43% adopted this solution. This technique offers a marvelous ability to detect and recognize almost everything, considered as the object of interest, that needs vision ability to distinguish and make a decision. Those could be various kinds of feature of interest such as: specific activities (working posture), changing conditions, things, human or even individual person and so (Khan and Al-Habsi 2020; MassirisFernández et al. 2020). Using only a camera to achievement the information being focused, this could simply suggest that no other kinds of information collecting devices are needed. This implies to the fact that less budget of investment is required. Moreover, it is able to replace the human-required tasks such as monitoring, overseeing and so with efficiency.

The computer vision, working with AI/ML algorithm means that it proceeds image frame by frame, from the video camera, in such a super short period of time which human do have limitation. These advantages had been quickly accepted, including those found in this study utilizing weather a video or image camera.

This is not only presenting the supportive role in reducing human workload but also filling the gap of human limitation. Moreover, it is capable of enhancing in broad aspects such as: energy consumption, work efficiency and labor cost. Beside these, the computer vision strongly showed another potential in safety aspect. Found in this study, it could be implemented via detecting and recognizing personal whether or not being wearing the safety gears or following the instruction.

Specially, the advanced technique for the computer vision, using the thermal imaging whether from a video or image camera, demonstrated the capability in overcoming the limitation of human in dealing with objects of interest that are hard to visualize or even impossible to notice with the naked eyes. As a consequence, up to 2 studies found utilizing this technique, one used the video thermal camera to detect and recognize methane gas leaking from the stack's top, while another used the photograph taken from the thermal image camera to find the leak of wet or moisture.

In many cases, computer vision is not capable of doing its unique job properly. This is due to the complexity in the analyzing process on various kinds of the feature of interest. AI/ML can come with other alternatives using diverse kind of information. This study had revealed another two methods using different way of supervised dataset and acquisition. In consequence of that, it would be much complicated to use a computer vision to detect and recognize some kinds of sources, for example chemical substance; which the use of relevant sensors would be a much efficient solution. Also, historic dataset could be another alternative, particularly in the prediction of the possible event in pollution control, which in this study found using in the mine industry. Other than these, related information from the internet could be used for the dataset as well to predict more precisely and most updated for the ongoing situation for example big data, internet of things (Unal et al. 2021).

5 Conclusions

Artificial intelligence/Machine learning had been proving itself in so many fields. An industrial ventilation for occupational health and safety is also included. It provided technological advantages in various ways: enhancing the system performance, reducing human workload, human limitation, labor cost and capable of smartly delivering better safety conditions to the workers and environments.

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Machine Learning Applications for Continuous Improvement in Integrated Management Systems: A Short Review

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Abstract The machine learning (ML) field is increasingly impacting industries within the Industry 4.0 paradigm, which among other things, enables the usage of vast amounts of data. Combining data and ML consequently enables continuous improvement that differs from conventional continuous improvement, especially in higher efficiency on default detection. However, scientific literature needs to be updated continuously. Hence, this work aims to gather research information on advancements in ML applications in organisations for continuous improvement purposes. Following the PRISMA Statement, 11 relevant articles were analysed. Results evidenced that most research is case-specific and focuses on applicability. Furthermore, it was observed that most papers are from the manufacturing industry. Although some theoretical research indicates the potential of ML applications in the operations domain (i.e., before and post-production processes), the literature in this segment is lacking. It can be concluded that the potential of ML in management systems is dependent on the amount and quality of data. However, this latter comes at a high cost and therefore, careful cost–benefit analysis should be made before adopting ML in businesses. Overall, this review provided promising perspectives for applying ML within quality systems and potential leading ways for continuous improvement in safety, environment and integrated management systems.

Keywords Total quality management · Industry 4.0 · Artificial intelligence · ISO 9001:2015 · Quality Control

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1 Introduction

With the advent of Industry 4.0, the Fourth Industrial Revolution encompassing the development of new capabilities through communication between the physical and virtual world, intelligent processes, and the interoperability among computer systems the competitiveness between organisations is increasing (Fernandes et al. 2019). Especially in developed countries like Germany, Italy, China and the USA, the Industry 4.0 ideology is widely adopted. Consequently, the quality of the products or services (henceforth referred to as products) that organisations supply is becoming ever more critical (Roosefert Mohan et al. 2021). Having emphasised the increasing importance of the degree of quality and the level of customer satisfaction delivered by an organisation, a logical next step is addressing how to obtain desired levels of quality.

The implementation of quality management systems (QMSs), which conform to ISO 9001:2015 standards (International Organisation of Standardisation 2015), assists organisations in defining foundational quality internally (Jarvis and Palmes 2018). Besides defining and ensuring quality within the organisation, maintaining ISO management standards also indicates quality for third parties (Hinsch 2019). The idea behind such QMSs is that they follow the principles of total quality management (TQM). The four fundamental principles of TQM are (i) guidance towards the customer, (ii) continuous improvement, (iii) involvement of people, and (iv) leadership (Alves 2020). Although all four of the fundamental principles are deemed key in TQM, continuous improvement is of particular interest when considering the recent advances associated with the rise of Industry 4.0.

Moreover, according to Rai et al. (2021), the increased availability of data generated by processes and stored by cloud technology fuels the drive to adopt machine learning (ML) applications capable of utilising this data for continuous improvement. To illustrate the potential of ML applications, according to the research of McKinsey employees (Chui et al. 2018), these applications account for $3.5 trillion—$5.8 trillion in annual value that can be created by analytics today (Rai et al. 2021). For the remainder of this paper, it is important to create a general understanding of the concept of ML and its context. A solid explanation is provided by Fernandes et al. (2019), who states that artificial intelligence (AI) has enabled computer science to invent efficient solutions to human problem-solving tasks. Within AI, one of the main branches is ML, which allows computers to learn and continuously improve without being explicitly programmed.

Although ML applications' already existing- and potential value has been identified in the prior paragraphs and throughout available literature (Perera et al. 2021; Rai et al. 2021; Buer et al. 2018), there exists no clear overview of recent advances within ML applications or trends that focus specifically on their contribution to continuous improvement. Therefore, this paper aims to present a literature review for ML applications that are (or can be) utilised for continuous improvement. The main goal of this research is to create an overview of the trends and advancements and identify potential gaps or opportunities for the various ML applications. To fulfil this research goal, Sect. 2 will focus on explaining the methods that have been used to gather relevant literature. Hereafter, the literature that has been found will be reviewed and summarised in Sect. 3. Section 4 aims to assess whether the ML applications that have been found can be utilised for alternative purposes or sectors than the original. Finally, the conclusion in Sect. 5 aims to summarise the research and its findings and comment on potential future perspectives.

2 Methodology

To ensure reproducibility and validity of the research, the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) expanded checklist of Page et al. (2021) has been used. According to the PRISMA checklist, a review paper must follow a given structure consisting of a title, abstract, introduction, methods, results, discussion, and possibly other information (Page et al. 2021). Within the different sections, several checklist items must be included. These checklist items will be identified within this section.

Firstly, the inclusion and exclusion (eligibility) criteria of the study itself must be stated. The literature search was conducted between the 27th of November and the 30th of December. Within the given period, articles written in either English or Dutch are considered due to the researcher's capabilities. Furthermore, no limitations regarding the country of origin of the paper are considered since this research focuses on the recent trends and advancements and should consider all eligible papers.

Secondly, the information sources must be identified; for this paper, the databases Scopus and Worldcat (Technical University of Delft) have been used. These sources have been used in between the previously stated dates. To create structure and an overview, the reference management software Mendeley was used.

Thirdly, the characteristics of the search must be delineated. Moreover, based on the characteristics of the study itself, the primary search string included the search terms "Machine Learning", "Quality Management", and "Continuous Improvement". In Scopus, these keywords have been limited to the title, abstract and keywords. Furthermore, the search string was limited by the dissemination dates 2018–2021. The resulting search string is depicted in Fig. 1.

The same search limitations were applied in Worldcat; however, the keywords are limited by occurrence in "full text" and "keyword" since the option "TITLE-ABS-KEY" (as depicted in Fig. 1) is not available. This search string is depicted in Fig. 2.

The fourth aspect that must be treated according to the PRISMA checklist is the study selection. Moreover, the articles found via the search strings, as depicted in

(TITLE-ABS-KEY ("machine learning") AND TITLE-ABS-KEY ("quality management") AND TITLE-ABS-KEY ("continuous improvement")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018))

Fig. 1 The primary search string entered in Scopus

kf:("machine learning") **AND kf**:("quality management") **AND kf**:("continuous improvement") **AND (LIMIT TO (pd**: 2018) **OR LIMIT TO (pd**: 2019) **OR LIMIT TO (pd**: 2020) **OR LIMIT TO (pd**: 2021))

Fig. 2 The primary search string entered in Worldcat (TU Delft)

Figs. 1 and 2, were first scanned on duplicates. The articles resulting from the search string were saved and converted to Mendeley. If there were any duplicates, the software indicated this, and consequently, duplicates were eliminated. Also, unavailable articles were removed from the literature list. After refining the literature list based on duplicates and unavailability, the titles and abstracts of the remainder of the articles were scanned. This scan resulted in excluding all documents related to ML applications within the medical sector. This limitation was added because the articles published within the medical sector address very specific technological applications (for specific diseases). After that, a full-text assessment resulted in the addition of another limitation; articles that did not focus on ML technologies applied within the Industry 4.0 paradigm were excluded. This limitation was added since this research is focused on the available ML technologies and not on the idea behind Industry 4.0.

After identifying and implementing the limitations, the PRISMA method states that the data collection process, or the method that is utilised to extract data from the articles, must be identified. Within this research, this is done by individually reading the articles and, throughout the reading process, identifying overlapping/comparable data items. The details of these data items will be further addressed in the next section.

3 Results

The search, as depicted in Fig. 1, resulted in a total of 6 articles. Whereas the search as depicted in Fig. 2 resulted in 13 articles. These search strings were the first step of the applied methodology and are presented in the top part of Fig. 3. The 19 articles that have been found were scanned on duplicates and accessibility. The scan on duplicates resulted in the exclusion of two articles, and the accessibility limitation excluded one additional article.

The scan of the abstract and the titles of the remainder of the articles resulted in excluding four articles since they focused on medical applications of ML technologies. Finally, the last exclusion criteria resulted in the elimination of one additional article since it did not focus on specific ML applications but rather the idea behind industry 4.0. The articles resulting from the search strings in combination with the exclusion criteria resulted in a total of 11 articles, forming the basis of this paper.

To assess the ML applications of the various articles, all of them were read again to find overlapping data items. Research by Rai et al. (2021) states that advances in ML are changing traditional manufacturing into smart manufacturing in the era of Industry 4.0. Moreover, they identify (1) computer vision-based inspection and monitoring, (2) fault detection or diagnosis, (3) cloud manufacturing and (4) process improvement and optimisation- as the most important categories of nowadays emerging ML technologies in manufacturing. A significant share of the papers that have been reviewed in the previous section is focused on the manufacturing industry; therefore, these classifiers might prove to be useful. However, manufacturing is not the sole industry experiencing the adoption of ML technologies. Moreover, apart from the four categories that are mentioned prior, Rai et al. (2021) also mention three aspects of the business in which organisations have been successfully implementing ML: (1) operation, (2) production, (3) post-production. To categorise and classify the ML applications, both are used to indicate at what stage of on organisation and what type of ML application is applied. This classification is shown in Table 1.

4 Discussion

This review aimed to gather relevant, up-to-date literature on ML applications for continuous improvement. Eleven articles met the inclusion criteria, with most of them focusing on ML applications within the manufacturing industry.

4.1 Summary of Key Findings of Papers

Computer vision-based approaches enable monitoring a product throughout the (entire) production process. Additionally, they can enable a higher quality in continuous process monitoring. Within computer vision-based approaches, ML technologies classify images (or videos). After that, these classifications can be used to, for example, further process specific parts of the products, resulting in higher efficiency of the process and improved quality of the end product Chen et al. (2020), as cited in Rai et al. (2021)). Research by Chen et al. (2020) developed an ML algorithm that inspects integrated circuit wire bonding defects. The created ML application could identify and classify wire bonding defects, including sagging wire, low loop, high loop, no wire, and a broken wire. The combination of identification and classification reached an accuracy of 91%, from which the authors concluded that the proposed ML application is effective. Also, they achieved a short inspection time, realising near real-time defect detection.

Another article by Zhang and Gao (2021) proposed a soft sensor method for the classification of iron ore tailings grade based on a hybrid deep neural network. They concluded that, compared with conventional classification methods, their ML application is capable of real-time classification of tailings froth grade, which is helpful for producers to adjust production conditions promptly and avoid economic losses. Furthermore, the research of Benbarrad et al. (2021) utilised a computer vision approach for developing a machine vision-based inspection model that detects and

Table 1 Categorisation of the ML applications that have been found in the literature. In the column labelled "categorisation" the number in between brackets links the type of ML application to one of the "categories of emerging ML technologies in manufacturing" as proposed by Rai et al. (2021)

ML application	Categorisation	Reference
Inspection of integrated circuit wire bonding defects	Production (1)	Chen et al. (2020)
Classification of iron tailings grade	Production/Post-production (1)	Zhang and Gao (2021)
Detection and classification of defaults in casting manufacturing products	Production (1)	Benbarrad et al. (2021)
Fault diagnosis of rolling bearing	Post-production (2)	Wang et al. (2020)
Fault detection in industrial cold forging	Production (2)	Glaeser et al. (2021)
No specific application—theoretical scheduling of manufacturing tasks	Operation (3)	Jian et al. 2020)
Process improvement and optimisation in injection moulding	Production/Post-production (4)	Rønsch et al. (2021)
No specific application—Identification of critical success factors of Lean Six Sigma for businesses	Operation (4)	Perera et al. (2021)
No specific application—Self-optimising Kanban system	Operation (4)	Buer et al. (2018)
Total productive maintenance of high-pressure hydraulic sand moulding process	Production (2)	Roosefert Mohan et al. (2021)
Identification of quality features and detection of rare quality events in automotive manufacturing (batteries and sub-assembly components)	Production (2)	Escobar and Morales-Menendez (2018)

classifies defaults in castings manufacturing products. Besides real-time error detection, their ML model could identify the process that caused the defect; consequently, it continuously improves the manufacturing process. The developed ML application achieved an accuracy in default detection and process identification of 95% in a relatively short period. Also, they concluded that the proposed architecture could be easily adapted and used for different use cases.

Another interesting approach was the one of Wang et al. (2020), which developed an ML method for rolling bearing fault diagnosis under multiple working conditions. The ML application allowed to assess the end-product and diagnose, if there are defaults, what part of the production process has caused this default. One of their conclusions is that their developed approach outperforms state-of-the-art non-ML methods. Other research by Glaeser et al. (2021) applied deep learning and a Convolutional Neural Network (CNN) ML method to improve fault detection in industrial cold forging. Also, in their research, the ML method outperforms the state-of-the-art non-ML methods. However, only a small dataset was used, and therefore their ML method could not be validated for business applications.

On the other hand, cloud manufacturing was also observed among retrieved results. Cloud manufacturing involves utilising manufacturing data that has been stored in the cloud through ML techniques (Rai et al. 2021). The ML techniques that utilise this data will help to reduce costs and drive profitability. A concrete example was provided by Jian et al. (2020) research, who proposed a cloud edge-based two-level hybrid scheduling learning model, which seemed promising; however, it needs further research to identify whether it can be utilised for complex manufacturing tasks. In addition, the research of Rønsch et al. (2021) is specifically focused on data sources for process improvement and optimisation in injection moulding. They concluded that the ML method they tested was as good as the data on which it had been trained. This suggests that the adoption of ML applications demands more data of higher quality. However, high-quality data is often expensive to generate or obtain; therefore, businesses that consider the utilisation of ML applications should create a thorough cost–benefit analysis of the adoption of ML applications in their organisation.

Furthermore, research of Perera et al. (2021) tried to identify whether ML technologies could help businesses that tried to implement Lean Six Sigma (LSS) (a combination of minimising defects: Six Sigma, and maximising efficiency: Lean) but failed. They identified that the critical success factors (CSFs) are key for the implementation of LSS. However, these CSFs are too many and poorly defined. To combat this problem, they use a deep supervised learning model to extract the essence of the CSFs in successful implementations that have been described in the literature. To clarify, they used an ML algorithm to search through available literature and identify the critical success factors of the implementation of LSS such that this information becomes more organised and accessible and allows organisations to implement LSS successfully. Although their ML method needs further research, it seems promising and applicable for improving and optimising a wide range of processes.

Research by Buer et al. (2018) analysed the influence of digitalisation on the Plan-Do-Act-Check cycle and provided an example of the application of ML on a well-known manufacturing tool for quality assurance: Kanban. They concluded that a self-optimising Kanban process could run the Kanban loop autonomously, use the collected data and continuously prioritise improvements. The Kanban system that uses ML adjusts the bin size and the number of cards in circulation (Buer et al. 2018). Although their work appeared innovative, it must be noted that they have not applied this ML-based Kanban system but rather indicated its potential theoretically. Research of Roosefert Mohan et al. (2021) compared a conventional total productive maintenance (TPM) model (Industry-3.0) with an intelligent TPM model that was supported by an Autoregressive Integrated Moving Average (ARIMA) ML algorithm (Industry 4.0). The two approaches were implemented in a high-pressure hydraulic sand moulding machine in an automotive grey casting manufacturing foundry. They concluded that utilising the ML-based method, the mean time between failures (MTBF) increased by 880%, and an 84% reduction in downtime was reached. Also, they claim that the ML method they applied can be deployed in Industry 3.0 to Industry 4.0 conversion without any major structural changes.

Research by Escobar and Morales-Menendez (2018) developed a learning process and pattern recognition strategy for a knowledge-based intelligent supervisory control system. The proposed combination aims to detect rare quality events in manufacturing systems and simultaneously identify the most relevant features to the quality of the product. In their research, the ML application can detect 100% of the defective units in both automotive manufacturing for battery tabs and sub-assembly components from an assembly process. Also, they conclude that their approach is easily adaptable and widely applicable for various manufacturing processes to boost the traditional quality methods' performance.

4.2 Applicability of ML Technologies

From the eleven articles that are depicted in Table 1, five claim that their ML application is "widely applicable", "easily adaptable", or "applicable without any significant changes". These are the papers of Benbarrad et al. (2021); Perera et al. (2021); Buer et al. (2018); Roosefert Mohan et al. (2021) and Escobar and Morales-Menendez (2018), respectively. Although this might be true for similar industries, the applicability of, for example, an ML algorithm that detects and classifies defaults in casting manufacturing products (Benbarrad et al. 2021), can be doubted in an organisation that provides a service such as a consultancy. Having said that, the research of Perera et al. (2021) seems interesting and potentially applicable for a larger variety of industry sectors. Therefore, its potential and applicability will be investigated further.

Moreover, as already summarised in the previous section, their research is focused on identifying and categorising critical success factors (CSFs) for Lean Six Sigma (LSS), in which they define CSFs as "elements of an organisational strategy that can influence the performance of the organisation while guiding towards a positive direction" (Perera et al. 2021). They consider LSS a project management approach rather than an overall organisational approach; therefore, the CSFs are subject to change in alternative projects within the same organisation. With their developed ML application, they can identify the CSFs that are key for specific processes of projects. The example they provide is Leadership Engagement, in which for the subprocess "managerial", the CSF "decentralised decision-making" is identified. However, most commonly, these CSFs are not altered for different projects. Since there is a direct correlation between CSFs and a satisfactory outcome in specific subject areas such as continuous improvement, static CSFs can lead to a lack of continuous improvement (Alkarney and Albraithen 2018).

According to Perera et al. (2021), 52% of the CSFs in existing literature are related to manufacturing, 14% are more general CSFs (both service and manufacturing), another 14% listed the CSFs of small and medium-sized enterprises, and the remainder (20%) represents other industries such as IT, healthcare, and aerospace. The vast amount of data available in different industries indicates the potential of the developed ML application. However, their proposed method is novel and not yet "operationalised" in any industry. Therefore, the applicability in industries cannot be validated yet. Furthermore, an important aspect that determines the applicability of ML applications, in general, is the amount of available data and their respective quality (Görzig et al. 2019). Also, for the ML applications in the articles that have not been treated extensively, the majority share of the papers that have been reviewed indicates that data availability and data quality is key for any ML application.

5 Conclusion

The main goal of this research was to create an overview of the trends and advancements of ML applications for organisations and identify their potential contribution towards continuous improvement. The literature search and selection process resulted in eleven scientific articles that focus on applications of ML in industries. The number of scientific papers found is not too large; therefore, future research should be directed towards extending the review process to increase the number of articles and map the already existing applications for ML in industries. Despite the room for improvement, some interesting conclusions can be drawn from the research at hand.

Firstly, the applicability of ML in industries is completely reliant on the availability- and quality of data. Almost 50% of the scientific papers that have been reviewed claim to have developed ML applications that are widely applicable. However, if there is no data available to train the ML application, the application itself will be useless. Moreover, according to Rønsch et al. (2021), industries that consider adopting ML applications within their processes should perform a cost–benefit analysis. The need for a cost–benefit analysis descends from the fact that, although there is enough data available in most cases, the quality of this data is key for the performance of the ML application. Obtaining high-quality data is often an expensive process, and conventional methods for continuous improvement are still reliant. Therefore, the pros and cons of implementing ML must be considered, especially since continuous improvement should deliver quality at a lower cost (Alves 2020).

Secondly, from the literature review, it can be concluded that most of the papers focus on ML applications in the manufacturing industry. They contribute towards continuous improvement primarily in zero defects and real-time fault detection;

however, some applications focus on other areas such as scheduling and strategizing. For ML applications to become part of modern processes, their ease of adaptability is critical for successfully integrating such systems into real production lines (Benbarrad et al. 2021).

Finally, according to Görzig et al. (2019), ML applications can reduce the direct involvement of humans and significantly increase the reduction of errors in a wide variety of processes. However, other areas that emerge may need to be staffed with humans' unique skills, for example, the issue of data quality. Furthermore, since ML applications are programmed to learn from data and continuously develop through self-learning without human intervention (Escobar and Morales-Menendez 2018), they may learn something that is not appropriate or desired for its specific applications (Görzig et al. 2019). Therefore, the results must always be validated by humans.

As it was observed within the results, applications of ML for continuous improvement are promising and will continue to improve. Although this paper primarily focuses on identifying ML applications for continuous improvement within quality management systems, the potential of ML applications for safety, environment and integrated systems also emerges throughout the review. Moreover, since vast amounts of data are used, some of the ML applications might also be utilised to predict maintenance on machinery to prevent work-related accidents and, consequently, improve the organisation's safety. Also, the data can be used to improve the environmental performance of the machinery by continuously monitoring the performance of specific processes. Consequently, these combined outcomes will lead to continuous improvement in an integrated management system perspective.

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BIM Application for Construction Health and Safety: Summary for a Systematic Review

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Abstract The AECO (Architecture, Engineering, Construction, and operation) industry is one of the highest-risk industries, bearing many accidents and fatalities every year. Hence, to have adequate site supervision, inspection, and training, BIM gradually incorporates digital technologies such as automatic rule checking, Augmented and Virtual Reality. This review aims to provide a general overview of building information modelling (BIM) approaches to improve construction workers' health and safety. In addition, identifying the most exploited tools, frameworks, and BIM dimensions and simultaneously listing the target groups, risks, construction fields, and locations. This short review is based on the findings of a systematic review involving 90 articles in the field of BIM-based health and safety in construction. The health and safety research field is becoming more investigated with several methods for risk prevention and maintaining health and safety during the project lifecycle. The authors mainly addressed fall-related risks while developing solutions to assisting safety managers with monitoring and inspection. Implementing and utilising BIM for health and safety has various limitations since every tool represents a standalone solution. BIM dimensions are still misunderstood, while BIM models still lack the standardisation and link to health and safety regulations.

Keywords Building information modelling · Construction health and safety · Automated Rule Checking · Augmented Reality · Virtual Reality

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1 Introduction

Construction health and safety preventative methods are developed and implemented in the AECO (Architectural, Engineering, Construction and Operation) sector. However, construction employees have the most severe accident and fatality rates among other sectors (Ahn et al. 2020).

Corresponding to Occupational Safety and Health Administration (OSHA) 2019 statistics, almost 200,000 injuries were documented in the AECO sector. Thus, accountable for 9.5 full-time workers fatalities per hundred thousand (Labor 2019). According to the U.S. Labour statistics, struck-by-objects, Falls, stuck-in, and electrocution were responsible for 58.6% of casualties of AECO workers in 2019 (Labour 2019).

Based on Wang's theory, five factors (Environment and heredity, Management, Personal factors, Job factors, Unsafe actions, and conditions) must be eliminated to prevent accidents (Wang 2018). Thus, it is essential to have safety education and training for workers prior to on-site construction activities to avoid unsafe actions. Since workers with limited worksite experience, especially new employees, are prone to accidents more than experienced workers (Mason et al. 2017). Moreover, there should be inspection, monitoring, and constant site arrangement to prevent accidents (Wang 2018).

However, traditional accident prevention methods are error-prone since they depend on manual inspection and monitoring. Nevertheless, they are still being executed (Eleftheriadis et al. 2017). Thus, safety management in the AECO sector needs digital transformation (Zhou et al. 2015). Accordingly, Building Information Modelling (BIM) is a promising instrument for facilitating the transformation and automation of safety management in the AECO sector (Eleftheriadis et al. 2017). Though, construction safety management still lacks proper visualisation and communication approaches (Sidani et al. 2021a, b). Nonetheless, BIM facilitates visualisation and enhances communication and numerous other safety issues, such as design for safety, planning, monitoring, inspection, collision detection, and safety at the facility and management phase (Clevenger et al. 2015).

The main objective of this short review is to highlight the best practices of BIM for health and safety implemented in the AECO sector. Thus, underlining the most effective methods, BIM dimensions, hardware, and software were utilised. In addition, identifying the target groups, project lifecycle phase, and risks the tools are addressing. Finally, mentioning the assessment methods and limitations.

2 Methodology

The current review is based on a BIM for health and safety in the AECO sector systematic review. The adopted systematic review is the Preferred Reporting Items for

Systematic Reviews and Meta-Analyses (PRISMA) (Page et al. 2021). The systematic review was performed with the top scientific electronic databases in Engineering, BIM, and occupational health and safety. The systematic review underwent a snowballing technique analysing the collected article's references to find additional articles that might be relevant to the study's objective (Wohlin 2014). A combination of Four keywords and their synonyms were considered for the search "Building Information Modelling, Construction, Occupational Health and Safety", and the synonyms are BIM, work, health and safety, accidents, risks. Afterwards, the systematic review followed a well-defined exclusion criterion, where review, conference, discussion, and unpublished articles were excluded. Second, articles not in construction, health and safety nor include BIM were rejected. Finally, 77 articles were considered for the review.

The following sections will demonstrate the results of the collected articles, following a discussion of the main finding, limitations, and the most promising tools to be considered—finally, conclusions and future proposals.

3 Results

3.1 Selected Articles

During the research phase, 179 articles were compiled. The second step was applying the exclusion criteria, which eliminated 49 articles due to article type. 17 papers were excluded due to the topic. Two papers were not in English, so they were excluded. Afterwards, using Mendeley, 19 duplicated articles were excluded. After analysing the titles and the abstracts, 32 papers were excluded for being off-topic, resulting in 119 excluded articles.

From the references of the selected articles, 45 articles were added due to a snowballing methodology followed based on Wohlin's approach (Wohlin 2014). The resulting 105 articles were assessed for eligibility. Next, 15 were rejected, of which four articles were conference papers, and 11 articles did not comply with the proposed objectives nor the use of BIM for health and safety. Figure 1 summarises the research process, adapted from PRISMA-P (Page et al. 2021), where a final count of 90 papers.

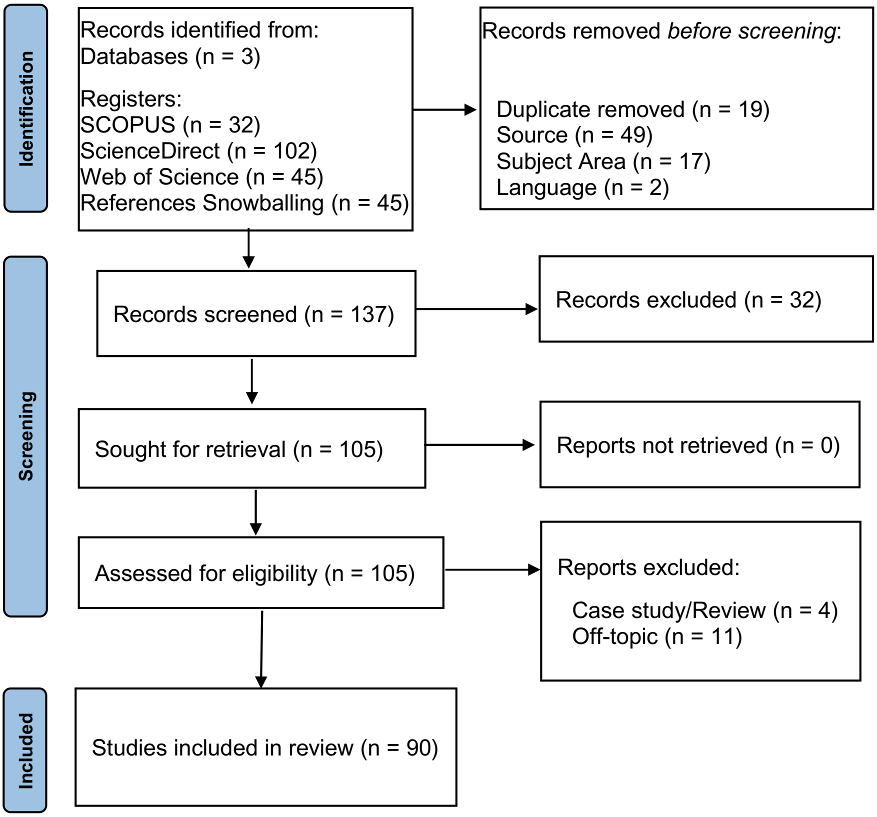

Fig. 1 Summary of articles collected

3.2 Publication Year

The articles' publication period is between 2008 and 2021. 2015 and 2019 have the most significant number of articles with 14 each, followed by 2018 and 2021 with 12 and 9, respectively. In addition, it could be observed that there has been an increasing interest in the BIM-based health and safety field in recent years. Figure 2 summarises this information.

3.3 Construction Stages, Fields, Target Groups

The articles created BIM-based safety and health solutions mainly for the construction phase of the project life cycles, with 40 authors focusing on this phase (Fig. 3). The second and third most addressed phases are design and pre-construction, with

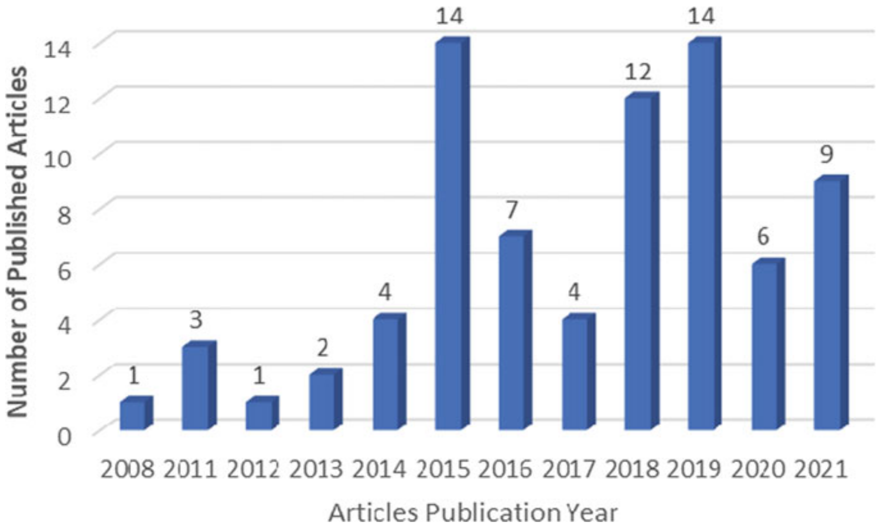

Fig. 2 Number of published articles per year

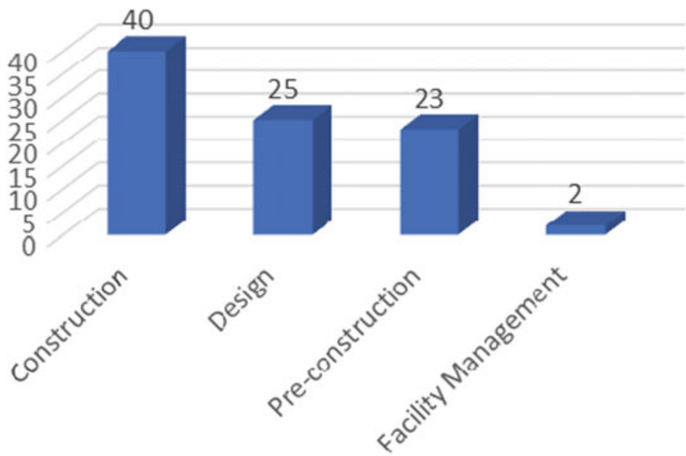

Fig. 3 Safety fields targeted by the authors

25 and 23, respectively. Finally, facility management had the least mentions, with just two mentions (Malekitabar et al. 2016; Riaz et al. 2017).

As shown in Fig. 4, the selected articles focus on Safety Manager, having 58 mentions. While designers and construction managers came in at second and third highest mentions with 17 and 15 respectively. Workers and engineers had fewer mentions with 11 and 10 respectively. Facility Managers were mentioned as the primary target groups in two articles (Getuli et al. 2020; Pham et al. 2020). At the same time, owners were mentioned twice as secondary target groups (Arslan et al.

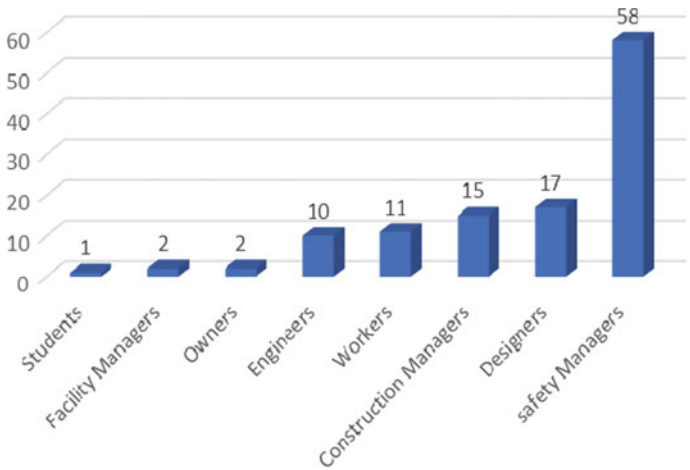

Fig. 4 Target groups of the collected articles

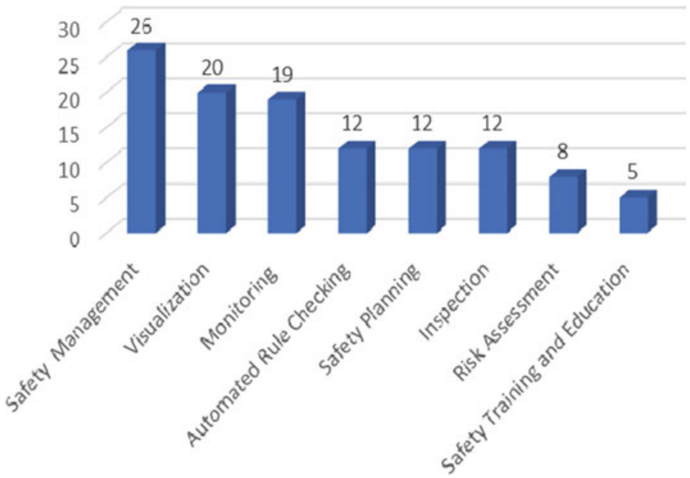

Fig. 5 Safety areas targeted by the authors

2019b; Wu et al. 2015). Furthermore, Students had just one article as a primary target group (Clevenger et al. 2015).

The safety areas targeted by the authors are shown in Fig. 5. Hence, safety management, with 26 mentions, was the most targeted field. Visualisation and monitoring have almost the same number of mentions of 20 and 19, respectively. Automated Rule Checking, Safety planning and inspection were mentioned 12 times each. Risk assessment with eight mentions, and the lowest addressed field was safety training and education with only five mentions.

3.4 BIM Dimensions Utilised

The most utilised BIM dimension for health and safety is 4D, with 42 mentions. Every article assessed the BIM's model geometry and some of the elements' properties. The authors considered articles focusing on geometry, rendering, and other elements' properties as a 3D model that was exploited 29 times. 5D was used six-time, while only two authors confirmed using 5D (Cortés-Pérez et al. 2020; Lu et al. 2021). Although three of the six articles mentioned that they are using 4D BIM but added cost which the authors considered it as a 5D model (Kim et al. 2018a; Marzouk and Daour 2018; Tak et al. 2021). Moreover, one article considered the 3D BIM model and added cost, and the authors considered it as a 5D model as well (Wang et al. 2015).

3.5 Targeted Risks

The collected articles address 16 different risk categories. Some authors tackled more than one risk; these risks were considered in different categories **Erro! A origem da referência não foi encontrada.**. Risks associated with masonry works were mentioned once (Zhang et al. 2015a, b). Similarly, transportation-related risks were targeted by Arslan et al. (2019a) as well as Roofers and carpenters were addressed only by Lu (Zhang et al. 2015a, b). Atmospheric Hazards such as toxic gases, high or low temperatures and humidity, and dust particles were mentioned by three (Arslan et al. 2014; Cheung et al. 2018; Smaoui et al. 2018). Fire related hazards were mentioned four times (Hosseini and Maghrebi 2021; Marzouk and Daour 2018; Mirahadi et al. 2019; Park and Kim 2015). Construction Risks related to scaffolding were addressed five-time (Clevenger et al. 2015; Hara et al. 2019; Kim et al. 2016, 2018a, b). Dangerous behaviour and environmental risks are a general category. Each article represents several or one risks. In total, ten articles handled hazardous behaviours. Falls and general site work risks were mentioned 17 and 18 times, respectively (Fig. 6).

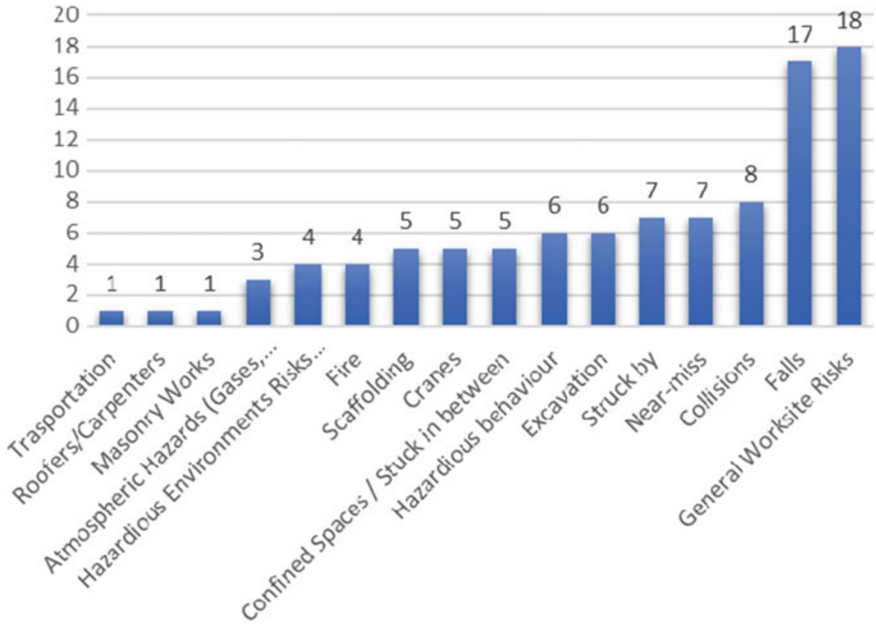

Fig. 6 Targeted risks

4 Discussion and Conclusions

The short review focus on BIM utilisation for construction safety and health.

The authors focused on creating solutions and tools for safety managers and professionals, mainly addressing fall hazards. Moreover, visualisation and inspection were given much importance and were considered one of the main methods to prevent accidents on the worksite. However, the results demonstrate a lack of diversity in exploring BIM dimensions within the health and safety field, interpreted as wasted opportunities for some research areas when leveraging BIM's full potential. In addition, there is a misconception and confusion concerning BIM's dimensions since studies concerning Prevention through Design (PtD) should have referred to 8D BIM model concepts (Kamardeen 2010). In addition, if using cost, the model should directly be described as 5D (Williams et al. 2015). This concludes that for most health and safety solutions, 4D models are the ideal solution, where as 3D models are sufficient for general visualisation, collision detection, and model walkthroughs.

Furthermore, BIM utilisation for safety education and training has been poorly exploited.

Nevertheless, the articles have various limitations. Several dangerous conditions or worker's behaviours cannot be recognised, and tracking workers cannot be implemented in most countries due to privacy policies. Furthermore, Clients should be more motivated to implement such tools to reduce time and costs and enhance collaboration. The authors should follow standards and specify the Level of Information Need (LOIN) or the Level of development (LOD).

Therefore, future BIM and health and safety investigations should overcome the mentioned limitations and barriers to take full advantage of the tool.

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Semi-quantitative Methods for Assessing the Risk of Occupational Accidents: A Literature Review

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Abstract This study reviewed the existing literature on the application of semi-quantitative methods to assess the risk of occupational accidents. The main goal was to identify and describe the methods used in practical applications. PRISMA methodology was applied in this systematic literature review. Scientific articles were searched in Science Direct, PubMed and B-on (from 2010 until March 2022). After defining and applying the inclusion and exclusion criteria, 3 articles were analyzed. It should be noted the limited availability of articles that describe the application of semi-quantitative methods to assess the risk of occupational accidents. Given its advantages in decision-making about risk acceptance and the need of control measures, we highlight the importance of future developments of these methods and the need to expand their practical applicability.

Keywords Occupational safety · Occupational accidents · Risk assessment · Risk management

1 Introduction

In a semi-quantitative risk assessment, the absolute value of risk is not determined, as it is done in a quantitative risk assessment. In fact, semi-quantitative methods only

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allows one to arrive at approximate results rather than exact results (Khan and Ahmed 2015). In this case, the risk level is classified as intolerable, tolerable, or acceptable (or other classifications depending on the method applied), being an important methodology for many companies to support decision-making about the risk of occupational accidents (Woodruff 2005; Rodrigues et al. 2014). In these methods, the level of risk is usually quantified with the combination of two variables, i.e., probability and severity, and compared with pre-defined acceptance criteria (Khanzode et al. 2012). Semi-quantitative risk assessment methods are usually presented in the format of risk matrices (Rodrigues et al. 2015). For risk estimation, historical accident records are used. Therefore, these methods contribute to avoid the subjectivity inherent to the risk assessment process when qualitative methods are applied, where risk level is defined based on the personal judgments of the professional who is assessing (Pasman et al. 2009; Hughes and Ferret 2011; Harms-Ringdahl 2013; Hopkins 2011).

Semi-quantitative methods have suggested by several authors as of paramount importance to assess the risk of occupational accidents, due to the use of objective data for risk estimation (Velkovski et al. 2015; Carrillo-Castrillo et al. 2014; Jacinto and Silva 2010). They usually resort to the accident history dataset of a sector or a company itself, to estimate the level of probability (or frequency) and the level of severity of the risk to be assessed (Rodrigues et al. 2015, 2017; Khan et al. 2015).

However, despite its relevance to support decision-making on the risk of occupational accidents, its application is more common in major accidents (Rodrigues et al. 2014, 2015).

The aim of this study is to review the available literature about the application of semi-quantitative risk assessment methods to assess the risk of occupational accidents, identifying and describing the methods used in practical applications. In this study, we only want to considered methods where risk estimation is supported in accident datasets. Methods were both probability and severity of a risk is determined considering subjective estimations are considered qualitative methods.

2 Methodology

The present systematic literature review was prepared according to the guidelines of the PRISMA method (Page et al. 2021). The PRISMA method defines the different phases of a systematic review, such as the definition of eligibility criteria, the description of information sources, the search strategies, the process of selection and exclusion of studies and results and data syntheses (Shamseer et al. 2015).

The present systematic approach under PRISMA covers developments in the field of semi-quantitative risk assessment methods for occupational accidents, variables for estimating probability and severity, as well as other relevant variables.

2.1 Literature Search Strategy

The literature search was restricted to scientific articles and limited in time. In view of this, only studies published since 2010 were considered for the present study, ensuring current results and in accordance with the recent trends of the scientific community about the use of semi-quantitative methods to assess the risk of accidents in occupational settings.

As recommended by the PRISMA methodology, different databases were used to ensure that all relevant studies were found. Thus, the following databases were used: Science Direct, PubMed and B-on.

The keywords used were the same for the different databases used:

1. "risk assessment" OR "risk level" OR "risk analysis"
2. "semi-quantitative" OR "semiquantitative";
3. "occupational risks" OR "occupational accidents";
4. #I AND #II AND #III.

2.2 Eligibility Criteria

Inclusion and exclusion criteria were defined and used to determine the eligibility of studies. Selected articles needed to meet the following inclusion criteria: (1) it needed to be related to occupational accidents risk assessment; (2) draw on the use of semi-quantitative methods for risk assessment; (3) demonstrate the applicability of the assessment method/methodology in occupational settings; (4) be written in English. Exclusion criteria included: (1) dissertations and conference proceedings; (2) books or book chapters; (3) editorial material; (4) articles that address semi-quantitative methodology in a narrative and non-demonstrative way (models); (5) articles that do not address semi-quantitative approaches.

2.3 Study Selection

Following the PRISMA methodology, scientific articles were selected for potential inclusion. Searched articles were exported to the bibliographic software package Mendeley. Then, titles of the studies obtained by the three databases were cross-checked to detect and eliminate duplicated articles. Then, taking into consideration the inclusion and exclusion criteria, articles were screened (independent titles, abstracts, and full texts).

An analysis was performed on the titles and abstracts of each of the papers, and those that were related to the topic of the study were selected. After this, from the selected articles, the full text of the articles was analyzed in what regards to the contribution to the purpose of the study, eligibility, and selected/rejected for inclusion in the systematic review. Additionally, the publications that were cited in the different articles were also taken into consideration in order to find other studies that could be relevant to the study.

2.4 Data Collection Process and Study Design

This study includes an extended review of publications related to the application of the semi-quantitative methods to assess the risk of occupational accidents, to identify the variables used for quantification and estimation of probability, severity, and risk level. To conduct this review, and to determine the impact and importance of the methods identified, the present study also considered the impact factor of the journals in which they are published.

Qualitative and quantitative data from the articles included in the study were analyzed and extracted for use and development in the present systematic review. The following data (if available) were extracted from each article: year of publication, title, authors, methodology, journal, the focus of the study (scenario evaluated), probability and severity determination, risk level estimation.

3 Results

3.1 Article Selection

A total of 36,265 records were obtained from the searched databases. After removing the duplicates, the screening phase involved the analysis of titles and abstracts of all the identified studies, resulting in 8 scientific studies to be considered for further analysis. Of these, 5 studies were excluded mainly because (1) they were not related to the risk assessment of occupational accidents, (2) they did not resort to the use of semi-quantitative methods for risk assessment, and (3) they did not demonstrate the applicability of the assessment methodology/tool in occupational settings. In the end of this procedure, were found 3 empirical studies that fully met the eligibility criteria (inclusion and exclusion criteria) previously defined. Table 1 summarize the scientific articles identified and selected by database.

3.2 Study Characteristics

Information about the 3 reviewed studies, including study title, journal where it was published, a short description and the sample used in study is summarized in Table 2. Data show that all studies were developed in industrial settings.

Table 1 Publications that relevant for the review

Database	Articles found	Candidate	Number of studies that considered to the research study
Science Direct	14,758	6	2
PubMed	488	1	0
B-on	21,019	1	1
Total	36,265	8	3

A deeper analysis of the studies was developed to obtain information about the methods applied, being the results summarized in Table 3. The data show that risk matrices were used in the 3 studies under analysis for risk estimation. For the quantification of the level of probability, the studies considered the frequency of occurrence of a critical event. On the other hand, for the estimation of severity, the consequence of the accident was assessed based on the days lost.

4 Discussion

Despite the small number of scientific articles identified in this study that apply semi-quantitative methods to assess risk of occupational accidents, they were found to be relevant to support decision making. All the methods used were resort to the accident history of the sector or the company itself, determining, based on this data, the frequency level (probability) and severity of the risk to be evaluated (Velkovski et al. 2015; Carrillo-Castrillo et al. 2014; Jacinto and Silva 2010). Risk level was estimated in all analyzed studies with a risk matrix. This kind of semi-quantitative approaches have been also noticed with other studies were other semi-quantitative were proposed, but not applied (see, e.g., Rodrigues et al. 2015).

The studies reviewed focused on risk assessment in industrial settings. This can be related to the fact that this sector faces several accidents each year (EUROSTAT 2022), denoting the relevance of new methods and approaches to decide about risk acceptance and on the need of risk control measures. The analyzed studies applied semi-quantitative methods different from each other, allowing a more comprehensive analysis of the applicability of different methods in similar contexts.

The analysis of the applied methods denoted that for the determination of probability level, it was considered the use a scale from "Very Likely" to "Very Unlikely" in intervals of values, which was determined considering the frequency of occupational accidents in each scenario under analysis. For the determination of the severity level, there was a predominance in the classification of the scale from "Minor Injury" to "Fatal", considering the lost work days of the occurred accidents has a reference for its determination (Carrillo-Castrillo et al. 2014; Jacinto and Silva 2010). As for the estimation of the risk level, all studies recurred to the use of a Risk Matrix,

Table 2 Summary of selected articles

Reference	Title	Journal	Short description	Sample/application
Velkovski et al. (2015)	Model of semi-quantitative risk assessment for safety at work in manufacturing industry	Mechanical Engineering—Scientific Journal	Occupational safety model for semi-quantitative analysis risk assessment in the manufacturing industry, based on real data for occupational injuries	Manufacturing industry
Carrillo-Castrillo et al. (2014)	Risk assessment of maintenance operations: the analysis of performing task and accident mechanism	International Journal of Injury Control and Safety Promotion	Method based on the concepts of task and accident mechanisms for an initial risk assessment, by taking into consideration the prevalence and severity of the maintenance accidents reported	Maintenance operations in the manufacturing sector of Andalusia
Jacinto and Silva (2010)	A semi-quantitative assessment of occupational risks using bow-tie representation	Safety Science	Semi-quantitative risk assessment that of risks related to occupational accidents in a shipbuilding yard environment, based on accidents databases	Ship Building Industry

Table 3 Summary of the methods applied for semi-quantitative assessment, by study

Table	Probability determination	Severity determination	Risk level estimation
Velkovski et al. (2015)	Probability of risk occurrence: Unlikely (almost impossible) → 0.00–0.10 Fairly Likely → 0.11–0.40 Likely → 0.41–0.80 Very Likely (in a certain time interval) → 0.81–1.00	Level of consequences that may occur: Very small or without → 0.00 –0.10 Small → 0.11–0.40 Medium → 0.41–0.80 High → 0.81–1.00	Risk Matrix with three decision levels
Carrillo-Castrillo et al. (2014)	Likelihood of being injured in an accident, determined with the frequency of past accidents: Highly unlikely → Relative frequency was less than 0.05; Unlikely → If it was higher than 0.05 and less than 0.10; Likely → If it was higher than 0.10 and less than 0.20; Very likely → If it was higher than 0.20	The expected severity of each accident mechanism was calculated based on mean (μ) and standard deviation (σ) of the proportions of severe accidents for all the accident mechanisms in each task were: Proportion of severe accidents for an accident mechanism $<\mu + \sigma$ → Slightly harmful Proportion was within the interval $\mu + \sigma$ to $\mu + 2\sigma$ → Moderately harmful Proportion $>\mu + 2\sigma$ or if there was any fatal accident → extremely harmful	Risk-matrix similar to that of BS 8800:2004—3 × 4 risk-matrix with five risk level classification
Jacinto and Silva (2010)	Likelihood of critical event determined with the frequency of past accidents: Very unlikely (0–1%) → 1 Unlikely (2–9%) → 2 Likely (10–20%) → 3 Very likely (>21%) → 4	Seriousness/ potential severity of harm, determined with the number of days lost: Slightly harmful → 1 Moderately harmful → 2 Very harmful → 3 Extremely harmful → 4 Fatal → 5	Risk-matrix similar to that of BS 8800:2004—4 × 5 risk-matrix with five risk level classification

being common to resort to the risk matrix proposed by the BS 8800 Standard: 2004 (Carrillo-Castrillo et al. 2014; Jacinto and Silva 2010).

The methods proposed presented limitations, as pointed by the authors. The method proposed by Jacinto and Silva 2010, presents some limitations, such as the fact that is based on aggregate statistics to define the variables "probability" and "potential severity", which does not allow for differentiating the risk level between tasks. In addition, the original bow-tie model is a probabilistic method with a complex applicability, so that only large organizations may be able to use the proposed tool.

Velkovski et al. 2015, proposes a method whose assessment accuracy depends directly on the validity of the data recorded in the reported documents. This dependence on the veracity of the information may represent a disadvantage due to the fact that the information is analyzed and reported by the employer and, in very rare cases, by the injured worker, hence the information presented may sometimes be unreliable.

The semiquantitative method proposed by Carrillo-Castrillo et al. 2014, and the adopted approach try to overcome the limitations of previous studies. It allows an in-depth view of safety issues, being useful to prioritize preventive activities for the accident mechanisms with higher risk levels. The semi-quantitative risk assessment as proposed allows estimating the probability and expected consequences of possible accident mechanisms in each task, providing information about the most frequent hazards in each task and that should be considered in the risk assessment (Carrillo-Castrillo et al. 2014). Thus, the method used is useful to assist Occupational Safety and Health (OSH) practitioners in the initial risk assessment, ensure that all possible hazards are considered, as well as the usefulness of accident reports according to the ESAW methodology, that provide relevant information for risk assessment at the task level (Carrillo-Castrillo et al. 2014).

The methods discussed in the present study, have all the potential to be applicable to different work activities in different sectors with industrial activity.

Considering the importance that the risk assessment process has in identifying the main scenarios and critical areas, providing essential information in OSH management, its main objective is to make informed choices and prioritize actions, to reduce risks to an acceptable level (Rodrigues et al. 2015; ISO 2009). In this way, it concerns a critical phase integral to the overall risk management process, important for organizations as it supports the decision-making process about the risk and the need to implement control measures (Rodrigues et al. 2016).

It is important to admit that there are limitations felt throughout this study, since there were found very few semi-quantitative methods and approaches to assess the risk of occupational accidents. In fact, qualitative methods are most frequent ones (Domínguez et al. 2019; Jusoh et al. 2016).

5 Conclusion

Three different semi-quantitative methods for estimating the risk level of occupational accidents were identified in this systematic literature review. The results of this study, considering the defined inclusion and exclusion criteria, demonstrated that there are few published studies that demonstrate the applicability if semi-quantitative methods in occupational settings to assess the risk of accidents.

Results denoted that probability and severity levels are determined considering accident records, where probability is frequently based on the frequency of accidents and severity on workdays lost. The estimation of the risk level is often based on a risk matrix, that included specific acceptance criteria.

As for the limitations of this literature review, the stringent inclusion and exclusion criteria defined can have left of this literature review other relevant studies, in particular the ones were new semi-quantitative methods and methodologies are proposed or even conference articles where some applications are exemplified.

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The Use of Biomonitoring in Occupational Health in Portugal: Evidence Available and Way Forward

Carla Martins and Susana Viegas

Abstract The occupational exposure to chemicals usually occurs in higher levels than for the general population, usually by inhalation and dermal absorption but inadvertent ingestion may also occur. Biomonitoring is a powerful tool to assess exposure at the individual level, thus providing additional and valuable information in comparison with air monitoring. The present review aimed to compile the biomonitoring studies performed in occupational settings in Portugal, to assess exposure to chemicals and discuss the further use of the results obtained. An extensive search was performed to identify scientific papers available in PubMed and Web of Science, reporting data of occupational studies performed in Portugal, which included biomonitoring as a tool to assess exposure to chemicals. From the twenty-five scientific papers available, it was possible to conclude that most of the biomonitoring studies developed in Portugal in the scope of occupational health aimed to characterize the exposure and to validate new biomarkers and matrices. The further use of biomonitoring data for regulatory risk assessment is scarce or absent. Therefore, several challenges are posed in this area of knowledge for the scientific community to increment the use of biomonitoring as a tool for exposure/risk assessment and risk management.

Keywords Biomonitoring · Occupational health · Portugal

1 Introduction

Chemicals are part of our daily lives, whether of natural origin or produced by human activities. Human exposure to chemicals may occur through the entire life cycle of

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chemicals in different scenarios: environment, use, consumption, and disposal of a product, or in an occupational context. This exposure may occur through different routes, including inhalation, ingestion, or dermal absorption (Prüss-Ustün et al. 2011). The occupational exposure usually occurs in higher levels than for the general population, being estimated that every year more than 1 billion workers are exposed to hazardous substances in their working environments (ILO 2021; Scheepers et al. 2021). The acknowledgment of this issue is fundamental for the development of risk assessment and management plans, where the exposure assessment plays a crucial role (Manno et al. 2010). The exposure assessment may comprehend environmental monitoring, biomonitoring or a combination of these methods understood as complementary (Prista and Sousa-Uva 2006).

Data obtained under biomonitoring (BM) studies reflect the internal concentrations of chemicals or their metabolites resulting from all routes of exposure, thus corresponding to the total body burden. These data also integrates the modifying influences in physiology, bioavailability, bioaccumulation and persistency (Ladeira and Viegas 2016; Louro et al. 2019). BM studies are possible through the detection and quantification of biomarkers in biological fluids (e.g., urine, blood, breast milk), that can be of three different types: biomarkers of exposure, biomarkers of effect and biomarkers of susceptibility (WHO 2015). The present review is dedicated to the biomarkers of exposure in the context of occupational exposure to chemicals. Biomarkers of exposure identify and quantify chemicals in tissue or body fluids, metabolites of xenobiotic compounds, or physiological outcomes that occur as a result of exposure (WHO 2015). The potential of BM in providing detailed data about workers' exposure to chemicals makes it as a useful tool to guarantee an adequate risk assessment and management (Viegas et al. 2020). Additionally, it may also support policy actions to prevent exposure of workers and indirectly of general population (Scheepers et al. 2021). The HBM4EU project (2017–2022) aimed to constitute an opportunity for the regulatory risk assessment (RA) community to improve and refine their high-impact assessments with high quality BM data (Louro et al. 2019). However, it was also recognized that some actions are still needed for a broader inclusion of BM data in regulatory risk assessment: (i) a guidance at EU level applicable to different regulatory schemes on the use of BM in RA; (ii) scientifically sound health-based biological limit/guidance values; (iii) development of approaches to integrate existing BM data, data using non-animal testing methods in combination with computational modelling to generate more reliable information on toxicokinetic and to provide linkages between adverse outcome pathways and human internal exposure levels (Louro et al. 2019). The challenges related with the inclusion of occupational BM data in RA in a regulatory context are also discussed and reinforced by Viegas et al. 2020.

The present review aimed to compile the BM studies performed in Portugal in the scope of occupational health, to assess exposure to chemicals. The combination with other methods to assess exposure to chemicals and its results, and the use as part of a RA process is also discussed herewith.

2 Materials and Methods

An extensive search was performed to identify scientific papers available in PubMed and Web of Science, reporting data of occupational studies performed in Portugal that included biomonitoring as a tool to assess exposure to chemicals, from 1995 until 2022 (last search 10 March 2022). The search was performed with the keywords: "occupational" AND "biomonitoring" AND "Portugal". The search returned 120 scientific articles for which abstract screening was performed, resulting in 95 articles excluded in two stages. If doubts arose regarding content, the screening was performed in the full article. In the first stage, articles were excluded due to not describing an occupational study (n = 48) and for being review papers (n = 27). In the second stage, articles were excluded if reporting exclusively exposure to other contaminants than chemicals (n = 11) and if data for biomarkers of exposure were not reported (n = 9).

3 Results and Discussion

From the bibliographic search performed, 25 scientific papers were selected and data regarding the occupational setting, the chemical substances studied, biological samples used, and other methods applied for collecting exposure data, were extracted, and presented in Table 1.

Several occupational settings were considered within these BM studies: mining, firefighting, industry, intensive animal production, food-related production, waste management and healthcare. Similarly, the studies considered under this review assessed the workers' exposure to several chemical substances (acrylonitrile, metals, n-hexane, styrene, polycyclic aromatic hydrocarbons (PAH), pesticides, mycotoxins, formaldehyde), where PAH, metals and mycotoxins were the most studied groups of substances.

The occupational setting of firefighting and the related exposure to PAHs was deeply analyzed and characterized. Studies available reported the exposure assessment performed through the determination of several metabolites, but also the influence of tobacco smoke (Oliveira et al. 2017a, b) and the impact on cardiovascular system was also determined (Oliveira et al. 2020).

Beyond the characterization of workers' exposure, several studies aimed to validate new biomarkers of exposure and/or effect, or the use of different biological matrices (e.g. hair, nails, blood, exhaled breath condensate) (Andrade et al. 2018; Borba et al. 1996; Costa et al. 2019; Teresa et al. 1997). Additionally, the validation of biomarkers was also attempted in some studies through the comparison with air monitoring levels, since both measurements provide adequate data to estimate toxicokinetic parameters (uptake, elimination, metabolism rates), contributing to fill gaps of knowledge (Lin 2005; Manno et al. 2010), and some conclusions were possible to be drawn for some chemical substances. Regarding n-hexane, Mayan et al. 2001

Table 1 Scientific papers using biomonitoring in Portugal

Reference	Occupational setting	Substances	Number of workers (n)	Biological sample	Contextual information collected (questionnaire)	Environmental monitoring
Borba et al. (1996)	Plant producing acrylic textile fibers	Acrylonitrile	47	Urine Blood	Yes	No
Teresa et al. (1997)	Welding	Fe, Ca, Mn, Zn, Cu, Pb	8	Blood Hair	Yes	Yes (air samples)
Mayan et al. (2001)	Shoe manufacturing	n-hexane	45	Urine	Yes	Yes (air samples)
Teixeira et al. (2010)	Production of various plastics, synthetic rubber and resins	Styrene	28	Urine Blood		No
García-Lestón et al. (2011)	Plants using inorganic lead	Lead	70	Blood	Yes	No
Viegas et al. (2012)	Intensive animal production	Aflatoxin B_1	31	Blood	Yes	Yes (air samples)
(Viegas et al. (2013a, b)	Intensive animal production	Aflatoxin B_1	28	Blood	Yes	Yes (air and surfaces samples, new and used floor coverage)
Viegas et al. (2013a, b)	Intensive animal production	Aflatoxin B_1	45	Blood	No	No
Costa et al. (2014)	Intensive animal production	Pesticides (pyrethroids, carbamates, organophosphates and other compounds)	36	Urine Blood	Yes	No

(continued)

Table 1 (continued)

Reference	Occupational setting	Substances	Number of workers (n)	Biological sample	Contextual information collected (questionnaire)	Environmental monitoring
Coelho et al. (2014)	Mining	As, Cd, Cu, Cr, Fe, Hg, Mg, Mn, Mo, Ni, Pb, S, Se, Si, Zn	41	Blood Urine Hair Nails	Yes	No
Viegas et al. (2014)	Waste management	Aflatoxin B_1	41	Blood	No	No
Viegas et al. (2016)	Intensive animal production	Aflatoxin B_1	30	Blood	No	No
Félix et al. (2015)	Battery recycling and manufacturing	Pb	92	EBC	Yes	No
Oliveira et al. (2016)	Firefighters	monohydroxyl metabolites of polycyclic aro-matic hydrocar-bons (OH-PAHs)	153	Urine	Yes	No
Oliveira et al. (2017a, b)	Firefighters	monohydroxyl metabolites of polycyclic aro-matic hydrocar-bons (OH-PAHs)	108	Urine	Yes	No

(continued)

Table 1 (continued)

Reference	Occupational setting	Substances	Number of workers (n)	Biological sample	Contextual information collected (questionnaire)	Environmental monitoring
Oliveira et al. (2017a, b)	Firefighters	monohydroxyl metabolites of polycyclic aromatic hydrocarbons (OH-PAHs)	NR	Urine	Yes	Yes (air samples)
Viegas et al. (2018a, b)	Bakers	Mycotoxins[a]	21	Urine	Yes	Yes (settled dust samples)
Viegas et al. (2018a, b)	Intensive animal production	Mycotoxins[b]	40	Blood	No	No
Viegas et al. (2018a, b)	Waste management	Mycotoxins[b]	40	Blood	No	No
Andrade et al. (2018)	Mining	Metals (As, Pb, Mn)	29	Urine	Yes	No
Serrazina et al. (2018)	Mining	Metals (As, Pb, Mn)	60	Urine Blood	No	No
Costa et al. (2019)	Anatomy-pathology laboratories workers	Formaldehyde	85	Urine Blood Buccal cells	Yes	Yes (air samples)
Viegas et al. (2019)	Intensive animal production	Mycotoxins[a]	25	Urine	Yes	Yes (air, litter and feed samples)
Oliveira et al. (2020)	Firefighters	monohydroxyl metabolites of polycyclic aro-matic hydrocar-bons (OH-PAHs)	171	Urine Blood	Yes	No

(continued)

Table 1 (continued)

Reference	Occupational setting	Substances	Number of workers (n)	Biological sample	Contextual information collected (questionnaire)	Environmental monitoring
Lopes de Andrade et al. (2021)	Mining	Metals (As, Pb, Mn)	46	Urine Blood	Yes	No

As Arsenic, *Ca* Calcium, *Cd* Cadmium, *Cu* Copper, *Cr* Chromium, *Fe* Iron, *Hg* Mercury, *Mg* Magnesium, *Mn* Manganese, *Mo* Molybdenum, *Ni* Niquel, *Pb* Lead, *S* Sulfur, *Se* Selenium, *Si* Silicon, *Zn* Zinc; *NR* Not reported; *EBC* Exhaled Breath Condensate

[a] aflatoxin B 1/2 /G 1/2 /M 1, patulin, nivalenol, deoxynivalenol, deoxynivalenol-3-glucoside, 15-acetyldeoxynivalenol, 3-acetyldeoxynivalenol, deepoxy-deoxynivalenol, deoxynivalenol-glucuronide, fusarenon-X, α-/β-zearalanol, α-/β-zearalenol, zearalenone, zearalenone, toxin T-2, toxin HT-2, toxin HT-2-4-glucuronide, T-2 tetraol, T-2 triol, neosolaniol, monoacetoxyscirpenol, diacetoxyscirpenol, fumonisin B1/2/3, roquefortine C, griseofulvin, ochratoxin A/B, ochratoxin alpha, mycophenolic acid, mevinolin, sterigmatocystin, citrinin, dihydrocitrinone, Enniatin B

[b] aflatoxin B 1/2 /G 1/2 /M 1, beauvericin, citrinin, enniatin A/A1/B/B1, fumonisin B1, zearalanone, α-/β-zearalenol, dihydrocitrinone, deoxynivalenol, 10-hydroxyochratoxin A, ochratoxin A, ochratoxin α, T-2 toxin, HT-2 toxin, zearalenone, alternuene, alternariol, alternariol monomethyl ether, 2'R-ochratoxin A, deoxynivalenol-3-glucuronic acid, HT-2-4-glucuronic acid

found a linear relation between air levels and the urinary biomarker 2,5-hexanedione, thus allowing to validate a biomarker of exposure. Félix et al. 2015 validated lead levels in exhaled breath condensed as a new biomarker of exposure to lead; on the contrary, the study performed by Borba et al. 1996 revealed that hair was not an adequate matrix to assess exposure in a context of mixture of metals. Regarding the determination of formic acid in urine as a possible biomarker of exposure to formaldehyde, it was reported by Costa et al. 2019 that workers presented significantly increased levels when compared to control group, however, these urinary formic acid levels did not correlate well with formaldehyde levels determined in air samples. The context of simultaneous occupational exposure to a mixture of chemicals was also considered in some studies, with the findings pointing out that a multiparameter analysis may improve exposure assessment accuracy (Borba et al. 1996; Lopes de Andrade et al. 2021; Serrazina et al. 2018; Teixeira et al. 2010; Viegas et al. 2019; Viegas et al. 2018a, b). Recently, under the project HBM4EU, multicentre studies were developed across Europe to characterize occupational exposure to several chemical substances (chromium, cadmium, lead, mercury, brominated flame retardants, polychlorobiphenyls, organophosphate flame retardants and phthalates) in industrial and e-waste management settings (Santonen et al. 2022; Scheepers et al. 2021; Viegas et al. 2022). Portugal was one of the participant countries and results regarding exposure to chromium in industrial settings are available in the literature (Viegas et al. 2022); however, data was presented aggregated at European level and due to this, it was not included as a result in the present chapter. These studies aimed to harmonize methodologies and standardize collection of the data useful for EU decision making. They also provided an integrative approach with the simultaneous collection of data from different sources (human biomonitoring, industrial hygiene samples (air and wipe samples), detailed questionnaires for collecting contextual information), as an attempt to overcome the difficulties in interpreting and using the data for RA as above mentioned. The importance of collecting comprehensive data from several sources was highlighted before by Viegas et al. 2020 as a contribute not only for exposure assessment but also for the identification of the most adequate risk management measures to implement in occupational settings. The association between risk management measures and exposure assessment to chromium during the major activities (welding, chromate plating and surface treatment, including painting and machining) made possible to identify the risk management measures contributing more to control the exposure using biomonitoring (urinary chromium), industrial hygiene data (air and hand wipe samples) and contextual data collected (Viegas et al. 2022). Following the project HBM4EU, the new European Partnership for Chemicals Risk Assessment (PARC) will also address the exposure to chemicals under occupational context in several working packages, aiming to answer to specific regulatory questions (ANSES 2020). Other international projects and networks such as the EPHOR (www.ephor-project.eu/) and OMEGA-NET (www.omeganetcohorts.eu/) are also key contributors for generating new scientific evidence and further expand the working life exposome knowledge base.

Regarding the further use of BM data for RA, García-Lestón et al. (2011) and Viegas et al. (2018a, b) compared obtained results with the health-based guidance values available. This comparison was performed for lead with the Biological Exposure Limit (70 μg/dL in blood, in place in 2011) and for deoxynivalenol with the Tolerable Daily Intake (1 μg/kg bw/day) after performing reverse dosimetry. In both studies, some workers were identified as exceeding the respective limits and therefore representing a potential health concern. In the study by Viegas et al. (2018a, b), the BM data allowed to conclude that the workplace represented an additional exposure to the one already occurring by food consumption. These results confirmed that the challenges, previously identified for the use of BM in RA and consequently in a regulatory context, are still valid but step by step are being surpassed due to several ongoing international activities and projects (Manno et al. 2010; Viegas et al. 2020).

4 Conclusions

Globally, and considering the gaps of knowledge in toxicokinetic of chemical substances that may hamper the use of biomarkers as an exposure assessment tool, most of the studies concluded for the recommendation of an integrative approach, where biomarkers of exposure are determined for exposed and non-exposed groups being this approach particularly relevant when exposure to the substance being studied can occur also outside the workplace environment (e.g. food consumption), in combination with the use of industrial hygiene samples (e.g. air samples, wipe samples, settled dust) to more easily identify the relevant exposure routes in each workplace. This approach may provide a broader view on the exposure scenarios and support the risk assessment (and risk management) and is being implemented under recent research projects. The use of BM as a tool to support regulatory RA is still under used and some identified gaps require further efforts of the scientific community, through the implementation of projects and collaborative networks during the following years.

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Potential of Saliva for Biomonitoring of Occupational Exposure: Collection of Evidence from the Literature

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Abstract *Introduction* workers are regularly exposed to several potential hazards including occupational pollutants that may affect their health. Occupational biomonitoring surveys predominantly use the collection of blood and/or urine. *Objectives* This work provides a compilation of available biomonitoring studies including the collection of saliva in occupationally exposed individuals. *Method* Literature research was performed in different online databases and, after applying the inclusion criteria, a total of 23 studies were selected. *Results* Available evidence demonstrates the use of saliva to assess recent exposure to metals and heavy metals (e.g., 3.03–129.0 μg/L of lead, 0.14–59.7 μg/L of cadmium, and 2.0–11.1 μg/L of mercury), volatile organic compounds (8.5–28.2 μg/L of styrene, 7.09 μg/L of toluene, 0.530–3.30 μg/L of phenanthrene, 0.437–1.48 μg/L of fluorene, 0.05–1.45 μg/L of acenaphthylene, 0.210–1.10 μg/L of fluoranthene, 0.230–0.860 μg/L of pyrene, 0.270–0.430 μg/L of naphthalene, and 0.199–0.329 μg/L of anthracene), and pesticides (0.047–4130 μg/L of atrazine, diazinon, and ethion) in workers. *Conclusion* Saliva has the potential to be used in occupational biomonitoring surveys. However, future health surveillance studies should include the collection of saliva to better characterize workers' recent exposure to occupational pollutants, explore its correlation with other biological fluids (e.g., serum, plasma, and urine), and improve occupational health risk assessment.

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1 Introduction

On a daily basis and depending on the work environment, workers can be subjected to several harmful hazards originating from various sources. Depending on the task performed, workers can be exposed to physical, ergonomic, and psychological/psychosocial risks, but also to chemical (e.g., particulate matter, volatile organic compounds, heavy metals, etc.) and biological (e.g., fungi, parasites, or viruses) hazards (WHO 2002). These occupational risks can have short- and long-term consequences on workers' health and will contribute to higher rates of morbidity and mortality. Regular occupational exposure to chemical hazards, e.g., particulate matter, heavy metals, and volatile organic pollutants including polycyclic aromatic hydrocarbons (PAHs) will promote the development/aggravation of cardiovascular and respiratory diseases and higher cancer incident rates (Kim et al. 2015; Oliveira et al. 2019; WHO 2006). Occupational exposure to biological active organisms has been associated with the development of allergies, infectious diseases, and cancer (EU-OSHA 2020). Human biomonitoring is a precious tool that allows programmed occupational surveillance, i.e., workers' exposure to pre-selected chemical risks, thus allowing the evaluation of the impact of preventive actions and procedures implemented in the occupational environment to improve workers' safety and health. Several biomonitoring surveys have been performed in workers from different occupational environments to assess their total internal levels of health-relevant pollutants through the direct quantification of pollutants or their main metabolites in biological fluids (Oliveira et al. 2020, 2021; Wang et al. 2015). Blood and urine are the most characterized and reliable matrices for human biomonitoring. However, over the last decade, other biological matrices (e.g., hair, skin, and saliva) have been considered in human biomonitoring studies (Liu et al. 2016; WHO 2015).

Saliva is an acidic oral secretion produced by the parotid, submandibular and sublingual salivary glands and is composed of 97–99% of water and some lipids, peptides, proteins, enzymes, electrolytes (e.g., sodium, potassium, calcium, and magnesium bicarbonates and phosphates), and immunoglobins with antibacterial activities (Almeida et al. 2008). This mucoserous exocrine secretion embodies several biological functions such as the taste, digestion, lubrication, buffering, maintenance of teeth integrity, clearance actions, antibacterial regulation, and protection (Humphrey and Williamson 2001). Saliva has been used to assess emotional, hormonal, neurologic, and immunologic status, nutritional, and metabolic conditions and to evaluate exposure to environmental and occupational hazardous pollutants (Humphrey and Williamson 2001; Milanowski et al. 2017; Michalke et al. 2015). This matrix has a good potential for being used in human biomonitoring studies because its collection is simple, non-invasive, inexpensive, and can be done by the worker without the help of a health professional; contrary to blood collection, the risks of infection, anemia, or thrombosis are inexistent (Milanowski et al. 2017).

Studies that report the use of saliva in human biomonitoring assays to evaluate occupational exposure date back to the 1970s and are getting more popular in the last decades (Michalke et al. 2015). Inorganic elements such as metals and heavy metals as well as pesticides, organic solvents, and PAHs are some of the compounds detected in these occupational exposure bioassays. This work aims to compile available data found in the literature related to the use of saliva in biomonitoring assays performed in different working environments.

2 Materials and Methods

Literature research was conducted in different online databases, namely ISI Web of Knowledge, Science Direct, PubMed, Google Scholar, Scopus, and Scielo. Information was searched by combining two or more of the following keywords: occupational exposure, occupational health, saliva, and biomonitoring. The following inclusion criteria were applied: (i) to be an original study published in indexed and peer-review scientific journals, (ii) to include the determination of organic and/or inorganic compounds in saliva, and (iii) to be performed in an occupational environment. All the studies published till December 2021 were abstract screened and after the elimination of duplicates and verification of inclusion criteria, a total of 23 studies were selected.

3 Results and Discussion

The selected literature reports the quantification of inorganic ($n = 14$) and organic ($n = 9$) compounds in the saliva of workers. Due to the limited information, studies including the development of methodologies to determine organic/inorganic compounds in saliva were also included. Information from all the selected studies is summarized in Table 1.

3.1 Inorganic Elements

Metals, metalloids, and heavy metals are amongst the most common and dangerous chemical hazards present in the workplace. Workers in the mining sector, foundries, metallic alloy, and chemical industries are some of the most exposed individuals to inorganic compounds, thus posing additional risks for their health. Some of these compounds are possible/probable carcinogenic to humans, can cause kidney and intestinal disfunctions and may lead to the development of brain disorders (e.g.,

Table 1 Available literature that used saliva as a human biomonitoring tool in occupational environments

Human biomonitoring with saliva in occupational environments			
Organic pollutants		Inorganic pollutants	
Nigg et al.	1993	El-Sadik and El-Dakhakhny	1970
Denovan et al.	2000	Gervais et al.	1981
Lu et al.	2006	Brodeur et al.	1983
Hines et al.	2006	Örtendahl et al.	1989
Semple et al.	2007	Zaichick et al.	1995
Ferrari et al.	2008	Menegário et al.	2001
Wang and Lu	2009	Koh et al.	2003
Bonanni et al.	2015	Wang et al.	2008
Santos et al.	2019	Chaari et al.	2009
–	–	Cowan et al.	2009
–	–	Gil et al.	2011
–	–	Thompson et al.	2012
–	–	Staff et al.	2014
–	–	Shawahna et al.	2021

Parkinson disease) (Huat et al. 2019; IARC 2021; WHO 2002). Available biomonitoring studies assessed the levels of lead (Pb), cadmium (Cd), manganese (Mn), mercury (Hg), copper (Cu), iron (Fe), cesium (Cs), chromium (Cr), nickel (Ni), and zinc (Zn) in the saliva of a wide variety of workers from different occupational environments (Table 2).

A total of seven studies determined the salivary lead content in workers from different industries, namely from a factory manufacturing lead based on polyvinyl chloride stabilizer (7.7 μg/L; Koh et al. 2003), aluminum, plastic, detergents and paint factories (7.9 μg/L; Shawahna et al. 2021), a Brazilian battery factory (18.8 μg/L; Menegário et al. 2001), Chinese welding factories (24.9 μg/L; Wang et al. 2008), and from a Palestinian automobile and cell phone repair store (32.7 μg/L; Shawahna et al. 2021) (Table 2). Moreover, Staff et al. (2014) performed a study with 105 British workers with history of being occupationally exposed to lead across a variety of different industries (not specified by the authors) and reported mean salivary lead values of 40.2 μg/L (43.5 μg/L in smokers and 36.9 μg/L in non-smokers). Three studies included the quantification of cadmium, a well-known carcinogenic heavy metal, in the saliva of workers (Gervais et al. 1981; Gil et al. 2011; Wang et al. 2008). Gervais et al. (1981) reported a mean concentration of 59.7 μg/L in the saliva of 35 workers (occupation not specified) exposed to cadmium dusts and fume. In a study performed with 49 Chinese welders, Wang et al. (2008) reported cadmium mean values of 0.36 μg/L, while Gil et al. (2011) reported levels ranging between 0.14 and 1.90 μg/L in 178 Spanish workers from a steel industry. The presence of inorganic mercury, in the saliva of occupationally exposed workers was described by three studies (Chaari et al. 2009; El-Sadik and El-Dakhakhny 1970; Ortendahl

Table 2 Concentrations (mean or range; μg/L, unless indicated otherwise) of metals and metalloids in the saliva of workers

Country	Occupation	Concentration	Reference
Lead			
Canada	Battery recycling industry	129	Brodeur et al. (1983)
Brazil	Battery factory	18.8	Menegário et al. (2001)
Singapore	Lead based PVC stabilizer factory	7.7	Koh et al. (2003)
China	Welding factory	24.9	Wang et al. 2008
Spain	Iron and steel industry	3.03	Gil et al. 2011
Great Britain	N/S	40.2	Staff et al. 2014
Palestine	Aluminum, plastic, detergent, and paint factory	7.9	Shawahna et al. (2021)
	Cell phone repair shop	32.7	
Cadmium			
Canada	N/S	59.7	Gervais et al. (1981)
China	Welding factory	0.36	Wang et al. (2008)
Spain	Steel industry	0.14–1.90	Gil et al. (2011)
Mercury			
Egypt	Sodium hydroxide production plant	4.1–6.0	El-Sadik and El-Dakhakhny (1970)
Sweden	Navy divers performing underwater electrical cutting	2.0–4.0	Örtendahl et al. (1989)
Tunisia	Dentists and assistants	11.1	Chaari et al. (2009)
Manganese			
China	Welding factory	44.5	Wang et al. (2008)
China	Ferroalloy factory	22.3–31.3	Cowan et al. (2009)
Spain	Steel industry	0.12–70.47	Gil et al. (2011)
Copper			
Sweden	Navy divers performing underwater electrical cutting	10.0–200.0	Örtendahl et al. (1989)
China	Welding factory	28.5	Wang et al. (2008)
Zinc			
China	Welding factory	191.0	Wang et al. (2008)
Iron			
China	Ferroalloy factory	139.0–141.0	Cowan et al. (2009)
Nickel			
Spain	Steel industry	0.12–188.50	Gil et al. (2011)
Chromium			
Spain	Steel industry	0.10–98.71	Gil et al. (2011)
Cesium			

(continued)

Table 2 (continued)

Country	Occupation	Concentration	Reference
Russia	Cleaning operations at the Chernobyl nuclear power plant	0.082[a]	Zaichick et al. (1995)

[a] Value presented in µg/g
N/S Not specified

et al. 1989). El-Sadik and El-Dakhakhny (1970) reported mean mercury values of 6.0, 4.1, and 5.7 µg/L in 52 workers from an Egyptian sodium hydroxide producing plant, respectively, with less than 6 months, between 6 months and 3 years, and with more than 3 years of exposure to mercury. Örtendahl et al. (1989) reported mercury concentrations ranging between 2.0 and 4.0 µg/L in 5 Swedish navy divers performing electrical cutting under water. Also, Chaari et al. (2009) found a total of 11.1 µg/L of mercury in the saliva of 52 Tunisian dentists and assistants. Regarding manganese, a total of three studies were found in the literature. Wang et al. (2008) reported a mean value of 4.45 µg/L in the saliva of Chinese welders. Other authors determined the salivary concentration of manganese in 95 high—(mean of 31.3 µg/L) and 122 low—(mean of 22.3 µg/L) exposed workers from a Chinese ferroalloy manufacturer (Cowan et al. 2009). More recently, Gil et al. (2011) detected manganese in the saliva of 178 workers from a Spanish steel industry with values varying between 0.12 to 70.47 µg/L. Despite the scarce information available, some authors found other metals and/or metalloids in the saliva of workers: 10.0–200.0 µg/L of copper in navy divers (Örtendahl et al. 1989) and 28.5 µg/L in Chinese welders (Wang et al. 2008); mean concentration of 191 µg/L of zinc in Chinese welders (Wang et al. 2008); 141 µg/L and 139 µg/L of iron, respectively for workers with high- and low-exposures in a Chinese ferroalloy manufacturer (Cowan et al. 2009); 0.12–188.50 µg/L (mean value of 7.8 µg/L) of nickel and 0.10–98.71 µg/L (mean value of 3.1 µg/L) of chromium in Spanish workers from a steel industry (Gil et al. 2011); 0.082 µg/g (dry weight) of cesium in workers involved in cleaning operations at the closed Chernobyl nuclear power-plant (Zaichick et al. 1995).

Available evidence points saliva as a biological fluid with potential to be included in future occupational biomonitoring assays to monitor workers´ recent exposure to health-relevant inorganic pollutants (Brodeur et al. 1983; Gervais et al. 1981; Gil et al. 2011; Staff et al. 2014; Wang et al. 2008; Zaichick et al. 1995). Saliva half-life time for some metals e.g., cadmium (50 months in mice saliva) and lead (5–7 days) are expected to be much lower than in blood (up to16 years for cadmium and 19–28 days for lead), which makes saliva a more reliable fluid to evaluate recent exposures at working environments (Brodeur et al. 1983; Järup et al. 1983; Matsubara-Khan 1974; Rabinowitz et al. 1976). Some authors highlighted that higher water content in saliva (<99.4%) contributes for increased levels of heavy metals and metalloids up to 10 times more concentrated in dry saliva than in the blood (Zaichick et al. 1995). Additionally, saliva is a useful fluid to determine metal toxicity due to its aqueous stability for metal analysis (Wang et al. 2008). However, the presence of some dental diseases (e.g., ulcers and/or oral candidiasis) can be a limiting factor, since these diseases may alter the metal contents in saliva (Wang et al. 2008).

3.2 Organic Compounds

In the literature, there are nine biomonitoring studies evaluating the presence of volatile and semi volatile organic compounds (VOCs; $n = 5$), and pesticides ($n = 4$) in the saliva of workers (Table 3).

Exposure to VOCs is frequent in different working environments, including in food, pharmaceutical, paint, glue, and textile industries, as well as in agriculture and firefighting activities, among many others (Barros et al. 2021; Lamplugh et al. 2019). VOCs are compounds with low boiling points that tend to evaporate easily at room temperature and to be absorbed by the human body, mainly via eyes and respiratory tract. These pollutants are known because of their toxicity and potential/known carcinogenic properties, being associated with eyes and skin irritation, allergies, skin disorders, and with the development/aggravation of respiratory diseases (WHO 2002). So far, only five study evaluated the occupational exposure to VOCs through the collection of saliva (Table 3). In 2008, Ferrari et al. measured the salivary concentration of toluene in 36 Italian workers from a synthetic leather manufacturer and reported mean post-shift levels of 7.09 μg/L. An identical study was performed by Wang and Lu (2009) with 34 Chinese workers from synthetic leather manufacturers and salivary concentrations of different organic solvents were determined: N-methyl formamide (3840 μg/L), dimethyl formamide (1400 μg/L), 2-propanol (1310 μg/L), acetone (540 μg/L), and methyl ethyl ketone (330 μg/L). Bonanni et al. (2015) assessed the concentrations of styrene in the saliva of 58 workers from a fiberglass reinforced plastic manufacturer, with concentrations ranging between 8.5 and 28.2 μg/L (mean of 19.1 μg/L). More recently, Santos et al. (2019) described the development of a fast, effective and sensitive methodology based on a new liquid–liquid extraction with-programmed temperature vaporizer gas chromatography with mass spectrometry that was used to measure seven PAHs (naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene and pyrene) in the saliva of firefighters in different moments of exposure to fires: immediately after, 6 h, and 12 h after firefighting; unexposed volunteers were included as a control group. All the seven PAHs were detected in the saliva samples collected immediately after the fire event, being phenanthrene (0.530–3.30 μg/L) and fluorene (0.437–1.48 μg/L) the most predominant compounds, followed by acenaphthylene (0.05–1.45 μg/L), fluoranthene (0.210–1.10 μg/L), pyrene (0.230–0.860 μg/L), naphthalene (0.270–0.430 μg/L), and anthracene (0.199–0.329 μg/L) (Santos et al. 2019). Fluorene and phenanthrene were the only compounds detected in the saliva of subjects from the control group, with values varying between 0.160–0.230 μg/L and 0.202–0.750 μg/L, respectively. The salivary concentrations of the samples obtained 12 h after the fire events were comparable to the levels found in the control group (Santos et al. 2019).

Table 3 Concentrations (mean or range; μg/L) of organic compounds in the saliva of workers

Country	Occupation	Concentration	Reference
Toluene			
Italy	Synthetic leather factory	7.09	Ferrari et al. (2008)
N-methyl formamide			
China	Synthetic leather factory	3840	Wang and Lu (2009)
Dimethyl formamide			
China	Synthetic leather factory	1400	Wang and Lu (2009)
2-propanol			
China	Synthetic leather factory	1310	Wang and Lu (2009)
Acetone			
China	Synthetic leather factory	540	Wang and Lu (2009)
Methyl ethyl ketone			
China	Synthetic leather factory	330	Wang and Lu (2009)
Styrene			
Italy	Fiberglass reinforced plastic factory	8.5–28.2	Bonnani et al. (2015)
PAHs[a]			
Spain	Firefighters	0.05–3.30	Santos et al. (2019)
Cotinine			
Scotland	Non-smoker bar workers	0.3–3.4	Semple et al. (2007)
	Smoker bar workers	218.2–234.1	
Atrazine			
USA	Pesticide applicators	0.57–150	Denovan et al. (2000) Hines et al. (2006)
Diazinone			
USA	Pesticide applicators	0.047–0.061	Lu et al. (2006)
Ethion			
Nicaragua	Pesticide preparators	907.0	Nigg et al. (1993)
	Pesticide applicators	4130	

[a] Naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, and pyrene

Additionally, to the above-mentioned studies, Semple et al. (2007) conducted a study with 371 bar workers to measure the effects of the implementation of smoke-free legislations in Scottish bars. The authors measured the levels of cotinine in the saliva of bar workers, since it is one of the compounds found in tobacco but mainly because it is the main metabolite of nicotine (stimulant and anxiolytic found naturally in tobacco) and a biomarker of exposure to tobacco smoke. The mean reported values were 3.4 versus 0.3 μg/L for non-smokers and 234.1 versus 218.2 μg/L for smokers, respectively before and after the implementation of the legislation (Semple et al. 2007).

Pesticides can be divided in three categories: insecticides, herbicides, and fungicides. These compounds are widely used in agriculture to increase productivity by controlling and eliminating pests (Hines et al. 2006; Lu et al. 2006; Nigg et al. 1993). Atrazine, a common herbicide, was the pesticide determined in a field study with post-event salivary values ranging between 0.57 and 150 μg/L in 15 male pesticides' applicators from the USA (Denovan et al. 2000; Hines et al. 2006). Those authors suggested saliva as a very sensitive, easy, and convenient matrix for the monitorization of recent exposure to atrazine. Also, diazinon (mean of 0.047 and 0.061 μg/L after 12 and 30 h post pesticide application) and ethion (mean of 907.0 μg/L in the worker that prepared the pesticide for application and 4130 μg/L for the pesticide' applicant), both well-known commercial insecticides, were found in the saliva of North American and Nicaraguan workers (Lu et al. 2006; Nigg et al. 1993).

In summa, available information suggests saliva as an adequate and reliable fluid to assess recent occupational exposure to health-relevant inorganic and organic pollutants which will contribute to a better characterization of a subjects' total exposure at the working environment. This biological fluid can complement data obtained from conventional human biomonitoring surveys performed with urine and blood analysis. However, the main disadvantages of saliva as a biological fluid are related to its complex and dynamic (bio)chemical composition, water affinity, and the inter- and intra-individual variability. Therefore, more studies are urgently needed to better characterize workers' exposure through ingestion via saliva.

4 Conclusions

Information concerning the use of saliva as a complementary biological matrix in addition to urine and blood has been slowly emerging over the last decades. Despite limited, available studies demonstrated recent occupational exposure to metals and metalloids (Pb, Cd, Mn, Hg, Cu, Fe, Cs, Cr, Ni, and Zn), several VOCs (including PAHs), pesticides (atrazine, diazinon, and ethion), and tobacco smoke. Nevertheless, there are no occupational exposure limits defined for the presence of those pollutants in saliva. Biomonitoring through saliva not only demonstrates occupational exposure to health-relevant pollutants but also represents the fraction of xenobiotics that is available to be assimilated on the buccal cavity and to be distributed and/or bioaccumulated in the tissues of the human body. However, biomonitoring studies performed with saliva need to account for its dynamic (bio)chemical composition, the inter- and intra-individual variability, and the existence of dental and/or buccal diseases which may interfere with the levels of some xenobiotics. Therefore, future biomonitoring studies should include workers' biomonitorization through the collection of saliva and evaluate its potential for occupational safety and health surveillance.

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Economic Impact of Work-Related Musculoskeletal Disorders—A Systematic Review

Ana Sophia Rosado, João Santos Baptista, Melina N. Haik Guilherme, and Joana C. Guedes

Abstract Overwork can predispose workers to develop illnesses. This study is a systematic review to describe the costs generated by musculoskeletal disorders. The search was performed in 4 electronic databases, applying the PRISMA Statement approach. Were retrieved records between 2015 and 2021 using 11 keywords combined by a Boolean operator. Articles with applied research on costs produced by work-related musculoskeletal disorders (WMSD) in different countries and activities were considered. Questionnaires proved to be reliable methods to evaluate the expenses. The risk of bias was assessed concerning the evaluated sample and limited surveys. The selection of the articles allowed to realise that the highest cost is due to lost production, compared to sickness absence and medical assistance. WMSD is detrimental to both workers' health and the business economy. Strategies to decrease muscle disorders could minimise the risk of illnesses, consequently decreasing costs originated by WMSD. The review article raises awareness of the costs produced due to WMSD around the world.

Keywords Absenteeism · Presenteeism · Medical care · Work ability · WMSD

1 Introduction

A multiplicity of factors contribute to the global burden of workers' diseases. Manipulative and cyclical tasks are factors that can impair muscles and joints. Awkward

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postures are also able to be damaging to the body structure. It can overload the muscular system, raising the risk of work-related musculoskeletal disorders (WMSD) (Hembecker et al. 2017) (Algarni et al. 2020a, b), which is a significant problem (Phongamwong and Deema 2015).

There are some occupations in which the risk of work-related musculoskeletal disorders (WMSD) has increased due to the nature of the job (Dong et al. 2019). High workload and occupational stress are known contributors to physical disorders (Atroszko et al. 2020), which may negatively affect work ability (Bayattork et al. 2019). Sickness absence is also a harmful consequence of WMSDs.

WMSD represents a high global disease burden (Atroszko et al. 2020). It results in a high impact on companies' economies, mainly due to medical and pharmaceutical expenses, presenteeism, and absenteeism (Nagata et al. 2018).

The economic burden of WMSD indicates 11% of the costs related to absenteeism per person per year, 64% due to presenteeism, and 25% related to medical/pharmaceutical expenses (NAGATA 2018) WMSD. The high expenditure due to the incidence of WMSD at work is undoubtedly harmful to the company's economy. Although the numbers can vary according to the country, activity, and environmental conditions, it is unquestionable the high monetary health expenses with the musculoskeletal condition.

Interventions at the individual and organisational levels, such as education and social support, are effective in improving the health and work ability of workers (Ammendolia et al. 2016); (Crawford et al. 2020).

Therefore, this systematic review aims to highlight the mainly causes of money expenditure resulting from the musculoskeletal disorder at work in order to better clarify where organisations can spend efforts to save money and improve workers' health.

2 Material and Methods

Studies involving working-age workers in any activity and country were considered for this systematic review.

This systematic review was performed according to the PRISMA Statement (2021). The bibliographic search was carried out between 2015 and 2021. The databases sources were Scopus, Web of Science, Science Direct, and Pubmed, valuable databases in multidisciplinary and engineering fields.

The search was performed using pertinent terms made up of groups of keywords. The set of keywords defined as "work ability", "work capacity", "work productivity", "musculoskeletal disorder", "reduce productivity", "fatigue", "overwork", "cost", "health", "absenteeism", "presenteeism". The keywords were combined and separated by the Boolean operator "AND" and "OR".

The selection of the articles was based on two phases of exclusion. Filters from databases were used, limiting the surveys by date (2015–2021), document type (review articles), source type (journals), and language (papers written only in

English). Some keywords were too broad, which resulted in a very large number of outcomes. As a consequence, the search has been restricted again, giving the area of interest according to the filters from the databases: Scopus: was limited by "Engineering" area, Science Direct: was restricted by "Engineering" area; Web of Science: was restricted by "Engineering", "Engineering Industrial", "Ergonomics" areas; Pubmed: was restricted by "Humans".

The articles not excluded by filters were analysed by reading the title and then by the abstract. If the abstract fulfills the goal of this review, the entire article was read by the authors to be considered.

Articles using unclear measurement methods, musculoskeletal disorders not related to work, an economic burden not related to WMSD, evaluation of sports activities, and evaluation of nutrition benefits for athletes were not considered. There were accepted articles that assessed the economic burden of WMSD in different activities and countries. The focus was to assess and compare the costs of presenteeism, absenteeism, and medical/pharmaceutical due to WMSD worldwide. Measurement methods, mainly questionnaires, were accepted and proved to be reliable.

To determine the quality of the primary studies, they were assessed for risk of bias. The characteristics (sample, activity performed, country, evaluation of the costs, methodological issues) of the scrutinised articles were assessed according to the aims of this review. The ethical committee and informed consent should be satisfied; limitations and difficulties were also recognised. The authors fulfilled a customised table in MSExcel with the information, which was evaluated to achieve the potential risk of bias in the results.

The MSExcel table involved questions such as country of the research, ethical standards, research subject, objective, study population, period of the analysis, analysis, and evaluation of economic expenses due to WMSD, limitations, detected biases, conclusions, and observations.

All items were noted, and each analysed question was filled in cells of the MSExcel file. Studies should answer more than 50% of the asked questions to be included in this article and satisfy at least one of the following conditions: (a) specify the causes of economic burden due to WMSD; (b) evaluate the monetary expenses of WMSD; (c) identify relevant studies and literature concerning WMSD.

3 Results

The search yielded 5449 records after removing duplicate articles. Applying the exclusion criteria: 2 945 papers were excluded by "date"; 429 were rejected by "document type" (only articles were accepted), one article was excluded by "source type"; 39 texts were refused due to "language" (only English accepted); 951 were refused by "other reasons", which reflect the area: engineering, engineering industrial, ergonomics and humans. After the exclusion of the articles, according to the explained criteria, the titles and abstracts of the remaining ones were read. Were excluded 4365 articles because were not consistent with the goal of this systematic review.

In the eligibility phase, 30 papers were considered. Eight additional records were identified through other sources (citation searching, google scholar) since they are important to enrich this review. It resulted in 38 studies (Fig. 1) and Tables 1 and 2 provide the characteristics of the primary studies.

The articles include several acronyms, especially related to the methods used to measure the research question. The abbreviations used in this study are: DISC—Demand-Induced Strain Compensation; DMQ—Dutch Musculoskeletal Questionnaire; DWECS—Danish Work Environment Cohort Study; JCQ—Job Content Questionnaire; NMQ—Nordic Musculoskeletal Questionnaire; WMSD—Work Related Musculoskeletal Disorders; WAI—Work Ability Index; WPAI-GH—Work Productivity and Activity Impairment-General Health'.

Concerning the evaluated surveys, the main observations regarding the economic burden are listed in Table 2.

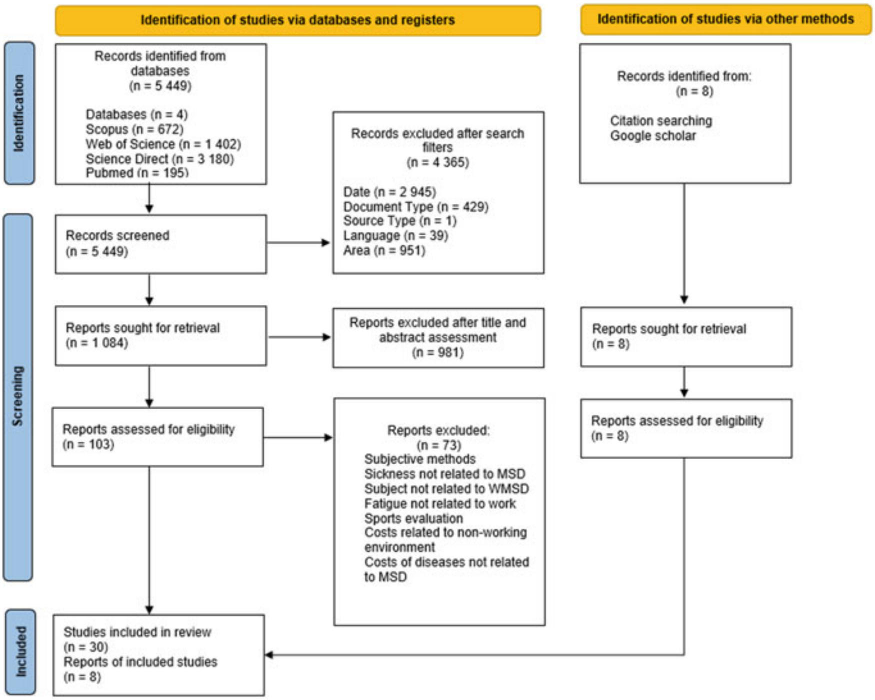

Fig. 1 Flow diagram of research, adopted from (Prisma Statement, 2020)

Table 1 Main observations from the articles related to the prevalence of WMSD and work ability

	Study population	Observations
Prevalence Of WMSD	Workers at the truck assembly plant	Measurements provide data of the body postures that can be helpful in the WMSD prevention program (Zare et al. 2020)
	Physical Therapist	Up to 90% of workers have WMSD during their careers, mainly females (Vieira et al. 2016)
	nurses	86.24% of workers reported musculoskeletal discomfort, with a higher prevalence in the back (Silva et al. 2018)
	3884 workers	Factors related to health, work, and lifestyle is associated with work ability (Pensolaet al. 2016)
	604 young workers	Multimorbidity prevalence is higher in females (63%). Absenteeism and presenteeism are associated with a health condition (Troelstra et al. 2020)
	193 supermarket cashiers	The majority of the participants (90%) had WMSD symptoms in at least one body region (Algarni et al. 2020a, b)
	254 grocery workers	Approximately 78% reported WMDS symptoms in at least one body region (Anton and Weeks 2016)
	226 manufacturing-sector workers	Lack of sleep and pauses are related to WMSD (Hembecker et al. 2017)
	13,657 healthcare professionals	WMSDs are associated with workload, psychological factors, and ergonomic factors (Dong et al. 2019)
	193 supermarket cashiers	90% of the participants have WMSD symptoms in at least one body region (Algarni et al. 2020a, b)

(continued)

Table 1 (continued)

	Study population	Observations
Health Maintenance and Work Ability	–	Effective interventions are beneficial for promoting work ability by increasing physical activity or decreasing the sedentary time of workers (Lusa et al. 2020)
	254 health care providers	Multi-site musculoskeletal pain is associated with poor work ability (Phongamwong and Deema 2015)
	10,427 workers	Increasing pain intensity in multiple body sites is associated with lower work ability (Bayattork et al. 2019)
	Workers—different occupations	The prevalence of musculoskeletal pain is 57% among white-collar and 53% among blue-collar workers, which increases the chance of low work ability (Vieira and Sato 2020)
	5377 workers	High demands at work are damaging to work ability (Skovlund et al. 2020)
	397 employees and 497 students	Maintaining healthy stability between resources and demands at work is vital for a viable environment (Jonge et al. 2019)
	264 health worker	Perceive strengths are necessary for evaluating and planning supportive supervision (Baral et al. 2018)
	–	Supervisor training and support are beneficial to work ability and reduce presenteeism (Ammendolia et al. 2016)
	–	Intervention at the individual and organisational level is essential to health (Crawford et al. 2020)

(continued)

Table 1 (continued)

	Study population	Observations
	–	Interventions increase productivity and reduce the economic burden of absenteeism (Santos and Mendes 2020)

4 Discussion

4.1 *Musculoskeletal Disorder*

WMSD has become a significant health problem worldwide (Phongamwong and Deema 2015). Regardless of the task, each individual responds differently to the time exposed to the risk. It is believed that the operators adopt distinct postures (Zare et al. 2020) while making the same task according to their anthropometry and particular conditions.

The positions can be hazardous, resulting in muscle pain or disorder. Likewise, demanding tasks without proper rest can affect negatively physical condition, raise musculoskeletal pain, and decrease work ability (Phongamwong and Deema 2015).

Eventually, muscle disorder can origin pain (Bayattork et al. 2019). It was verified that the prevalence of musculoskeletal pain is nearly 57% among white-collar and 53% among blue-collar workers, which increases the chance of low work ability (Vieira and Sato 2020). Approximately 80–90% of workers showed symptoms of WMSDs in at least one body part (Anton and Weeks 2016) (Algarni et al. 2020a, b).

Several parts of the body can be affected by musculoskeletal disorder. Among workers, the body regions that have increased the risk of pain and WMSD are the back and neck (Algarni et al. 2020a, b) (Vieira and Sato 2020). To better substantiate the high prevalence of WMSD, in 2008, the European Musculoskeletal Conditions Surveillance and Information Network (eumusc.net 2014) exposed the high incidence of low back pain (LBP) as great health and socioeconomic problem in several countries (Austria, Latvia, Hungary, Czech Republic, Spain, Estonia, Cyprus and Malta). Dong et al. (2019) evaluated the incidence of LBP in many countries around the world. Figure 2 illustrates the conclusions of these two investigations related to the prevalence of LBP.

Although the incidence of LBP among countries is discrepant, the consequences can be damaging to the workers' health and the economy of companies.

The cost per year due to WMSD among European countries is nearly 2% of the Gross Domestic Product (GDP) (Crawford et al. 2020). It is a significant amount that could be minimised with supportive supervisors and ergonomic interventions, that successfully improve work environments (Santos and Mendes 2020). Healthy workers, not disturbed by pain or WMSD, have a better quality of life (Algarni et al. 2020a, b), which is reflected in positive outcomes and efficiency at work and in private

Table 2 Most important comments on the economic burden generated by *WMSD* at work

	Study population	Measurement methods	Observations
Economic Burden Due to WMSD	Nurses	Likert scale	Levels of absenteeism are high in Iceland (74%) and Australia (73%) (Burmeister et al. 2019)
	–	–	An obsessive–compulsive personality disorder produces the highest direct and indirect medical costs (Atroszko et al. 2020)
	–	–	Presenteeism is related to the absence of interventions at work, absenteeism, and productivity loss (Lohaus and Habermann 2019)
	–	–	Presenteeism costs are higher than absenteeism costs and consist of 52% (19%–85%) (Kigozi et al. 2017)
	758 managers from different sectors	Job characteristics questionnaire	The total cost of presenteeism is higher than absenteeism (Strömberg et al. 2017)
	Employees	WPAI-GH	Productivity losses (absenteeism and presenteeism) due to work stress are costly (Brunner et al. 2019)
	10,427 general workers	DEWCS	Poor work ability combined with chronic diseases is associated with sickness absence (Sundstrup et al. 2017)
	249 economic evaluations	–	Pharmaceutical costs are unnoticed in economic evaluations, implying significant societal costs (Krol et al. 2016)

(continued)

Table 2 (continued)

	Study population	Measurement methods	Observations
	–	Self-administered questionnaire	Economic burden due to absenteeism per person per year (11%), presenteeism (64%), and medical/pharmaceutical expenses (25%) (Nagata et al. 2018)
	534 pharmacists	WPAI-GH questionnaire	The prevalence of sickness presenteeism (91%) and sickness absenteeism (45%) (Farah et al. 2020)
	2511 employees	Questionnaires	The higher cost is due to medical treatments associated with occupational stress, followed by presenteeism and absenteeism (Siu et al. 2020)
	–	Intervention mapping methodology	Presenteeism's economic costs are higher than absenteeism and employer health costs (Ammendolia et al. 2016)

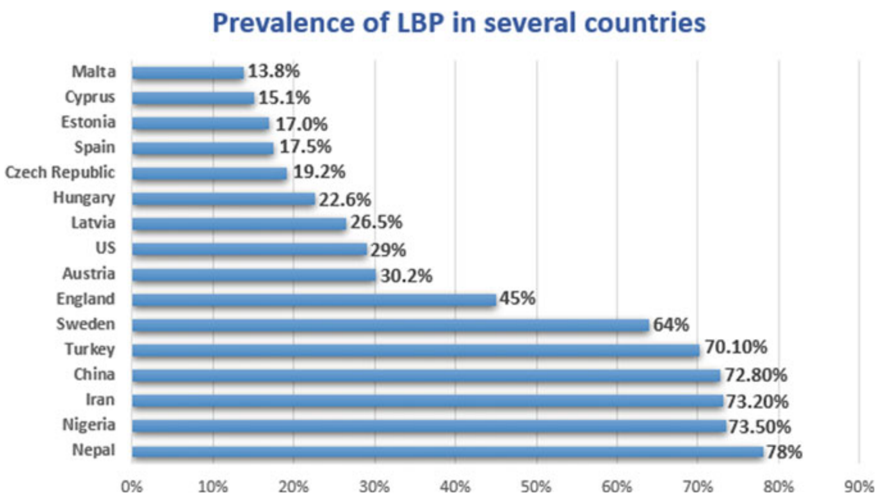

Fig. 2 Percentage of LBP in several countries eumusc.net (2014)

life. Consequently, reducing the economic burden of presenteeism (Ammendolia et al. 2016) and absenteeism (Santos and Mendes 2020).

4.2 Work Ability

Work ability is the balance between physical demand and physical capacity (Skovlund et al. 2020). Thus, it can be affected by musculoskeletal disorders and pain (Bayattork et al. 2019); (Vieira and Sato 2020).

Concerning pain, a relationship was observed between the number of pain sites (Phongamwong and Deema 2015) and pain intensity with lower work ability (Bayattork et al. 2019) for both younger and older workers as well as those with sedentary and physical work (Bayattork et al. 2019). Phongamwong and Deema (2015) also stated that multi-site pain is prone to origin chronic pain, which decreases work ability. In addition to pain, musculoskeletal disorders also have been associated with impaired work ability (Pensola et al. 2016); (Silva et al. 2018).

Multiple occupational and lifestyle factors may influence work ability. There is evidence that performance declines approximately 4% with each additional age year, and the decline was greater in women with multi-site pain (Pensola et al. 2016).

It is a great challenge for workers and employers to guarantee a healthy lifestyle. Physical activity can be adopted to assure well-being and enhance work ability (Lusa et al. 2020).

Musculoskeletal pain and disorder can decrease workers' health and work ability. Consequently, it may also increase economic costs for companies.

4.3 Economic Burden Arising from Absenteeism, Presenteeism, and Medical Care

Demanding work activities are prone to increase physical disorders, which is a great cause of the global burden of disease (Atroszko et al. 2020). According to the Health Organization, a hostile working environment also may lead to physical and mental health problems, creating high economic costs (Baral et al. 2018).

Depending on the activity and environment, workers can be exposed to several factors that can be detrimental to health, increase the incidence of WMSD, and result in extra costs. The expenditures of musculoskeletal pain and disorders result mainly due to medical and pharmaceutical treatments, presenteeism, and absenteeism (Nagata et al. 2018).

WMSD implies a high proportion of working days lost (EU-OSHA—European Agency for Safety and Health 2019). It is the leading cause of sick leave in Europe and impacts over 40 million workers. Also, it leads to 20–33% inability worldwide and implies over 40% of work-related budgets (Moussavi et al. 2019); (Santos and Mendes 2020); (Crawford et al. 2020).

Compared to absenteeism, evaluating the expenditure of presenteeism is more complex because it can be a hidden cost, that reduces effectiveness and productivity (Ammendolia et al. 2016).

Regarding medical and pharmaceutical expenses, multimorbidity is also associated with reduced physical condition, with increased use of healthcare services (Troelstra et al. 2020). There is a shortage of studies regarding the costs of medical assistance. However, there are sufficient surveys to aware of the high impact.

The harmful consequences of illnesses at work usually reflect a high economic burden. Figure 3 demonstrates the expenses related to presenteeism, absenteeism, and medical/pharmaceutical assistance due to WMSD and pain among workers in several countries. It is important to highlight that the costs were evaluated in different countries, with discrepant realities.

It is observed that, regarding WMSD and pain among workers, presenteeism is more costly than absenteeism when comparing both (Van der Burg et al. 2020) (Lohaus and Habermann 2019), which are more pricey than medical care and pharmacy expenses (Nagata et al. 2018).

When compared with absenteeism cost, the higher amount of presenteeism can be noticed, especially by analysing the following countries: China, Lebanon, Norwegian, Swiss, and the USA.

A report made by the Institute for Employment Studies (2016) across Europe, concerning the average days of presenteeism over the last 12 months, assumed that women are generally more affected by presenteeism than men, representing 60.4% (Dantas and Cardoso 2020). Contemplating both genders, presenteeism was higher in Montenegro, Slovenia, Malta, Denmark, and Sweden: above 50% of the working

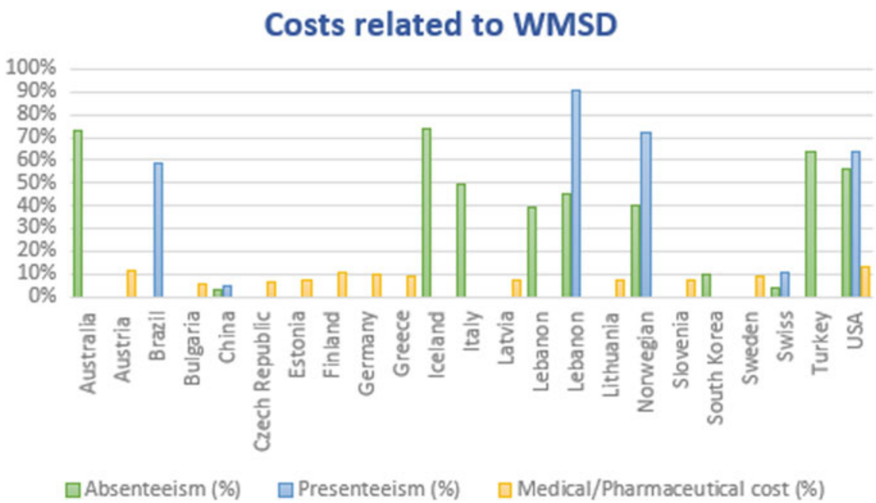

Fig. 3 The economic burden related to absenteeism, presenteeism, and health care

days. The lowest position was in Italy, Portugal, Poland, and Bulgaria: 23–25%, resulting in an elevated economic burden (Garrow 2016).

Due to the high cost of presenteeism, have been studied the reason why employees decide to work while sick instead of staying home to restore health. The high discount rates reflect the primary justification for sickness absence (Lohaus and Habermann 2019). Another important issue to continue working on is the struggle to replace equal productivity (Strömberg et al. 2017).

Although sickness absence is often perceived as economically damaging, newer reports highlight the positive aspect because it prevents further consequences and can strengthen mental and physical health (Farah et al. 2020).

Concerning pharmaceutical and medical costs due to WMSD, the evaluation has been constantly mistreated, although it is understood that the expenses are elevated. Eurostat has published "Health expenditure on inpatient care by diseases as a percentage of allocated inpatient care in 2013" around 10%, which is costly (Eurostat 2016). The topic should be more assessed, as WMSD has a high share of inpatient spending.

Due to the high costs, there has been a growing interest in building sustainable organisations to create a healthy working environment (Jonge et al. 2019).

5 Limitations

This investigation assessed a limited number of professionals. Consequently, this study was not exhaustive, making it difficult to generalise the results to real conditions of the entire population. Future studies should focus on identifying defined categories of professionals with pain and musculoskeletal disorders around the world.

6 Conclusions

Musculoskeletal disorders represent the most significant global percentage related to occupational diseases. It is damaging to the worker since it can affect daily activities and work efficiency. For the employer, the consequences are monetary, mainly due to presenteeism, absenteeism, medical and pharmaceutical care.

Presenteeism, although its hidden expenditures, has shown to be particularly costly. Current studies suggest absenteeism as the best option when ill, as it allows workers to improve their health and heal illnesses before returning to work.

A healthy work environment and organised strategies according to the demands of companies are important to safeguard workers' health and reduce the economic burden, which impairs businesses.

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Flood Risk Assessment and Emergency Planning—A Short Review

Rita Alves, Jaqueline Castelo Branco, and João Santos Baptista

Abstract Fluvial floods are one of the most dangerous natural hazards, affecting billions of people worldwide and causing significant social and economic damage. Flood risk assessment is crucial for understanding the level of risk of a given place, and emergency strategies are important to minimise the consequences of a fluvial flood. This work aims to identify the main flood risk assessment methods to understand which mitigation measures are applied in an urban context and which emergency measures are used to protect the affected population. This work was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analysis Statement guidelines. A total of ten combinations of keywords were used to search in two databases. Risk scenarios and risk indexes are the key risk assessment methods identified. Evacuation is the principal procedure adopted in emergency planning, and the main mitigation procedures are engineering and natural appliances with the transition to flood resilience in recent years.

Keywords Flood risk · Risk analysis · Flood mitigation · Emergency

1 Introduction

Globally, floods are among the most destructive natural hazards (Xia et al. 2019; Tariq et al. 2020). Over the past decades, floods have affected billions of people (Tariq et al. 2020; Zhuo and Han 2020; Schröter et al. 2021) and have caused considerable

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economic damage (de Ruiter et al. 2017; Ivčević et al. 2019; Xia et al. 2019; Tariq et al. 2020; Schröter et al. 2021).

Major floods affect extensive areas of several thousand square kilometres, spanning multiple river basins with direct national and regional impacts (He et al. 2020; Schröter et al. 2021). Fluvial flooding caused by heavy or prolonged rainfall is a common threat to people's lives and property in almost every part of the world, and it can result in many fatalities (Xia et al. 2019; Wang et al. 2020).

Recent studies suggest that climate change may lead to more extreme weather events and substantially increase flood risk (Ivčević et al. 2019; Xia et al. 2019; He et al. 2020). Therefore, it is vitally important to develop effective strategies to manage fluvial flood risk and improve resilience (Xia et al. 2019; Zhuo and Han 2020).

Between 1995 and 2015, flooding accounted for 43% of all natural hazards, with 2.3 billion people affected and 157,000 deaths worldwide. Economically the damage caused by floods was 662 billion US$ globally and 262 billion US$ in Europe (CRED and UNISDR 2015). In Europe, between 1970 and 2019, 38% of the natural hazards were flooding, and 44% of the economic losses were due to floods (WMO 2020).

A fluvial flood risk system comprises a chain of meteorological, hydrological, open channel flow, flooding, and damage processes. Flood risk arises from these processes, usually triggered by rainfall that forms run-off in the affected catchments depending on weather, topography, land cover and soil conditions. Run-off from the catchments concentrates in streams and propagates within the river network. Discharges above the total basin capacity induce flooding and affect exposed elements (Mudashiru et al. 2021; Schröter et al. 2021).

Effective flood risk management is a vast and global challenge. Policymakers worldwide are aware of the current significant risks to lives, infrastructure, and communities (Tariq et al. 2020; Webber et al. 2021). However, despite the established understanding of future threats, new evidence indicates that the scope and scale of these challenges have been systematically underestimated, and these threats are likely to pose a more significant challenge than previously anticipated (Ivčević et al. 2019; Zhuo and Han 2020; Webber et al. 2021). Adding to this ever-increasing threat are the economic pressures faced by decision-makers and a growing trend of population migration to cities (Webber et al. 2021), population growth, urbanisation within flood-prone areas and impermeabilisation of the soil (Zhuo and Han 2020).

Studies involving risk assessments of fluvial flooding are essential to increase risk perception and develop measures capable of minimising the consequences of a flood. Emergency measures play a key role in minimising the impacts caused by fluvial floods. This paper aims to:

- To know the main flood risk assessment methods used in recent years,
- To understand which main mitigation measures can be applied in an urban context,
- To identify which emergency measures are used to protect the affected population.

2 Methodology

This short review was conducted following the guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) Statement (Page et al. 2021). The search was conducted in two databases: Scopus and Web of Science. In Scopus, the search was conducted in a combination of "Title + Abstract + Keywords", and in Web of Science, the search was conducted in "All Fields". The keywords used were "flood risk" in combination with "civil protection", "municipal emergency planning" separated by the Boolean operator "AND"; "flood risk management" in combination with "urban susceptibility", "emergency planning", "fluvial flood" and "urban vulnerability" separated by the Boolean operator "AND" and the combination of the following keywords: "flood risk assessment" and "fluvial flood", "flood risk", "risk management" and "emergency planning", "risk management" and "river flood", "urban flood resilience" and "risk management". In all searches, it was used as criterion "risk assessment", "risk evaluation", and "risk management", separated by the Boolean operator OR. The set of exclusion criteria applied were: (1) date—only papers after 2017 were considered; (2) type of document—only research articles were selected; (3) source type—only journals were considered; (4) language—only articles in English were considered. After applying the exclusion criteria, the papers were screened by title and abstract and the ones on-topic were considered. The eligibility criterion was established as "risk assessment". After this, the papers were screened again by title and abstract and the full text of those remaining after the screening was analysed.

3 Results

After the databases search, 2061 results were retrieved from which 1417 were removed after applying the search filters. After the first screening, 438 papers were excluded as off-topic, resulting in 206. The duplicates were removed, resulting in a total of 140 screened using the eligibility criterion, resulting in 34 papers for full-text analysis. After the full-text analysis, four were excluded, given they were off-topic, resulting in 30 selected papers. Figure 1 summarises this process.

The 30 papers analysed were divided by their geographic distribution. The country with more papers is Italy (Arosio et al. 2021; Arrighi et al. 2018; Cuca 2020; Dottori et al. 2018; Minucci et al. 2020; Tiepolo et al. 2021), followed by the United Kingdom (Hammond et al. 2018; Speight et al. 2017; Webber et al. 2021; Yin et al. 2021), Brazil (Miguez et al. 2019; Rezende et al. 2020; Veról et al. 2019), China (Liu et al. 2020; Wang et al. 2020), Germany (Bhola et al. 2020; Schröter et al. 2021), Greece (Diakakis et al. 2020; Papaioannou et al. 2018), and Portugal (Figueiredo et al. 2020; Santos et al. 2018), Japan (Kinoshita et al. 2018), Poland (Borowska-Stefańska et al. 2019), and Serbia (Gigović et al. 2017). Some authors participated in more than one

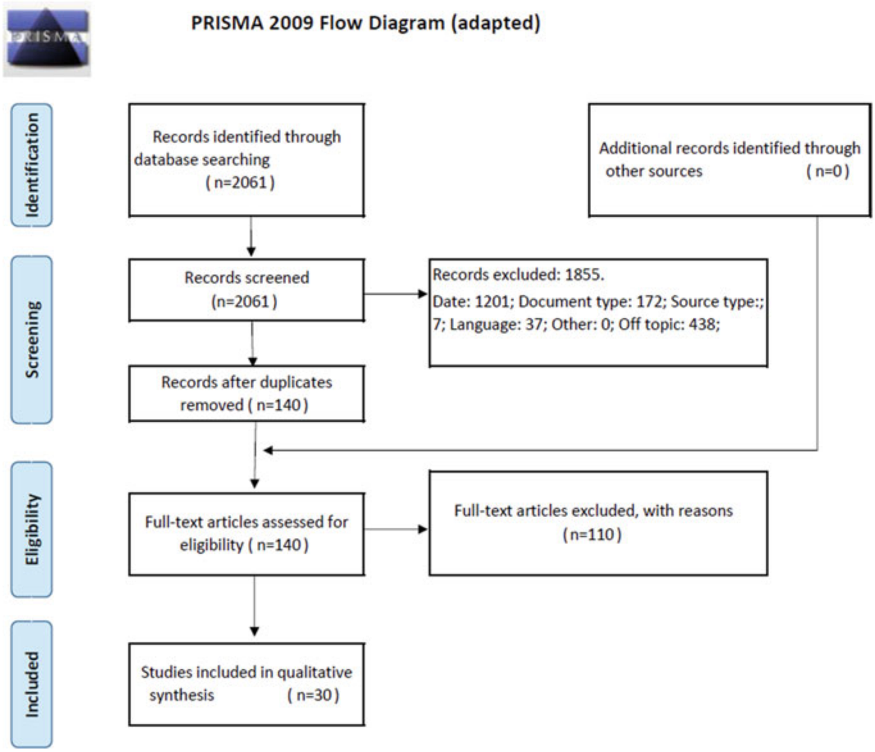

Fig. 1 Diagram flow (Moher et al. 2009)

article, which may mean a more continuous work on the subject (Arrighi et al. 2018; Dottori et al. 2018; Miguez et al. 2019; Veról et al. 2019; Arosio et al. 2021).

Next, a division by study area was made. This analysis is relevant since there are many articles within this topic, but with different approaches depending on the field in which they were developed. Thus, the central area of study of the analysed articles corresponds to Flood Risk Management (Bhola et al. 2020; Dottori et al. 2018; Miguez et al. 2019; Minucci et al. 2020; Omar et al. 2020; Speight et al. 2017; Tiepolo et al. 2021; Wang et al. 2020; Webber et al. 2021; Zevenbergen et al. 2020), followed by Environment (Arrighi et al. 2018; Borowska-Stefańska et al. 2019; Ignjacevic et al. 2020; Kinoshita et al. 2018; Rezende et al. 2020; Xu et al. 2017; Yin et al. 2021), Hydrology (Arosio et al. 2021; Liu et al. 2020; Papaioannou et al. 2018; Rehan 2018; Sadegh et al. 2018), Engineering (Hammond et al. 2018), Architecture (Veról et al. 2019), Emergency Management (Cuca 2020), Geology (Diakakis et al. 2020), Geography (Santos et al. 2018), Geosciences (Schröter et al. 2021), Risk Management (Figueiredo et al. 2020) and Water Management (Gigović et al. 2017).

Most of the analysed articles used rivers or hydrographic basins as case studies (Arosio et al. 2021; Bhola et al. 2020; Cuca 2020; Gigović et al. 2017; Liu et al. 2020;

Miguez et al. 2019; Rehan 2018; Rezende et al. 2020; Sadegh et al. 2018; Santos et al. 2018; Speight et al. 2017; Tiepolo et al. 2021; Veról et al. 2019; Xu et al. 2017). The surrounding environment in which these rivers or hydrographic basins are located has been analysed. The majority are in an urban setting (Arosio et al. 2021; Arrighi et al. 2018; Bhola et al. 2020; Borowska-Stefańska et al. 2019; Cuca 2020; Gigović et al. 2017; Hammond et al. 2018; Liu et al. 2020; Minucci et al. 2020; Rehan 2018; Rezende et al. 2020; Sadegh et al. 2018; Webber et al. 2021), and the rest of them are in what was classified as a "mixed" environment (Dottori et al. 2018; Figueiredo et al. 2020; Miguez et al. 2019; Papaioannou et al. 2018; Santos et al. 2018; Schröter et al. 2021; Speight et al. 2017; Tiepolo et al. 2021; Veról et al. 2019; Wang et al. 2020; Xu et al. 2017; Zevenbergen et al. 2020) given that a large portion of the river or hydrographic basin being studied crosses different types of environments (either urban, suburban and/or rural). There were papers in which there was no information regarding the surrounding because the authors mainly focused on a theoretical risk approach (Kinoshita et al. 2018; Ignjacevic et al. 2020; Yin et al. 2021) or emergency action measures (Diakakis et al. 2020; Omar et al. 2020).

4 Discussion

4.1 Risk Assessment

The articles that have no information on risk assessment refer to studies that focus mainly on emergency measures and where no risk quantification is made (Borowska-Stefańska et al. 2019; Diakakis et al. 2020; Omar et al. 2020; Wang et al. 2020). Some approaches to resilience measures (Zevenbergen et al. 2020), and flood risk, were done without quantifying the risk or just using a specific technique (Gigović et al. 2017; Veról et al. 2019; Cuca 2020; Minucci et al. 2020).

The techniques used more often are flood indexes and scenarios (or a combination of the two), which will be the focus of this review. Apart from these methods, statistical models—Rehan (2018) used the probability of extreme discharge for risk evaluation—or risk frameworks—where a flood risk approach is developed—(Speight et al. 2017; Hammond et al. 2018; Ignjacevic et al. 2020) are also used.

Regarding flood indexes, some authors validate indexes used by others (Xu et al. 2017; Santos et al. 2018; Miguez et al. 2019), and others are testing their indexes (Dottori et al. 2018; Figueiredo et al. 2020; Rezende et al. 2020). Risk indexes are a technique used to quantify the risk of flooding at a given location, considering several parameters. The used indexes have different associated parameters, sometimes adapted to suit the case study (Xu et al. 2017; Santos et al. 2018; Figueiredo et al. 2020). The various parameters used by the authors can be seen in Table 1.

Flood risk scenarios are events with given characteristics used to evaluate how a flood could impact the location in the study. Usually, different return periods are considered, and authors use this technique in different ways depending on the focus

Table 1 Risk indexes

Author and year	Risk analysis technique	Index	Parameters of the index	Comments
Xu et al. (2017)	Indexes	Flood Regulation Index and Flood Hazard Index (adapted)	FEPI (Flood Exceedance Probability), FDI (Flood Duration Index), FMI (Flood Magnitude Index), FFI (Flood Frequency Index)	Modified from Cheng et al. (2013); Logsdon and Chaubey (2013)
Santos et al. (2018)	Indexes	FSI (Flood Severity Index)	Classification of the severity of floods (1—minor flood; 2—moderate flood; 3—serious flood; 4—severe flood; 5—catastrophic flood)	Modified from Schroeder et al. (2016)
Dottori et al. (2018)	Indexes	I_W (Flood Intensity Index)	Water surface slope, flow velocity, water depth; iteration process for single or complex flood sources	By the authors (Dottori 2012)
Miguez et al. (2019)	Indexes	FRI (Flood Risk Index) (adapted)	Flood properties (depth, duration factor); consequences (dwelling density, income per capita, inadequate sanitation)	Modified from (Zonensein et al. 2008)
Figueiredo et al. (2020)	Indexes; scenarios	HFR (Heritage Flood Risk)	Hazard scenarios, the annual probability of occurrence of the hazard scenario, value index of the cultural heritage asset, HFI (water depth and flood impact)	By the authors

(continued)

Table 1 (continued)

Author and year	Risk analysis technique	Index	Parameters of the index	Comments
Rezende et al. (2020)	Indexes; scenarios	Ri-SoRCI (Risk to Socioeconomic Recovery Capacity Index)	I_{RV} (Relative Value Indicator), I_S (building susceptibility indicator); I_{SV} (Social Vulnerability Indicator), I_{VP} (an indicator of vulnerable people), I_{VF} (velocity factor)	By the authors

of their work. Some use the scenarios directly as a method to quantify the level of risk of a flood in a specific location (Arrighi et al. 2018; Sadegh et al. 2018; Arosio et al. 2021; Tiepolo et al. 2021). Other authors use scenarios to evaluate the disruption caused by floods (such as disruption in services or the closing of roads) (Arrighi et al. 2018; Liu et al. 2020; Arosio et al. 2021). Some authors use different climate change scenarios to evaluate how the risk of flood can vary in the future (Xu et al. 2017; Ignjacevic et al. 2020; Webber et al. 2021; Yin et al. 2021). Sometimes they use scenarios to complement flood modelling (Kinoshita et al. 2018; Papaioannou et al. 2018; Bhola et al. 2020; Ignjacevic et al. 2020; Liu et al. 2020). Table 2 shows a summary of the studies that use this technique.

Figueiredo et al. (2020) and Rezende et al. (2020) used a combination of scenarios and indexes. E.g., Figueiredo et al. (2020) consider that each scenario represents a flood event probability. This is then used in calculating the risk index (Table 1).

Flood risk maps are the most used technique to represent a risk, being used by almost all the authors of the analysed articles. Risk maps are not only a tool that allows for communicating the risk efficiently, but it is also something that has become required with the European Flood Directive 2007/60/CE (Minucci et al. 2020). For their elaboration, the most used tools are Geographic Information Systems (GIS) (Xu et al. 2017; Gigović et al. 2017; Glenis et al. 2018; Santos et al. 2018; Figueiredo et al. 2020) and remote sensing (Cuca 2020; Arosio et al. 2021). Other forms of representation are graphs (Speight et al. 2017; Dottori et al. 2018; Rehan 2018; Sadegh et al. 2018) resulting from statistical or mathematical models.

Regarding consequences, these can be divided into four categories: direct (caused by direct water contact with humans, property, or other objects), indirect (induced by the effects of direct damage and can occur both in space and time—outside the flood event, e.g., interruption of traffic, transport and public services—and tangible (can be valued in monetary terms) and intangible (cannot be valued in financial terms) (Hammond et al. 2018; Santos et al. 2018). Depending on the type of consequence being analysed, the outcome of the risk analysis can vary depending on each study.

Table 2 Risk scenarios

Authors	Scenarios	Return period (years)	Brief explanation	Comments
Papaioannou et al. (2018)	Low, average, high (correspond to the average hydrological scenarios); 2 extreme scenarios (providing lower and upper uncertainty bounds)	50, 100, 1000	For each return period, the average, minimum and maximum extension of the flood is calculated; they also calculate scenarios considering the hydrological conditions (input rainfall, soil moisture conditions, and roughness coefficients of return periods), which gives a total of 9 scenarios	The scenarios originate 3 flood risk maps for each scenario; the authors studied 3 rivers that incorporate the city understudy
Kinoshita et al. (2018)	Vulnerability scenarios were developed according to 3 socioeconomic scenarios	No information	The authors estimated future potential flood consequences by combining future flood inundations simulations, socioeconomic shared pathways (SSP), and vulnerability scenarios associated with SSPs. The authors obtained 105 scenarios for a potential flood damage assessment	Authors estimated future potential flood impact on a global scale according to a dynamic inundation model and modelled flood vulnerability scenarios; they also considered the effect of climate change (rise of 1.5 and 2 °C)

(continued)

Table 2 (continued)

Authors	Scenarios	Return period (years)	Brief explanation	Comments
Sadegh et al. (2018)	General framework for multihazard design and risk assessment scenarios and their corresponding likelihoods	25, 50, 100, 200	The authors introduce a novel copula-based weighted average threshold scenario for an expected event with multiple drivers	Work applicable to various events (ocean and fluvial flooding, drought, and heatwaves)
Arrighi et al. (2018)	Reference scenarios	30, 100	Baseline scenarios were used to assess the safety of pedestrians, traffic, and emergency provision in the event of a flood	Risk map showing the risk for residents and pedestrians' vulnerability
Bhola et al. (2020)	Exceedance probability scenarios (high, average, low)	No information	The authors have designed three scenarios with differentiated exceedance probabilities, each referring to the subjective classification of buildings with varying flood impact	The work purpose is to differentiate impacts of flooding depending on the building use, enabling, therefore, more flexibility for stakeholders' variable risk perception profile
Liu et al. (2020)	Each scenario considers the maximum inundation depth	2, 5, 10, 20	The scenarios considered were meant to explore the most effective flood control strategy for small and medium-scale rivers in highly urbanised areas	–

(continued)

Table 2 (continued)

Authors	Scenarios	Return period (years)	Brief explanation	Comments
Yin et al. (2021)	Baseline scenarios are compared with 6 scenarios considering climate change; scenarios considering climate change and socioeconomic development	No information	Scenarios consider different increases in temperature and socioeconomic developments	The scenarios were considered in 6 countries
Arosio et al. (2021)	Probabilistic scenarios	10, 100, 200	For each considered scenario, the impacts (accessibility of roads and the connection between providers and users of services in a city) were calculated	The scenarios aim to assess the service accessibility risk of a city
Tiepolo et al. (2021)	Frequent, moderate, rare	10, 30, 100	For each scenario, two baselines were considered: with and without risk reduction, resulting in 12 scenarios	A cost–benefit analysis of the implemented measures was also conducted
Webber et al. (2021)	Comparison of 2 scenarios with different return periods	Baseline scenario: 20, 100, 200; Future scenario 20, 200, 1000	Comparison of a baseline scenario (present circumstances) and a future scenario considering climate change	The use of scenarios is to evaluate the flood reduction benefits of property flood resilience

Some of the consequences identified by the authors are the impacts of a flood on different types of buildings (Rehan 2018; Bhola et al. 2020; Webber et al. 2021), damage to material cultural heritage (Papaioannou et al. 2018; Cuca 2020; Figueiredo et al. 2020), damage to roads or transport (Arrighi et al. 2018; Hammond et al. 2018), damage to vehicles (Arrighi et al. 2018), damage to human health or life

(Hammond et al. 2018; Kinoshita et al. 2018; Papaioannou et al. 2018; Zevenbergen et al. 2020), economic damage (Kinoshita et al. 2018; Rezende et al. 2020; Ignjacevic et al. 2020; Zevenbergen et al. 2020), and environmental damage (Papaioannou et al. 2018; Zevenbergen et al. 2020).

4.2 Emergency

The main prevention measure adopted is the preventive evacuation of the population exposed to the flood (Arrighi et al. 2019; Borowska-Stefańska et al. 2019; Wang et al. 2020). Another measure presented by Santos et al. (2018) and Omar et al. (2020) is early warning systems or the surveillance of specific meteorological conditions since floods are associated with specific meteorological phenomena, as mentioned before. Borowska-Stefańska et al. (2019) suggest that flood damage prevention can be achieved by abolishing the construction of residential housing and industrial facilities in flood-threatened areas. Furthermore, the vulnerability and cost assessment of different measures might allow the implementation of strategies capable of decreasing impacts on residential buildings (Rehan 2018). Good knowledge of flood impacts is also considered necessary to outline flood prevention strategies (Arrighi et al. 2019; Borowska-Stefańska et al. 2019).

During the flood event, the main measures focus on materialising the previously defined emergency measures and emergency evacuations (Arrighi et al. 2018; Borowska-Stefańska et al. 2019; Wang et al. 2020).

After the flood event, Borowska-Stefańska et al. (2019) state that normal functioning should be re-established, and there should be rapid mitigation of the effects caused by floods, both socially and economically.

4.3 Flood Mitigation Measures in an Urban Context

As for mitigation measures, the main ones identified are engineering measures (such as dam construction) (Borowska-Stefańska et al. 2019; Cuca 2020; Liu et al. 2020; Zevenbergen et al. 2020). Recently, was referred the transition to natural mitigation measures (such as having green spaces near waterways to facilitate water drainage) and avoiding the construction of buildings near rivers or areas that may be vulnerable to flooding (Borowska-Stefańska et al. 2019; Miguez et al. 2019; Zevenbergen et al. 2020). It is also advocated to develop vulnerability assessments to understand which measures best suit the site under study (Kinoshita et al. 2018; Rehan 2018). Hammond et al. (2018) compiled the main existing measures (pp. 432–433, Hammond et al. 2018).

As an alternative strategy, some authors refer to river restoration, an approach to control floods and restore the quality of the river environment. The concept of river restoration refers to a wide variety of ecological, physical, spatial, and management measures and practices to restore the natural state and functioning of the river system in support of biodiversity, recreation, flood management, and landscape development. The key factor for river restoration in an urban context is to find the balance point between the coexistence of the city and the river in a better state of ecological quality, leading to a compromise solution between the natural landscape and the built environment. However, this strategy does not always prove economically feasible (Miguez et al. 2019; Veról et al. 2019).

As a more recent approach, flood resilience is emerging. This perspective aims to go beyond the ability to 'withstand' when exposed to high water levels that were predicted at design towards the ability to "recover" from a flood event (and/or reduce the impacts that arise when flows that exceed the design standard occur) and to "adapt" or "transform" the existing approach based on the recognition that conditions have been or will change in the future. To this end, the concept of resilience in flood risk management has contributed to the notion that societies must learn to live with floods and must mitigate the disastrous consequences rather than seek to avoid them altogether. It follows from the above that a resilient flood risk management strategy should encompass the implementation of flood risk reduction measures through a combination of protection, prevention, and preparedness covering a wide range of flood probabilities to reduce flood risk and associated consequences (Zevenbergen et al. 2020).

5 Conclusion

The most utilised risk assessment methods used risk scenarios with different return periods and risk indices using different parameters. Other mentioned methods are statistical models and risk frameworks. Some studies use risk assessment methods as part of flood modelling. Regarding emergency measures, evacuation is the most recommended practice. A planned evacuation is essential for good execution in a flood event. As for mitigation of the impacts of a flood in an urban context, the main actions are engineering and natural measures. In recent years there has been a transition to flood resilience.

As a limitation of this study, a search for flood mitigation measures was not explicitly conducted. The mitigation measures were identified from the full-text analysis of the selected articles.

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Human-Car Interface: A Systematic Literature Review

Felipe Gabriele and Laura Martins

Abstract A systematic literature review, or SLR, seeks to structure the review carried out in the defined areas in a replicable and auditable method, in order to facilitate and objectify both the search for answers to research questions and their accessibility by peers. In this study, we present an SLR carried out in November 2021 by the PRISMA method, on interaction and interface design focused on the automotive User Experience, having these three research questions: (RQ1) What are the objects of study of the articles? (RQ2) Which methods are used to analyze the object of study? (RQ3) What are the samples size of the surveys carried out? At the end of the Screening, 20 articles were selected to answer the research questions, and some data deserve attention, such as the 60% that didn't identify the use of UX assessment questionnaires or the 35% that had incomplete demographic data. We also saw that the objects of study are concentrated in 3 major areas and that the methodology used is, for the most part, similar in structure. The lack of studies carried out in South America prompted us to develop a research project focused on the Brazilian User.

Keywords User experience · UX · SLR · Interaction design · Human–Computer interaction

1 Introduction

User Experience, commonly known as UX, is generally the responsible factor for establishing the quality of a product or service (Díaz-Oreiro et al. 2021) and, although it can be described in different ways, here we will define it according to ISO (ISO 9241-210:2019, 2019) that is: the perceptions and responses of a user resulting from the use of a product, system or service. When analyzing the UX, we usually jointly analyze the interaction, the exchange of information between the user and the system,

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which in the case of this study is the automobile. Automotive interaction design is an area that is gaining increasing importance in academy as vehicles in general are increasingly computerized and intelligent. If in the last two decades there has been rapid development in the smartphone sector, there will probably be this same growth in the next two, but in the automotive sector (Wang 2021).

Software-based systems play an increasingly important role and enable most of the innovations in modern cars (Broy 2006; Burkacky et al. 2018). With the increasing impact of digital solutions, in-car UX is highly dependent on the user's experience with those digital systems since, apart from the driving task, they are the main interaction method. The main goal of today's digital product development process is to create a good UX such that the product satisfies the user's expectations (Ebel et al. 2021). Thinking about the "car" system as a whole brings a few more degrees of difficulty to a UX evaluation when taking into account that there are different levels of use, user and experience involved, each one with its complexities and interdependent systems.

The purpose of this article is to present the Systematic Literature Review (SLR) carried out in November of 2021, as described and structured below.

2 Methodology

The purpose of this SLR is to analyze the state of the art of interaction and interface design in the automotive sector, specifically in applied research focusing on the user experience in automobiles. For that, the PRISMA method (Liberati et al. 2009) was used as a basis, which can be seen in its synthesis in Fig. 1. The objective of the following paragraphs is to document this SLR in a way that makes it replicable and auditable. For this reason, we present below the structure used in the review.

2.1 Structure

This review had the following methodological structure:

- In the **Primary Search**, the articles databases to be analysed were defined. After an initial analysis of the available databases and those that could have more data on the area of interest, it was decided to use *Scopus* and the *Web of Science*. Both were accessed through the Federated Academic Community (CAFe), a community of the CAPES Periodicals Portal (CAPES 2021).
- In the **Screening**, an analysis was carried out by title and abstract, seeking to remove from the review articles that didn't discuss the themes. At this stage, the abstracts of each article were read, where labels were assigned to catalog the discussed topics. Two other exclusion criteria were defined in the Screening: duplicate articles and those that didn't discuss the User Experience in automobiles.

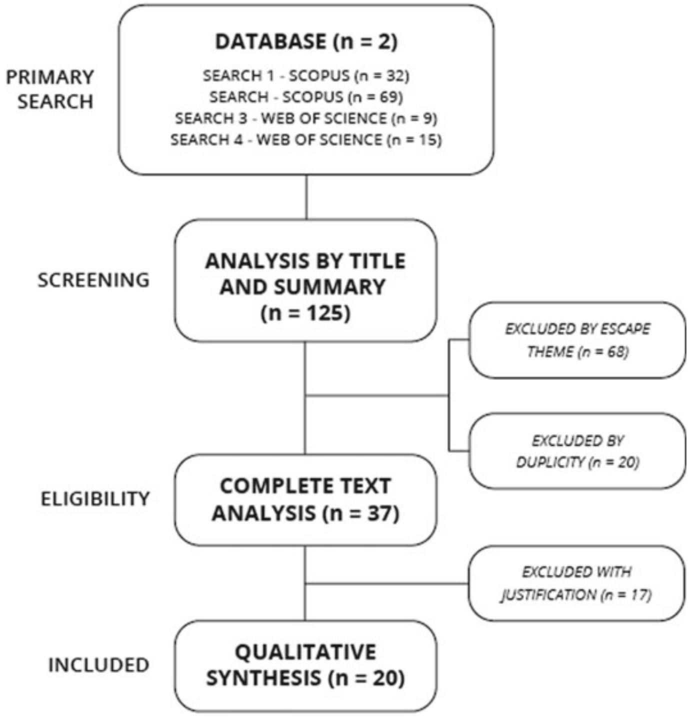

Fig. 1 Synthesis of the SLR flow, based on the PRISMA model (Liberati et al. 2009). *Source* From the authors

- In **Eligibility**, the approved articles are analysed, and those that don't answer the research questions are excluded from the review at this stage, leaving the remaining articles for the Qualitative Synthesis. Articles that didn't respond concomitantly to the three proposed research questions (RQ1, RQ2 and RQ3) were discarded as exclusion criteria, since the questions were formulated to complement each other and not to work separately.
- In **Qualitative Synthesis** the data of the eligible articles were analysed and processed in tables, answering the research questions.

2.2 Research Questions

To achieve the defined objective, the following research questions were stipulated: **(RQ1)** What are the objects of study of the articles? **(RQ2)** Which methods are used to analyze the object of study? **(RQ3)** What are the samples size of the surveys carried out?

RQ1 intends to understand what researchers specifically study. The areas of interaction and interface design, even when the user experience filter is applied, still have a wide spectrum of study focuses for analysis. The purpose of this question is to have a qualitative survey of the most studied objects in these areas. RQ2 is a complement to the first question, and it provides important data for scientific research: what was the study process? Here the proposal is to analyze possible paths for future research. RQ3 proposes to bring a simplified demographic survey of the sample of users used by the study, more specifically: the number of users in the sample, gender and average age. These data are also important for future studies.

3 Results

3.1 Primary Search

A total of four different searches were carried out, two in each database, on November 10, 2021, using the terms Search 1, 2, 3 and 4 as registration codes, respectively, as shown in Table 1.

The following terms were used as search descriptors: ("User Experience" AND "Car") in Search 1 and 3; and ("User Experience" AND "Vehicle") in Search 2 and 4. It should be noted that the search yielded a much higher number of results when performed using the following descriptor: ("User Experience" AND "Car" OR "Vehicle"), when compared to the 4 searches carried out as explained above, including results that were outside the theme, and that is why the decision was made to carry out the searches separately, even if this increased the time of data collection. It should be noted that the authors chose not to use the term "UX" as a descriptor because they considered that the search would be repetitive with the descriptor "User Experience". Authors may even use the term widely known, but usually spell it out in full in their articles.

Articles with up to 10 years of publication (2011–2021), in English or Portuguese and which are open access were defined as inclusion criteria in the Primary Search. Thematic filters from the databases were also used, namely: Ergonomics, Computer Science, Social Science, Decision Science, Psychology, Arts and Humanities, Neuroscience and Multidisciplinary. As exclusion criteria, still in this first stage of the

Table 1 Primary search summary

Code	Database	Articles	Descriptors
Search 1	Scopus	32 (25.6%)	("User Experience" AND "Car")
Search 2	Scopus	69 (55.2%)	("User Experience" AND "Vehicle")
Search 3	Web of science	9 (7.2%)	("User Experience" AND "Car")
Search 4	Web of science	15 (12%)	("User Experience" AND "Vehicle")
	Total for screening	125 (100%)	

Source From the authors

review, restricted access was defined, articles in other languages and from different thematic areas. As can be seen in Table 1, the total number of articles found was 125. The search results were exported to the Mendeley Reference Manager (Elsevier 2021), a platform for organizing scientific articles from Elsevier Publisher. The free plan was used. The free software Google Sheets was also used as an aid in managing the research and generating the necessary graphics.

3.2 Screening

Screening was also performed on November 10, 2021, by one researcher. Of the total number of articles in the Primary Search ($n = 125$), 88 (70.4%) were discarded by the screening exclusion criteria, totaling 37 articles eligible for qualitative analysis.

3.3 Eligibility

In this phase, held between November 12 and December 5, 2021, the full texts of eligible articles from the previous phase ($n = 37$) were read, and a code (from 01 to 37) was assigned to each one of the studies. In total, 17 were excluded (45.9%). Table 2 shows the reasons for the exclusion of each one of them, and then the data obtained in the qualitative synthesis of the 20 approved articles are discussed. It should be noted that article code 16 was a duplicate that went unnoticed by Screening, and therefore was excluded at this stage.

During the qualitative synthesis, the data related to the answers to the research questions (RQ1, RQ2 and RQ3) were analysed and some analytical data relevant to a literature review study were collected, as follows:

1. Most studies were published in Journals (60%), compared to those published in Conferences (40%).
2. Studies carried out in Germany ($n = 6$) and in the United Kingdom ($n = 4$) represent half of the total number of articles analysed, while Europe represents 70% of the total ($n = 14$). Asia is in second place, with 20% of studies ($n = 4$), followed by the United States ($n = 2$), with 10%, as shown in Fig. 2. There is a clear trend of research focused on the area in European countries, with particular emphasis on Germany, home to traditional companies in the automotive sector.
3. There was also a clear growth in the number of publications in this field in 2020, with 8 published studies (40%). Publications from 2021 (up to the time of the search) add up to half of this value (20%).

Table 2 Articles excluded from eligibility

Code	Title	Exclusion justification
02	Human–Computer Interaction Design of Intelligent Vehicle-Mounted Products Based on the Internet of Things (Wang 2021)	The objects of study are IoT (Internet of Things) devices, not user experience
05	Human-Centered AI to Support an Adaptive Management of Human–Machine Transitions with Vehicle Automation (Bellet et al. 2020)	The aim of this study is to develop an artificial intelligence algorithm that provides contextual management in the Human–Machine transition between drivers and vehicle automation
06	The reliability of routing protocols as an important factor for road safety applications in VANET-based autonomous cars (Sasongko et al. 2020)	The objects of study are the protocols of the routes of autonomous vehicles
07	Transforming Cars into Computers: Interdisciplinary Opportunities for HCI (Eden 2018)	It is a theoretical study, which does not have applied research with users
09	Rare Occurrence: Exploring IoT, news media, calm interfaces and infrequent interactions (Mills et al. 2016)	The objects of study are IoT (Internet of Things) devices, not user experience
12	Using eye-tracking to support interaction with layered 3D interfaces on stereoscopic displays (Alt et al. 2014)	The object of study is not limited to automobiles
13	A Theoretical Framework of Haptic Processing in Automotive User Interfaces and Its Implications on Design and Engineering (Breitschaft et al. 2019)	It is a theoretical study, which does not have applied research with users
14	Analysis and Implementation of User Interface of Smart Drive System Using Goal-Directed Design Method (Pangestuti et al. 2017)	The object of study is an intelligent driving system, not the user experience
16	Designing Mid-Air Haptic Gesture Controlled User Interfaces for Cars (Young et al. 2020a)	Duplicate article with Article 03
18	Effects of user experience on user resistance to change to the voice user interface of an in-vehicle infotainment system: Implications for platform and standards competition (Kim and Lee 2016)	It is a theoretical study, which does not have applied research with users
19	Efficient Paradigm to Measure Street-Crossing Onset Time of Pedestrians in Video-Based Interactions with Vehicles (Faas et al. 2020)	The object of study is the pedestrian

(continued)

Table 2 (continued)

Code	Title	Exclusion justification
22	Floor-vibration VR: Mitigating Cybersickness Using Whole-body Tactile Stimuli in Highly Realistic Vehicle Driving Experiences (Jung et al. 2021)	The object of study is the user experience in Virtual Reality (VR), not driving a car
26	Participatory Prototyping to Inform the Development of a Remote UX Design System in the Automotive Domain (Tasoudis and Perry 2018)	The subject of the study is the UX Design professional, not the user
27	Supporting User Onboarding in Automated Vehicles through Multimodal Augmented Reality Tutorials (Detjen et al. 2021)	The object of study is the Automobile Manual
29	Topic classification of electric vehicle consumer experiences with transformer-based deep learning (Ha et al. 2021)	It is a theoretical study, which does not have applied research with users
30	UX Evaluation with Standardized Questionnaires in Ubiquitous Computing and Ambient Intelligence: A Systematic Literature Review (Díaz-Oreiro et al. 2021)	It is a theoretical study, which does not have applied research with users
33	Advances in automotive interior lighting concerning new LED approach and optical performance (Blankenbach et al. 2020)	It is a theoretical study, which does not have applied research with users

Source From the authors

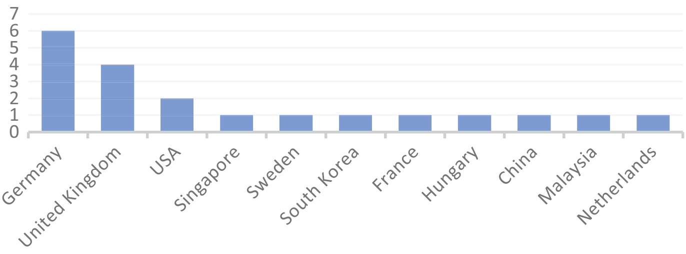

Fig. 2 Articles per country (study location). Font: From the authors

3.3.1 RQ1 Results

The complete answers to RQ1 (*What are the objects of study of the articles?)* can be accessed in Table 3. It could be observed that the studies focus on three major areas:

- **Reliability of autonomous driving** (at its different levels, in addition to the interaction between users in different vehicles and/or between vehicles and pedestrians and/or between autonomous vehicle systems).
- **Confidence in electric vehicles** (autonomy, supply network, new technologies).

Table 3 RQ1 answers

Code	Title	RQ1 answers
01	An AR-Enabled Interactive Car Door to Extend In-Car Infotainment Systems for Rear Seat Passengers (Berger et al. 2021)	Interactive rear passenger door
03	Designing Mid-Air Haptic Gesture Controlled User Interfaces for Cars (Young et al. 2020b)	On-air gesture control feedback
04	Anticipatory experience in everyday autonomous driving (Lindgren et al. 2020)	User experience in autonomous driving
08	Are You Ready for a Drive? User Perspectives on Autonomous Vehicles (Niculescu et al. 2017)	Users' perception of autonomous vehicles and potential requirements for the future
10	Freehand versus micro gestures in the car: Driving performance and user experience (Hauslschmid et al. 2015)	The use of gestures and micro-gestures in the control of car commands
11	Exploring virtual depth for automotive instrument cluster concepts (Broy et al. 2014)	Virtual panels with stereoscopic 3D and parallax effect
15	Augmenting the Driver's View with Peripheral Information on a Windshield Display (Häuslschmid et al. 2015)	Performance and experience of using displays on the windshield
17	Effects of an Unexpected and Expected Event on Older Adults' Autonomic Arousal and Eye Fixations During Autonomous Driving (Stephenson et al. 2020)	Investigation of visual attention and arousal responses of elderly people to safety–critical events in autonomous driving
20	ExplAIn Yourself! Transparency for Positive UX in Autonomous Driving (Schneider et al. 2021)	The responses of a system during autonomous driving and its possible improvements to the user experience
21	Exploring Personalized Autonomous Vehicles to Influence User Trust (Sun et al. 2020)	Confidence in autonomous vehicles with the addition of personalization
23	Increasing the Efficient Usage of Electric Vehicle Range—Effects of Driving Experience and Coping Information (Rauh et al. 2017)	The efficiency of the autonomy of electric vehicles and the effects on the user experience
24	Increasing the User Experience in Autonomous Driving through different Feedback Modalities (Schneider et al. 2021)	The increase in the experience of using autonomous cars with better and different types of feedback
25	Influence of Adaptive Human–Machine Interface on Electric-Vehicle Range-Anxiety Mitigation (Musabini et al. 2020)	The influence of a Human–Machine interface in mitigating anxiety about the autonomy of electric vehicles

(continued)

Table 3 (continued)

Code	Title	RQ1 answers
28	The Decline of User Experience in Transition from Automated Driving to Manual Driving (Johansson et al. 2021)	The level of user experience when transitioning from autonomous to manual driving
31	Vehicle Politeness in Driving Situations (Lee et al. 2019)	Advanced driving assistance systems
32	Application of the Fuzzy System for an Emotional Pattern Generator (Trautmann et al. 2020)	Texture generator system for vehicle interior design
34	The utility of psychological measures in evaluating perceived usability of automated vehicle interfaces—A study with older adults (Voinescu et al. 2020)	Perceived Usability in Human–Machine Interaction between Autonomous Vehicles and Elderly
35	The effect of peripheral visual feedforward system in enhancing situation awareness and mitigating motion sickness in fully automated driving (Karjanto et al. 2018)	Motion nausea in autonomous driving
36	The influence of system transparency on trust: Evaluating interfaces in a highly automated vehicle (Oliveira et al. 2020)	The influence of the autonomous vehicle interface on user trust
37	An approach to vehicle design: In-depth audit to understand the needs of older drivers (Karali et al. 2017)	Elderly interactions with car cabin controls

Source From the authors

- **Human–Computer Interaction** (assistance and/or entertainment systems, screen and command interface, new interface formats, user attention, tactile feedback from touchscreen and/or gesture control screens, head-up displays, different formats of displays).

Nine papers addressed the reliability of autonomous driving (45%), while seven papers (35%) discussed issues related to Human–Computer Interaction, and two (10%) studied trust in electric vehicles. Two articles (10%) had their objects of study included in both themes (Autonomous Driving Reliability and Human–Computer Interaction).

3.3.2 RQ2 Results

The summarized answers to RQ2 (*Which methods are used to analyze the object of study?*) can be seen bellow. In general, the studies follow a similar methodology: (1) a previous interview or questionnaire with personal data and/or demographics; (2) analysis and evaluation of the prototype/carrying out tasks in a simulator/carrying out tasks in a prototype or commercial vehicle; (3) a subsequent interview or questionnaire. The steps of each analysis change between studies, but we can observe, in addition to the similarity in structure, the common use of some tools, as follows:

- The AttrakDiff User Experience Assessment Questionnaire (Hassenzahl et al. 2003) was used in two (10%) of the studies, while the UEQ-S Questionnaire (Schrepp et al. 2017) was used in three (15%). According to Diaz-Oreiro et al. (2021), AttrakDiff is the predominant questionnaire in studies related to vehicle systems, although the UEQ-S is a platform that has been gaining strength since 2017, when it was developed. Two other studies (10%) used their own questionnaires to assess the user experience, and one study (5%) used the UX-Curve procedure (Kujala et al. 2011) as an evaluation. Most studies (60%) did not specify or did not use any type of questionnaire to assess the user experience.
- In 35% of the studies ($n = 7$), the participants used a static simulator to perform the tests and tasks predetermined by the research team. In two studies (10%), the use of virtual reality was added to the static simulator. In 25% of the surveys ($n = 5$), participants actually drove the vehicles, or at least were inside them, in the case of self-driving car trips. Among these five, in three studies the Wizard of Oz—WoZ protocol (Kelley 1985) was used. This is a real driving simulation. The user believes they are in an autonomous vehicle when, in fact, a human pilot is driving. In 30% of the studies ($n = 6$) there was no use of simulators or driving routes.
- Regarding the use of interviews, 35% of the surveys ($n = 7$) used this technique at some point in the study, whether structured or not. It should be noted that, in two of the studies, more than one interview was carried out (one before and one after carrying out the predetermined tasks).

3.3.3 RQ3 Results

The complete answers to RQ3 (*What are the samples size of the surveys carried out?*), can be seen in Table 4. In the data compiled from RQ3 it can be seen that:

- The samples have an average of 32.5 users. The smallest sample was from study 01, with 11 users, while the largest was from study 23, which had 93 users.
- Most participants are male (60.8%), in relation to the number of female users (39.2%).
- The average age of the participants was 36.2 years. It should be noted that three of the studies approved in the synthesis are focused on the elderly (articles 17, 34 and 37), whose average age of the participants was, respectively, 68.3 and 70.2 years. Study 37, unfortunately, did not provide this data. If we consider the average age of users apart from these three studies, we have a value of 31.1 years.
- Some data were left with an asterisk (*) because they were not made available in their articles and, therefore, were not considered in the calculations.

Table 4 RQ3 answers

Code	Title	N	M (%)	F (%)	Median age
01	An AR-Enabled Interactive Car Door to Extend In-Car Infotainment Systems for Rear Seat Passengers (Berger et al. 2021)	11	81.8	18.2	23.8
03	Designing Mid-Air Haptic Gesture Controlled User Interfaces for Cars (Young et al. 2020b)	59	42.4	57.6	41.0
04	Anticipatory experience in everyday autonomous driving (Lindgren et al. 2020)	18	55.5	44.5	*
08	Are You Ready for a Drive? User Perspectives on Autonomous Vehicles (Niculescu et al. 2017)	29	61.0	39.0	35.0
10	Freehand versus micro gestures in the car: Driving performance and user experience (Hauslschmid et al. 2015)	24	*	*	*
11	Exploring virtual depth for automotive instrument cluster concepts (Broy et al. 2014)	12	66.7	33.3	25.0
15	Augmenting the Driver's View with Peripheral Information on a Windshield Display (Häuslschmid et al. 2015)	20	70.0	30.0	28.0
17	Effects of an Unexpected and Expected Event on Older Adults' Autonomic Arousal and Eye Fixations During Autonomous Driving (Stephenson et al. 2020)	37	56.8	43.2	68.3
20	ExplAIn Yourself! Transparency for Positive UX in Autonomous Driving (Schneider et al. 2021)	40	65.0	35.0	24.6
21	Exploring Personalized Autonomous Vehicles to Influence User Trust (Sun et al. 2020)	36	66.7	33.3	36.4
23	Increasing the Efficient Usage of Electric Vehicle Range—Effects of Driving Experience and Coping Information (Rauh et al. 2017)	93	81.7	18.3	34.0
24	Increasing the User Experience in Autonomous Driving through different Feedback Modalities (Schneider et al. 2021)	22	45.5	54.5	28.4
25	Influence of Adaptive Human–Machine Interface on Electric-Vehicle Range-Anxiety Mitigation (Musabini et al. 2020)	22	54.5	45.5	*
28	The Decline of User Experience in Transition from Automated Driving to Manual Driving (Johansson et al. 2021)	20	45.0	55.0	41.5
31	Vehicle Politeness in Driving Situations (Lee et al. 2019)	56	48.2	51.8	23.3
32	Application of the Fuzzy System for an Emotional Pattern Generator (Trautmann et al. 2020)	33	60.0	40.0	37.5

(continued)

Table 4 (continued)

Code	Title	N	M (%)	F (%)	Median age
34	The utility of psychological measures in evaluating perceived usability of automated vehicle interfaces—A study with older adults (Voinescu et al. 2020)	25	*	*	70.2
35	The effect of peripheral visual feedforward system in enhancing situation awareness and mitigating motion sickness in fully automated driving (Karjanto et al. 2018)	20	48.1	51.9	26.2
36	The influence of system transparency on trust: Evaluating interfaces in a highly automated vehicle (Oliveira et al. 2020)	25	84.0	16.0	*
37	An approach to vehicle design: In-depth audit to understand the needs of older drivers (Karali et al. 2017)	47	62.0	38.0	*
	Medians	32.5	60.8	39.2	36.2

Source From the authors
* defines the blank data

4 Conclusions

Developing a systematic review promotes strengths in two ways. The researcher objectively collects the information necessary to answer their questions while detailing and disseminating the processed and analyzed data, allowing their access, review, and validation, in addition to increasing academic efficiency in similar research.

Some data proved intriguing. It was noticed that this area is relatively new in the academy, with a much higher concentration of studies in the last two years. Still, there is a predominance of studies on Europe, mainly in Germany and the United Kingdom, but the lack of studies in South America made us realize the importance of developing studies focused on the Brazilian User. It should be noted that the SLR was carried out in international databases, and one of the deployments of this research may be a review in local sites.

The review was also important to realize that the articles do not always provide the data that the researcher is looking for. In 10% of the approved studies ($n = 2$) the articles did not specify the gender of the participants in the research sample, while in 25% ($n = 5$) there was no data on the mean age of these participants. These are numbers that we consider high, mainly because we are talking about research focused on user experience, where basic data such as gender and age are essential to understand who we are designing for or who we are analyzing.

Another important data in this regard is that 60% of the studies ($n = 12$) did not specify in their articles whether they used any user experience assessment questionnaire or whether they carried out such an assessment. An in-depth look at different ways of evaluating UX is one more of the developments of this study, using as a starting point these articles that caused us the initial strangeness. Another development that comes from this review and from the answers to the research questions (RQ1, RQ2 and RQ3) is the development of a research project focused on user experience and automotive interaction design, with a focus on Brazilian Users.

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Prevalence of Pneumoconiosis in the Construction Industry: A Systematic Review

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Abstract Construction workers can be exposed to fibres, dust, and other toxic particles that can cause pneumoconiosis from silica, asbestos, and mixed dust. This systematic review aims to analyse how pneumoconiosis caused by exposure to dust contributed to the rise of occupational diseases in construction workers from 2001 to 2021. Sixteen keywords were combined to perform the search in six databases. Were included 26 articles which fulfilled all the defined inclusion criteria. A global analysis of risk disease distribution shows that exposures to mixed dust (41.1%), silica (37.5%) and asbestos (21.4%) were related to pneumoconiosis. In addition, individual analysis revealed that pneumoconiosis caused by exposure to chemical agents (silica, asbestos, and their dust) in the construction industry are predominantly related to the exposure to silica (Silicosis 38.1%), asbestos (asbestosis 33.3%, lung cancer 33.3%), and mixed dust (lung cancer 21.7%). Mixed dust seems to be the source of the highest incidence of pneumoconiosis, silica associated with silicosis is the most frequent disease.

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Keywords Silica · Asbestos · Mixed dust · Diseases · Exposure limit

1 Introduction

The construction industry is related to the mining industry, i.e., in extracting sand and stones as aggregates and subjecting workers to exposure to mixed dust (Agioutanti et al. 2020; Sauvé 2015). Several authors mention pneumoconiosis originated from occupational exposure to dust and fibres as one of the work-related diseases in the construction industry (Stocks et al. 2011; Sauvé 2015; Cummings et al. 2019; Bell and Mazurek 2020). These dusts, derived from different minerals such as silica and asbestos, are suspended in the air, resulting in diseases such as silicosis and asbestosis (Stocks et al. 2011; Nelson et al. 2011; Sauvé 2015; Nicol et al. 2015; Walters et al. 2018). Also the mineral nanoparticles are very toxic. They enter the body and can affect several vital mechanisms through blood circulation (Ophir et al. 2019; Bajpayee et al. 2004). In a comparative study on pneumoconiosis between China, Australia, and the United States, it was observed that China lags in studying health concerning safety. This lag is due to companies' emphasis on eliminating work accidents with visible consequences rather than invisible causes such as pneumoconiosis diseases (Han et al. 2018). Between 2001 and 2016 in the United Kingdom, in the Birmingham region, Occupational Lung Disease Services (OLDS) conducted a study to assess the prevalence of pneumoconiosis from asbestos in various industries. There were 160 cases found, of which 71 (44%) were from the construction industry (Walters et al. 2018). Due to the long incubation period, patients with asbestosis were detected only after working in construction for 25, 30 or 40 years (Philteos et al. 2004). However, exposure to silica, asbestos, and mixed dust, forces companies to have greater attention to mitigating health effects considered incurable and characteristics suggestive of asbestosis disease that can impair worker performance, such as oxidative stress, fibrotic degeneration of lung tissue, complexation iron, apoptosis, and inflammation (Chong et al. 2006; Perret et al. 2017; Schmajuk et al. 2019). Likewise, asbestos, silica, and mixed dust were considered risk factors for pneumoconiosis in a study about Global Burden diseases (GBD 2016) and Risk Factors Collaborators (RFC 2016). The WHO/ILO (World Health Organization/International Labour Organization) in 2018 presented a systematical review protocol that designed quantitative studies on the prevalence of pneumoconiosis attributed to risk factors. This study was about the chemical agents (asbestos, silica, and mixed dust) from 1960 to 2018 among the working-age population and disaggregated by country, sex, age, and industrial sector occupation, including the construction industry (Mandrioli et al. 2018; Hall et al. 2020; Kurth et al. 2020; Dhatrak and Nandi 2020).

To investigate pneumoconiosis, it is necessary to consider confounding factors in the manifestation of the disease, such as age, sex, biomass, smoking, tuberculosis, socioeconomic status, pathological conditions and type of work (Han et al. 2017). In addition, the permissible exposure limit (PEL) for free silica was established to prevent the development of the disease. Several studies noted significant differences

(Liu et al. 2017). Some of them were set by OSHA and ACGIH (Linch 2002; Dhatrak and Nandi 2020). For identifying pneumoconiosis, an exposure questionnaire (Ben Saad et al. 2013), spirometry tests (Prasad et al. 2020; Quanjer et al. 2012) and chest X-rays were also suggested to check rounded or irregular opacities, especially in the upper and lower lung fields (Han et al. 2018; Baur 2020; Dhatrak and Nandi 2020). Other authors suggest post-mortem pathophysiological diagnoses of lung tissue (Naidoo et al. 2005; Ndlovu et al. 2016).

This review focuses on pneumoconiosis resulting from exposure to workplace chemical agents such as silica, asbestos, and mixed dust. Some studies which have been visited recognise that silica, asbestos, and mixed dust are risk factors for pneumoconiosis in the construction industry. So, the present systematic literature review (SLR) intends to answer the following questions:

To what extent does the prevalence of pneumoconiosis contribute to illness in civil construction between 2001 and 2021?

Which chemical agent has the greatest weight in the prevalence of pneumoconiosis?

2 Materials and Methods

The research used the PRISMA Statement (Page et al. 2021). The information to compose the research was extracted from six electronic academic databases: Scopus; Ovid Medline with Daily Update; OSH update; Web of Science; EMBASE; and PubMed. Cited references were extracted using keywords related to the topic. A checklist was created to facilitate the analysis of the results, considering the following items: the authors' surnames and publication year, prevalence of pneumoconiosis, exposure to chemical agents, i.e., exposure to silica, asbestos and/or mixed dust, and the disease(s) derived from chemical agents. After selecting the articles related to the construction industry, the authors included pneumoconiosis papers related to other sectors, such as mining, to compare data and results.

2.1 Search Strategy

The strategy used in data extraction was based on a 20-year time horizon (2001–2021). "Data were extracted from works published between January 2001 and December 2021," taking into account title contents, abstracts, and keywords of all articles retrieved from the six databases. The following keywords have been considered, using the booleans "OR" and "AND": [(construction AND asbestos); OR (construction AND silica) OR (asbestos AND mixed dust)]; [(concrete AND asbestos) OR (silica AND mixed dust)]; [(occupational lung disease AND construction)]; [(permissible exposure limit AND silica) OR (construction industry AND mixed dust)]; [(pneumoconiosis AND construction)]; [(abrasive blasting AND silicosis) OR (pneumoconiosis AND asbestosis)]; [(pneumoconiosis AND spirometry)]; [(chest r-x AND pneumoconiosis) OR (asbestos AND mixed dust)]; (construction AND accidents); (pneumoconiosis AND accidents). The asterisk symbol was used to ensure that all possible variations of the terms were considered.

Data were extracted using a standard form developed in Excel to organise and compare information from the articles.

To be included/excluded in this review, studies had to meet the following criteria: experimental random or observational analytical studies focused on pneumoconiosis prevalence caused by silica, asbestos, and mixed dust in the construction industry or related activities with measurements (similar tasks of mining has been included). In addition, the articles need to have available full text and be written in English.

2.2 Data Analyses

The absolute frequencies of diseases in the included studies associated with exposure to at least one of the chemical agents (silica, asbestos and mixed dust) as well as the associated risk factor were sought.

The determination of the absolute and relative frequencies and the verification of the level of prevalence, in percentage, was through the following equation:

$$\mathrm{fr} = \mathrm{fi}/\mathrm{N} \times 100\%$$

where:

fi—(absolute frequency) shows how many times the disease appeared for each article reviewed according to its risk factor;
N—refers to the total number of diseases associated with a risk factor;
fr—(relative frequency) shows the impact number converted into a percentage.

3 Results

3.1 Study Selection and Characteristics

A comprehensive selection of studies was carried out in this systematic review, using the six databases and observing the inclusion/exclusion criteria referred to in the methodology. A total of 1823 records were screened, 1357 of which were removed because they were duplicates, incomplete, not peer-reviewed, not published in scientific journals, or off-topic. Were screened 466 articles having these been removed 440 because they did not correspond to the period under study (2001–2021), had contradictory objectives, or were not written in English. There were found 26

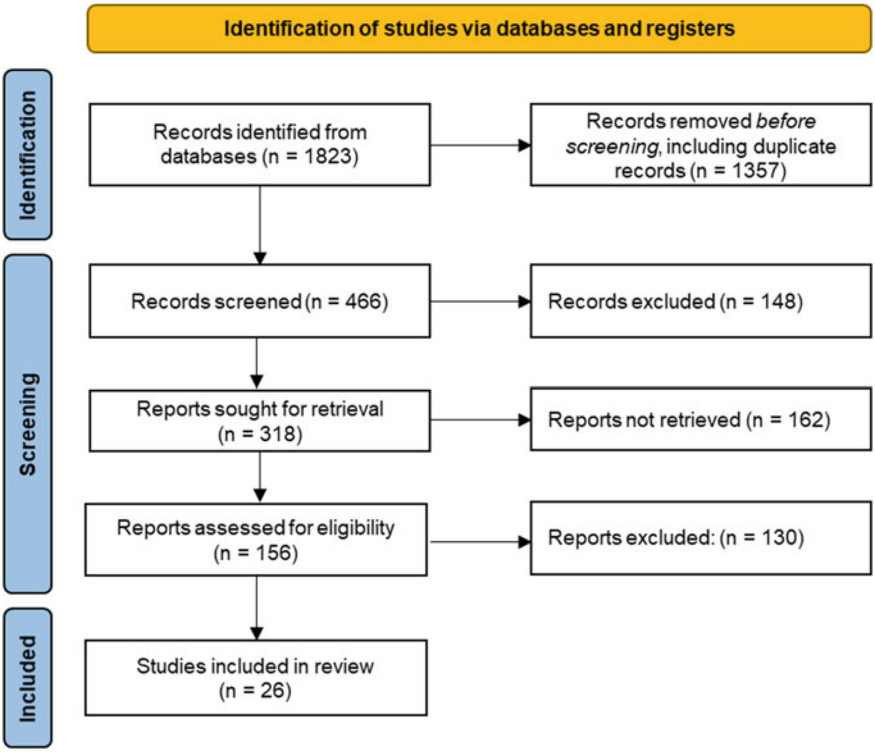

Fig. 1 Study screening diagram (Page et al. 2021)

articles considered eligible (Fig. 1). The extracted information is summarised in Table 1.

3.2 Distribution of Diseases According to Exposure Agent

The construction industry involves a wide range of activities, such as stone-breaking, concrete or brick cutting, pipe cutting, abrasive blasting, and tunnelling (Wang and Meng 2018). Exposure to crystalline silica, asbestos and mixed dust (risk factor) develops silicosis and asbestosis. Mixed dust is a blend of minerals, and it has the potential to cause pneumoconiosis (Nelson et al. 2010). A statistical analysis has been performed with the compiled data from items and characteristics described in Table 2. Moreover, diseases associated with different risk factors can be identified. Note that a disease may be associated with more than one risk factor.

The comparison of prevalence was represented by the absolute and relative frequencies of each type of disease caused by the three chemical agents: silica, asbestos and mixed dust.

Table 1 Characteristics related to pneumoconiosis occurrence from exposure to silica, asbestos, and mixed dust

#	Pneumoconiosis occurrence/detection	Exposure to chemical agents	Occupational Diseases from exposure
Agioutanti et al. (2020)	Respirable rock dust	Dust: from rock and coal	Unknown pneumoconiosis;
Bajpayee et al. (2004)	Of 100,000 workers, 15.3% are in the construction industry	Asbestos	Asbestosis
Baur (2020)	Components of cement and concrete dust in the construction industry	Asbestos and mixed dust	Idiopathic interstitial lung disease
Bell and Mazurek (2020)	In U.S 2738 in 1999 to 1632 in 2018. mortality ratio per million from 12.8 to 5.3	Asbestos, 60.1% of mortality; 820 deaths (25%) occurred in the construction industry; Silica 31.6%; 63 (18.9%); Mixed dust in construction caused 32 deaths (4%)	Asbestosis; Silicosis; Mixed dust pneumoconiosis
Ben Saad et al. (2013)	1992 workers in Tunisia/Africa submitted to a spirometry test: 71.31% lung function disability	Mixed dust	Lung disability
Chong et al. (2006)	Computed tomography (CT) and magnetic tomography studies identified silicosis	Silica	Silicosis and mixed dust; Progressive massive fibrosis; Lung cancer
Cummings et al. (2019)	In 2017, after 50 years, NIOSH used spirometry and X-ray chest	Silica	Silicosis Lung cancer
Dhatrak and Nandi (2020)	12.3% of 1012 X-ray chest performed (PEL) was 0.15 mg/m^3	Silica and mixed dust	Silicosis; Unknown pneumoconiosis
Hall et al. (2020)	109 workers, 1.9%, suffered from pneumoconiosis	Silica and mixed dust	PMF
Han et al. (2017)	495 workers were diagnosed with pneumoconiosis, 95 died	Mix dust	Pneumoconiosis; Chronic pulmonary obstructive (CPOD); Lung cancer; Tuberculosis

(continued)

Table 1 (continued)

#	Pneumoconiosis occurrence/detection	Exposure to chemical agents	Occupational Diseases from exposure
Han et al. (2018)	Increased mortality: 6.02% in China (2001–2011), 0.8% in the UK (1998–2000) and 3.2% in the USA (1998–2000)	Silica, asbestos and mixed dust	Pneumonia; Pulmonary tuberculosis; Lung cancer; Chronic pulmonary obstructive disease (CPOD); Accidents
Kurth et al. (2020)	Health Surveillance Program (CWHSP) found a 7.7% increase in pneumoconiosis severity	Mixed dust	Lung disease
Leonard et al. (2020)	NIOSH findings in the twenty-first century determined the prevalence of pneumoconiosis in young workers	Silica and mixed dust	Silicosis; Deficit lung function; Emphysema
Linch (2002)	NIOSH: 1992 and 1998, exposure to silica in 8 h of (PEL) of 0.05 mg/m^3	Crystalline silica (quartz) coming from the concrete	Silicosis; Unknown pneumoconiosis
Liu et al. (2017)	Low level exposure: 0.05; 0.01 and 0.35 mg/m^3 of silica and mortality	Silica	Silicosis
Mandrioli et al. (2018)	Noted prevalence from1960 to 2018	Asbestos, silica, and mixed dust	Pneumoconiosis from asbestosis, Silicosis; Mixed dust
Miller et al. (2005)	Spirometry standardisation	Silica, asbestos and mixed dust	Disability lung function
Naidoo et al. (2005)	Black miners had 8.3 and 1.2%. White miners had an increased risk of 1.4–5.4% for silicosis	Silica and mixed dust	Silicosis; Moderate to marked emphysema
Ndlovu et al. 2016	Silicosis and pulmonary tuberculosis were 12.0 and 13.0% in black and 20.5 and 2.4% in white miners	Asbestos and mixed dust	Silicosis and pulmonary tuberculosis

(continued)

Table 1 (continued)

#	Pneumoconiosis occurrence/detection	Exposure to chemical agents	Occupational Diseases from exposure
Nicol et al. (2015)	Six cases of eight symptomatic silicoses in six years of study	Silica	Silicosis; (PMF)
Perret et al. (2017)	Of 2257 least one year of experience, 2.0% ($n = 46$) were found CWP, and 0.5% ($n = 12$) had PMF	Mixed dust	Progressive massive fibrosis (PMF)
Philteos et al. (2004)	X-ray chest was performed on a 40-year-long construction worker	Asbestos	Asbestosis; Benign asbestosis lung diseases; Chronic interstitial lung disease
Prasad et al. (2020)	43.91% of workers found asbestos?	Asbestos	Asbestosis
Sauvé (2015)	19% of construction workers were exposed to silica	Silica	Silicosis
Stocks et al. (2011)	18,509 workers were detected 95% of respirable lung diseases and 98% attributed to asbestos	Asbestos and silica	Pneumoconiosis; Lung cancer; Mesothelioma; Non-malignant pleural disease
Waters et al. (2018)	Between 2001 and 2016, found 160 cases of asbestosis in all industries, 71 (44%) were in construction	Asbestos	Asbestosis; Mesothelioma; Bronchial cancer

Regarding the global analysis of the disease distribution in relation to pneumoconiosis, is noted: silica (37.5%), asbestos (21.4%), and mixed dust (41.1%). Obtained through the relative frequencies of the diseases of each agent divided by the total occurrence of the diseases (56%).

Analysing the occurrence of individualised diseases in relation to their risk agent, the following higher frequencies are noted: silica for (Silicosis 38.1%); asbestos for (asbestosis and lung cancer 33.3%), and mix dust for (lung cancer 21.7%) Table 2.

3.3 *Permissible Exposure Limit*

The literature review shows the need to establish an exposure limit value, given the risk factors for pneumoconiosis in the mining and construction industries (Hall

Table 2 Absolute and relative frequencies of risk factors and diseases

Risk factor	Diseases	fi	Fr (%)
Silica	Silicosis	8	38.1
	Unknown pneumoconiosis	2	9.5
	Lung cancer	4	19.0
	Mesothelioma	1	4.8
	Chronic pulmonary obstructive disease (CPOD)	2	9.5
	Progressive massive fibrosis (PMF)	2	9.5
	Moderate to marked emphysema	2	9.5
Total		21	100.0
Asbestos	Asbestosis	4	33.3
	Lung cancer	4	33.3
	Unknown pneumoconiosis	1	8.3
	Mesothelioma	1	8.3
	Chronic pulmonary obstructive disease (CPOD)	1	8.3
	Pulmonary tuberculosis	1	8.3
Total		12	100.0
Mixed dust	Mixed dust Pneumoconiosis	4	17.4
	Unknown pneumoconiosis	1	4.3
	Silicosis	4	17.4
	Lung cancer	5	21.7
	Chronic pulmonary obstructive disease (CPOD)	3	13.0
	Moderate to marked emphysema	2	8.7
	Pulmonary tuberculosis	2	8.7
	Progressive massive fibrosis (PMF)	2	8.7
Total		23	100.0

fi—absolute frequency; Fr—relative frequency; Unknown pneumoconiosis—diseases that have not been identified with any risk factor in the workplace (silica and asbestos)

et al. 2020). Despite the effort involving several organisations that deal with workers' health, there has been no consensus on standardising exposure values.

Whether due to the continuous exposure to risk factors or too high values of the Permissible Exposure Limit (PEL) (Liu et al. 2017), there are differences in standard levels of silica compared to those recommended by Occupational Safety and Health (OSH) and international organisations in several countries, (Linch 2002; Dhatrak and Nandi 2020) (Fig. 3). The two values corresponding to the United States belong to NIOSH (0.05 mg/m^3) and MSHA (0.10 mg/m^3). China values vary according to the type of ore, from 0.07 to 0.35 mg/m^3. There is currently a difference in exposure values in countries such as India, France, and Portugal, contributing to the prevalence of diseases related to pneumoconiosis, Fig. 2.

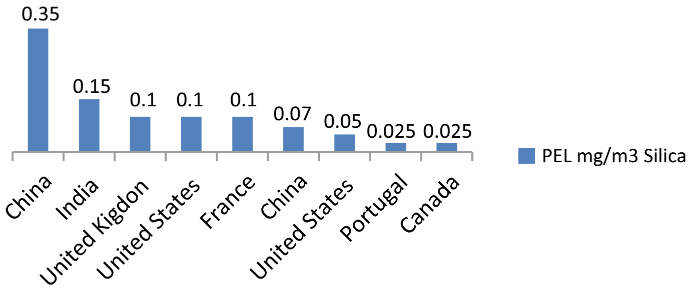

Fig. 2 Permissible exposure limit depending on the country (Linch 2002)

4 Discussion

The prevalence of pneumoconiosis in the construction industry has been studied since the last century (Linch 2002; Higgins et al. 2011; Sauvé 2015; Mandrioli et al. 2018; FCL 2021). In addition, there were studies on asbestos, silica, and mixed dust considered the risk factor for occupational pneumoconiosis, responsible for 100% of this disease (GBD 2016; RFC 2016). Review shows that exposure to chemical agents (silica, asbestos, and mixed dust) are responsible for diseases such as; Silicosis, asbestosis, lung cancer, chronic pulmonary obstructive diseases, moderate to marked emphysema, mixed dust pneumoconiosis, unknown pneumoconiosis, pulmonary tuberculosis, and progressive massive fibrosis (PMF) Tables 1 and 2. These diseases are associated with causes of pneumoconiosis morbidity and mortality in the construction industry due to dust and fibres (Stocks et al. 2011; Agioutanti et al. 2020).

Based on the global review analyse, Table 2, it is noted that mixed dust has a higher frequency of diseases with 41.1%. This can be justified by the presence of two elements together, namely silica and asbestos, forming a compound, joining the diseases of each element (Baur 2020). Then, silica with 37.5% and asbestos with 21.7% caused a long latency fibrotic lung diseases/pneumoconiosis (Stocks et al. 2011; Walters et al. 2018), referenced in Table 2. There is a long latency period for these diseases and a lack of health care for workers in the construction industry. These two factors make employers decline their responsibility (Ndlovu et al. 2016). In pneumoconiosis, workers may have signs of pulmonary dysfunction (pneumoconiosis) 20, 30, 40 or more years after leaving the company. Few studies have shown shorter times (Philteos et al. 2004; Nicol et al. 2015). The individual analysis of the maximum frequencies of diseases related to exposure to the three chemical agents supports the prevalence of pneumoconiosis in the construction industry with the following values: silica (Silicosis 38.1%), asbestos (asbestosis and lung cancer 33.3% both); and mixed dust (lung cancer 21.7%). Although the research shows evidence of pneumoconiosis from silicosis in the mines (Bajpayee et al. 2004; Stocks et al. 2011; Dhatrak and Nandi 2020; Baur 2020), the higher values of silicosis concerning asbestos and mixed dust referred to in Table 2, can support its impact on the construction industry. Knowledge of the risk factors with the most significant impact on the work environment helps identify the causes and, consequently, implement preventive and corrective actions (Bell and Mazurek 2020).

More evidence was seen at the South African Conference on silicosis analysis over 75 years. It was found that silica still affects 19% of construction industry workers (Sauvé 2015). The presence of different levels of exposure in many countries may influence the pneumoconiosis prevalence value (Fig. 2). Exposure Limit Values are not the same in all countries, although there are international organisations that seek to establish a common value for all countries. The existence of different limits influences the value of the prevalence of pneumoconiosis (Linch 2002; Dhatrak and Nandi 2020).

Construction industry workers are subject to the use and handling of products and machines such as explosive pressure vessels, explosives and breakers, machines and loaders, mixed dust, silica and asbestos (Baur 2020; Agioutanti et al. 2020). Proposals to combat pneumoconiosis were suggested, from preventive (work education) and corrective actions, which can be added using diagnosis like exposure questionnaires, spirometry (Prasad et al. 2020), chest X-ray (Dhatrak and Nandi 2020), Computer Tomographic (CT), and Magnetic Tomography Imaging (Ben Saad et al. 2013).

5 Conclusion

After the present literature review, 26 articles were considered eligible. The research shows that the prevalence of pneumoconiosis in the construction industry is due to the raw materials containing chemical elements considered risk factors, namely silica, asbestos and mixed dust. In the global analysis of the risk factors for pneumoconiosis, it was found that mixed dust is responsible for the higher frequency of pneumoconiosis (41.1%), followed by silicosis and asbestosis with 37.5% and 21.7%, respectively. In the individual analysis of the diseases, silicosis is observed more frequently, with 38.1% associated with silica, followed by asbestosis and lung cancer with 33.3% both related to asbestos and mixed dust with lung cancer (21.7%). In conclusion, the three risk factors contribute to diseases that cause pneumoconiosis; mixed dust has the highest number of diseases, while silicosis is the most frequently associated with silica.

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Resilience Engineering in Healthcare: A Systematic Literature Review

J. Fernandes, P. M. Arezes, and M. A. Rodrigues

Abstract Resilience engineering is a new safety paradigm, which seeks to understand and improve safety in complex socio-technical systems. The domain of healthcare is particularly relevant, as it requires an enormous capacity to adapt and respond to different situations. For this, appropriate methods and tools to the complexity of these processes and systems should be applied. This study aims to identify the methods and tools that have been developed and applied in the healthcare domain within the scope of resilience engineering, as well as the scope of its application, through a systematic literature review. A review of 109 studies published between 2012 and February 2022 was carried out. We searched two academic databases, Web of Science and Scopus. Only studies in English and original peer-reviewed scientific journals that attended to inclusion criteria were included, resulting in a total of 13 publications. The results of the analysed studies showed that the Functional Resonance Analysis Method (FRAM) was the method mostly used. It was also possible to verify that interviews, observations, document analysis and workshops have been used in the development of FRAM models.

Keywords Complex systems · Safety II · Safety management

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1 Introduction

Conventional risk management, as suggested by Hollnagel (2013), aims to keep adverse outcomes as low as reasonably possible. This is called Safety I and is characterized by being essentially reactive (Hollnagel et al. 2006). Orthodox safety methods, such as the measure of safety incidents/accidents, the investigation and analysis of the causes of accidents, are suggested by Safety I approaches (Hollnagel 2014). In contrast, Safety II is seen as a proactive approach, associated with the ability of the systems to be successful in different situations, requiring performance adjustments and adaptations to respond (Hollnagel 2013). Resilience engineering follows the Safety II approach, in which an organization or a system considers the unpredictability of the day-to-day work (Hollnagel et al. 2006). In view of this, it is important to understand not only how things go wrong, as in the Safety I perspective, but also how things go right in a day-to-day work (Hollnagel 2013). Hollnagel (2017) states that to an organization or a system be considered resilient, it must have the ability to function in the most diverse situations.

The abilities or capacities that an organization or system must have to achieve resilient performance are four (Hollnagel 2017): monitoring, which implies in knowing what to look for, or being able to monitor what could seriously affect the system's performance in the near term, positively or negatively; responding, which implies in knowing what to do, or being able to respond to regular and irregular changes, disturbances, and opportunities in the system; learning, which implies in knowing what has happened, or being able to learn from experience, in particular to acquire the right lessons from the right experience; and anticipating, which implies in knowing what to expect, or being able to prepare for developments further into the future, such as disruptions, constraints or opportunities in the system. In order to an organization or a system achieve a performance considered resilient, it is necessary that these four potentials, called pillars or capacities of resilience be continually maintained and improved (Hollnagel 2017).

Many studies have been developed within the scope of resilience engineering because their seminal authors ended up influencing other researchers to apply this new safety approach to the most different domains, such as in healthcare. Due to the characteristics of healthcare organizations and their systems, understanding and constantly improving quality is extremely important (Hollnagel et al. 2013). Healthcare is much more complex than a linear model suggests because, inherently, it involves significant organizational risks and include a large number of influencing factors (Braithwaite et al. 2015). In the last few years, healthcare field has given increasing attention to the investigation of successful processes. This new perspective paves the way for developing methods and tools for investigating and understanding the systems and processes functions, and how variability can contribute to both success and failure. To this end, it is important to identify the methods and tools that are being developed and applied. In view of above, the present study aims, through a systematic literature review, to report and analyse the methods and tools adopted in the healthcare domain. The results of this review may be useful to academics and practitioners researching and working in this field. They could improve their knowledge of the developments and application of these new methods and tools. All studies chosen for this literature review were methodically analysed in terms of the following questions:

(a) What are the methods and tools that have been developed and applied in the healthcare domain within the scope of resilience engineering?
(b) What is the purpose of applying these methods and tools?
(c) What approaches to data collection are being used?

2 Methodology

The systematic approach followed in this research relies on Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Page et al. 2020).

2.1 Research Strategy

This research consists of a systematic literature review, which followed the steps suggested by Page et al. (2020): identification, analyse, selection, and inclusion of studies. In the identification step, two databases were considered: Scopus and Web of Science. Firstly, the query referred to the Scopus database as the main source, as it is the largest repository of peer-reviewed literature (Elsevier 2018). However, it was considered necessary to expand the consultation to other databases, and it was decided to include the Web of Science.

Scopus and Web of Science allowed the use of a structured query and the documents were filtered by title, abstract and keywords content: TITLE-ABS-KEY ((“Resilience Engineering” OR “Safety II”) AND (“Healthcare” OR “Health care” OR “Hospital”)). The databases were required 14th of February 2022. Two researchers who are all involved in risk and safety research have conducted the review. Inclusion and exclusion criteria were defined and used to determine the eligibility of the studies.

2.2 Eligibility Criteria

Studies were chosen for this review based on the following criteria:

(a) Studies that apply the principles of resilience engineering in the healthcare domain;
(b) Original peer-reviewed scientific journals;
(c) Studies published between 2012 and February 2022;

(d) Studies published in English.

The following exclusion criteria were considered:

(a) Books, review papers, conference papers, paper-based PhD thesis, monography PhD Thesis, technical/institutional reports or white papers;
(b) Studies published in a language other than English.

2.3 Screening Criteria

Search results were exported to EndNote software. Studies were selected for eligibility against specified inclusion and exclusion criteria, using a three-step systematic approach. Initially, the titles of studies were examined for relevance. Secondly, the abstracts were selected, giving special importance to the objectives and methodology of the study. Finally, full-text were retrieved for studies that appeared to meet the eligibility criteria, and for those in which the information in the title and abstract was insufficient for exclusion.

The extracted data and information were synthesized so that the research questions of the review could be addressed and the information interpreted in detail. The information extracted includes the following categories: Author(s) and year of publication; Publication title; Objective(s); Method(s); Tool(s); Data collection approach; Conclusions.

3 Results and Discussion

The results of the search were 175 studies, containing 100 from Scopus, and 75 from Web of Science. After removing duplicate studies (66 records), 109 studies were identified. In the analysis, 11 studies were excluded according to two criteria: studies written in languages other than English (7 records) and studies that were literature reviews (4 records). After analysing titles and abstracts, 46 studies were excluded, according to the inclusion criteria, since they did not demonstrate the use of methods or tools developed within the scope of resilience engineering. In addition to these, another 20 studies were excluded because they were essentially theoretical. A total of 32 studies were included for full-text review. In the end, 13 studies were selected and included for this review.

As shown in Table 1, 7 of the 13 studies included in this review applied FRAM to serve different objectives in the healthcare domain. The objective of Arcuri et al. (2022) was to predict the behaviour of the system, while Damen et al. (2021) explored the system and utility of FRAM in the differences between Work-As-Done (WAD) and Work-As-Imagined (WAI). The objective of Kaya et al. (2019) was understand performance variability as conditions change and how variability in functions influences the system. In the study developed by O'hara et al. (2020) the focus was to understand the WAD from the perspective of different stakeholders. In turn, Patriarca et al. (2018) performed a risk assessment. Raben et al, (2018) sought to understand how a system can produce emergent results due to unexpected combinations of performance variability in the process. Finally, Sujan et al. (2022) explored and analysed WAD and how this analysis can help strengthen resilience and improve outcomes. It was also possible to identify more three studies that used FRAM with other different methods, namely the Leading Indicator Identification Method (LIIM) (Raben et al. 2017), Building Information Modelling (BIM) (Ransolin et al. 2020) and Lean (Rosso and Saurin 2018).

Two of the studies used the Resilience Assessment Grid (RAG) (Chuang et al. 2020; Hegde et al. 2020a). Chuang et al. (2020) adapted the RAG to an emergency department in order to measure resilience potential. Hegde et al. (2020a) developed the Resilience Mapping Framework (RMF), which was based on the main thematic categories to systematically represent and map the different resilient capacities. Additionally, 1 of the studies aimed to review and validate the design of Resilience Engineering Tool to Improve Patient Safety (RETIPS) (Hegde et al. 2020b). The data and information extracted from the 13 studies were summarized in Table 1.

The FRAM is a Safety II approach for investigating safety related problems and challenges in complex socio-technical systems (Hollnagel 2012). It has become popular over the last decade as a new method to help safety and risk management. In the specific domain of healthcare, the growing interest in FRAM is noted especially in health practices and processes (Arcuri et al. 2022; O'Hara et al. 2020; Patriarca et al. 2018). When FRAM is applied in healthcare, the core idea is the distinction between WAI and WAD (Damen et al. 2021) or investigate the relationships among WAI and WAD (Patriarca et al. 2018).

FRAM was also applied in combination with other methods or approaches. Rosso and Saurin (2018) proposed the joint use of the FRAM and value stream mapping to understand how resilience played out in the patient flow from an emergency department to an intensive care unit. Thus, value stream mapping with process analysis and improvement has been combined with the FRAM for risk assessment and systems modelling in healthcare applying the method on day-to-day work (Rosso and Saurin 2018). In turn, LIIM method was applied in a case study, describing blood sampling with a FRAM model. This case study described a common, yet complex process, taking place on a regular basis in the healthcare system. The FRAM model covered the process from ordering blood samples until the samples were sent for analysis (Raben et al. 2017). In the study developed by Ransolin et al. (2020), a framework was proposed for the integrated modelling of the built environment and functional requirements, supporting the analysis of resilient performance. The structure articulates FRAM and BIM under a requirements management logic, from requirements identification to the development of design solutions (Ransolin et al. 2020). As the FRAM is the central element, the framework naturally raises questions about resilient performance.

Employing complementary approaches can be useful for develop FRAM models such as Abstraction/Agency framework or Monte Carlo framework as highlighted

Table 1 Summary of studies

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
Arcuri et al. (2022)	On the brink of disruption: Applying Resilience Engineering to anticipate system performance under crisis	Assess how Resilience Engineering concepts and methods can be used to identify and predict the behaviour of complex systems after they are put under stressful situations, based solely on previous understanding of their normal functioning	FRAM	–	Semi-structured interviews Worksite technical description Observation	The use of the FRAM for modelling regular operation based on in-depth data on work-as-done enabled a prospective scenario analysis that accurately predicted disruptions in system functioning during abnormal conditions. Resilience engineering approach should be considered as an important complement to traditional approaches in managing system safety
Chuang et al. 2020	Measurement of resilience potential-development of a resilience assessment grid for emergency departments	Redesign the Hollnagel's Resilience Assessment Grid (RAG) into a custom-made RAG to support resilience management in Emergency Department (ED)	–	RAG	Questionnaire	The ED-RAG represents a snapshot of emergency department's resilience under specific conditions. It might be performed multiple times by a single hospital to monitor the directions and contents of improvement that can supplement conventional safety management toward resilience

(continued)

Table 1 (continued)

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
Damen et al. (2021)	Preoperative Anticoagulation Management in Everyday Clinical Practice: An International Comparative Analysis of Work-as-Done Using the Functional Resonance Analysis Method	Assess preoperative anticoagulation management in everyday practice and explore the usability and utility of FRAM	FRAM	–	Semi-structured interviews	In both centres, work-as-done differed from work-as-imagined, such as in the division of tasks among disciplines, but control mechanisms had been developed locally to ensure safe care. Centres had organized the process differently, revealing opportunities for improvement regarding patient information and clustering of clinic visits. Presenting FRAM models to staff initiated discussion on improvement of functions in the model that are vital for success
Hegde et al. (2020a)	Knowledge Elicitation to Understand Resilience: A Method and Findings From a Health Care Case Study	Develop and implement a new knowledge-elicitation protocol to learn about how frontline care providers achieve safe and effective patient care in their everyday work	–	RAG	Semi-structured interviews	A Resilience Mapping Framework (RMF) was developed based on major thematic categories to systematically represent and map various resilient capacities across different levels of system scale. RMF are a trigger for deeper learning work-as-done and proactively investigating ways to support or enhance system resilience

(continued)

Table 1 (continued)

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
Hegde et al. (2020b)	Qualitative findings from a pilot stage implementation of a novel organizational learning tool toward operationalizing the Safety-II paradigm in health care	Revise and validate the design of RETIPS	–	RETIPS	Questionnaires Reports analysis	A review of the reports obtained shows a strong alignment of responses with the conceptual basis of the tool, i.e. learning about how things go well in everyday work. These findings support RETIPS as a tool to operationalize the Safety II paradigm in healthcare
Kaya et al. (2019)	Using the functional resonance analysis method on the drug administration process to assess performance variability	Application of FRAM to the medication drug administration process in neonatal intensive care units to understand performance variability under changing conditions, as well as to understand how variability in functions influences the system	FRAM	–	Semi-structured interviews Observation Workshops	The delivery of successful care can be challenging in complex healthcare settings such as NICUs. The data presented in the paper suggests that the FRAM is able to understand the complexity of the drug administration process in a NICU context, as well as the interactions among different functions, the potential performance variability of function outputs and their likely impact on the system

(continued)

Table 1 (continued)

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
O'Hara et al. (2020)	Handing over to the patient: A FRAM analysis of transitional care combining multiple stakeholder perspectives	Application of FRAM to develop a model of transitional care, with a system boundary spanning an older patient's admission to hospital, through to thirty days post-discharge	FRAM	–	Observation Semi-structured interviews	The study represents the first to use an approach that explicitly recognizes the work-as-done from the perspective of patients and families, as well as healthcare professionals. Supporting certain patient-facing upstream hospital functions (e.g. encouraging mobility, supporting a better understanding of medication and condition), may lead to improved outcomes for patients following hospital discharge
Patriarca et al. (2018)	Resilience engineering for socio-technical risk analysis: Application in neuro-surgery	Modelling anaesthesia practices to assess risks for iatrogenic disease in a peri-operative domain	FRAM	–	Semi-structured interviews Open-ended interviews Observation Focus group Documentary study	The study confirms that resilience engineering meant as a discipline that designs, maintains and operates on the resilience of sociotechnical systems. The FRAM, in its enhanced multi-layer semi-quantitative version, demonstrates to have the potential for supporting decision-making actions to enhance healthcare safety, productivity, and thus resilience

(continued)

Table 1 (continued)

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
Raben et al. (2017)	Proposing leading indicators for blood sampling: application of a method based on the principles of resilient healthcare	Identify leading indicators for blood sampling among patients in a Biomedical Department within a Danish hospital	FRAM and LIIM	–	Observation Semi-structured interviews	Error detection is still a central aspect in healthcare, and few measures are dedicated toward positive events The method is applicable on different processes related to healthcare processes and can help uncover the importance of functions or activities in healthcare processes that are normally not considered. The study will help enrich the discussions of how we can improve safety by looking at processes with successful outcomes, in addition to processes that result in failure
Raben et al. (2018)	Application of a non-linear model to understand healthcare processes: using the functional resonance analysis method on a case study of the early detection of sepsis	Understand how a healthcare system works on an everyday basis namely the process of early detection of sepsis in a medical ward in a Danish hospital by using a systematic method	FRAM	–	Semi-structured interviews Focus group Document analyses	The FRAM proved to be a useful method to understand a complex process in healthcare with the ability to highlight how a system might produce emergent outcomes due to unexpected combinations of performance variability in the process. The study showed that it is possible to apply the FRAM to patient safety processes and, through the conceptualization, to gain new insights and perspectives on which factors play a central part in successful process outcomes

(continued)

Table 1 (continued)

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
Ransolin et al. (2020)	Integrated modelling of built environment and functional requirements: Implications for resilience	Design and test a framework for integrated modelling of the built environment and other functional requirements in an intensive care unit	FRAM and BIM	–	Semi-structured interviews Observation Document analyses	Framework articulates FRAM and BIM under a requirements management logic, from requirements identification to the development of design solutions. Design solutions devised in the final stage of the framework can contribute to resilient performance. This is a contribution mostly to the resilient healthcare discipline, as the connection between resilient performance during every day work in healthcare systems and the built environment is an under explored topic
Rosso and Saurin (2018)	The joint use of resilience engineering and lean production for work system design: A study in healthcare	Develop a framework for supporting the design of socio-technical systems, which combines insights from LP and RE, in a system involving a patient flow from an emergency department to an intensive care unit	FRAM and LEAN	–	Semi-structured interviews Observation Document analyses	A strength of the framework is the characterization of the work system using tools from both lean production (VSM) and resilience engineering (FRAM). These tools offered complementary data and perspectives for system re-design. As a whole, both the framework and the propositions offer new theoretically and empirically grounded guidance for the integration between lean production and resilience engineering

(continued)

Table 1 (continued)

Authors	Title	Objective(s)	Method(s)	Tool(s)	Data collection	Conclusions
Sujan et al. (2022)	Failure to rescue following emergency surgery: A FRAM analysis of the management of the deteriorating patient	Study the response to the deteriorating patient following emergency abdominal surgery in a large surgical emergency unit, using the Functional Resonance Analysis Method (FRAM)	FRAM	–	Semi-structured interviews Workshops	Application of FRAM provided a detailed and plausible description of the process of recognizing and rescuing deteriorating surgical patients using a different perspective from the conventional problem-seeking approach. Linking variability back to resilience abilities allowed some conclusions to be drawn about potential interventions that might strengthen resilience and thereby patient safety

by Patriarca et al. (2018). In the developed study, the authors adopted of a semi-quantitative Monte Carlo framework for FRAM to assess iatrogenic-related potential risks for patients undergoing neuro-surgery. The study also demonstrated the importance of the Abstraction/Agency framework to support complex knowledge management, and the applicability of a semi-quantitative framework to gather and manage variability data systematically.

The benefits of applying FRAM are often highlighted in different studies, include the possibility to identify differences between WAI and WAD (Damen et al. 2021), the potential to highlight essential system functions (Raben et al. 2018; Sujan et al. 2022) and the potential to support decision-making actions (Patriarca et al. 2018). According Arcuri et al. (2022) a broader perspective, focused on understanding system interdependencies and describing deviations from the system's normal functioning based on effective practices, should be employed to help avoiding disturbances affecting professionals work.

Semi-structured interviews (Arcuri et al. 2022; Damen et al. 2021; O'Hara et al. 2020; Kaya et al. 2019; Patriarca et al. 2018; Raben et al. 2018; Ransolin et at. 2020; Rosso and Saurin 2018; Sujan et al. 2022) were used to develop FRAM models. This is aligned with the Hollnagel (2012) recommendation about the sources of information used in data collection for the application of the FRAM, which are document analysis, interviews and observation. In concordance, Patton (2002) suggests that open or semi-structured interviews have a greater potential to allow the description of complex socio-technical domains. According Kaya et al. (2019), interviews with experts, workshops, and discussions may be the most important ways for validating developed FRAM models. Unlike most of the traditional safety management tools, the FRAM does not consider variability as a failure (Hollnagel 2012) and these encourage participants to speak freely about performance variability.

Table 1 also revealed that 8 out of the 13 studies under analysis employed observation as a data collection approach. Observation is also one of the techniques adopted and it proves to be useful to develop a FRAM model because allows a deeper view of complex systems and a better understanding of their real functioning (Hollnagel 2012; Kaya et al. 2019). The global results of the analysed studies highlighted that semi-structured interviews, observations, document analyses, focus groups and workshops have been used to develop FRAM models. In total, a combination of various approaches was used in a considerable number of the analysed studies for developing and validating FRAM models.

In addition to the FRAM, Hollnagel (2017) presents the RAG, which consists of a set of general questions that can be adapted to different realities, considering the specific characteristics of each organization or system according to the activities carried out. The RAG is intended as a way to profile the four pillars of resilience and compare these profiles over time, to track how an organization develops (Hollnagel 2017). According to Hollnagel et al. (2013) for the questionnaire to be useful, it is advisable to apply a 6-point Likert scale. The study developed by Chuang et al. (2020) proposes a novel scoring method to avoid the issue of abusing ordinal data. On the other hand, Hegde et al., (2020a) presents a framework, developed based on the qualitative findings from the interviews and the purpose of the protocol developed was to understand what works well in everyday work, regardless any events. The questions were developed based on the resilience capacities and their elements described in the RAG.

Regarding to the RETIPS, it is a new lesson sharing tool designed around the Safety II approach. The instrument consists in a set of questions designed to elicit narratives of adaptations that contributed to the effectiveness of care. The tool was revised based on feedback from clinicians (Hegde et al. 2020b).

Despite much discussion around resilience engineering, the fact that it is a relatively recent approach, there is still no published literature in large numbers. The fact that only 13 studies were obtained may be due to the fact that the term resilience is used in several areas of knowledge (Woods 2015). However, efforts have been made to develop methods and tools to support the adoption of Safety II in the field of healthcare.

4 Conclusions

This systematic literature review analysed and reported published studies that used methods and tools developed in the field of resilience engineering, namely FRAM and RAG. In addition, a study that validated RETIPS, a new tool that follows the Safety II approach, was introduced. A total of 13 studies were included in the review. The results highlight that FRAM is the most used method. Regarding the data collection, semi-structured interviews, observation, document analysis and workshops are the most common approaches.

The results presented in this review revealed that healthcare environments have a significant interest in the concepts, methods and tools developed within the scope of resilience engineering. The application of these methods and tools in the healthcare is increasingly relevant because frontline health professionals have to constantly adapt to working conditions. Studies confirm that resilience engineering can be applied to manage these complex working environments. At the same time, studies have shown that further empirical research in this field is of crucial importance to build and support these systems and processes to be more resilient. In fact, FRAM has already proven to be a useful method for understanding and analyzing complex socio-technical systems. The method offers an alternative way of investigating safety–critical processes in healthcare. It is possible to apply the FRAM to patient safety processes and to gain new insights on which factors play a central part in successful process outcomes. However, the application of the method is extremely complex and requires the need to re-evaluate the model obtained for any changes in the work domain. Thus, additional modelling efforts are needed to increase the potential of FRAM to be a reliable decision support tool.

5 Limitations

One of the limitations of the present review is that the studies selection process was narrowly defined to include only peer-reviewed journal articles. However, some of the excluded studies could add some value to the review performed, such as books, paper-based PhD thesis, monography PhD Thesis, technical/institutional reports or white papers. The application of FRAM has already proven to be of great importance for future research in the health area, but the construction of a FRAM model is very time consuming. Future studies are needed to explore and improve FRAM in order to reduce the time required for its application. In addition, the RAG can be adapted to different systems or processes in the healthcare domain.

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Psychological Diseases in Firefighters: A Short Review

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Abstract The demanding activity of firefighters has a significant impact on their psychological state. This study aimed to analyse the prevalence of anxiety, Burnout, depression, and post-traumatic stress in firefighters. The *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* was used for the systematic literature review. The research was developed in SCOPUS, Web of Science, and Pubmed scientific databases. Fifty-three articles were included in the present study and were distributed in subthemes: Prevalence of Anxiety, Burnout and Depression; Prevalence of post-traumatic stress. Firefighters' psychological disorders were associated with exposure to traumatic events during activity. Age and years of experience related to the prevalence of post-traumatic stress. It is necessary to develop further studies in this area of research, finding ways to reduce the psychological impacts caused by the activity.

Keywords Anxiety · Post-traumatic stress disorder · Depression · Burnout

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1 Introduction

It has already been proven that stress triggers a set of bio mechanisms of response and defence against situations that put the individual's physical and psychophysiological integrity at risk (Teixeira et al. 2021). The physiological reaction of the cardiovascular system correlated with the levels of physical and subjective stress of individuals during exposure to a firefighting task (Smith et al. 2019).

The activity performed by firefighters requires a high emotional demand on individuals, leading to the development of disorders such as anxiety, depression and Burnout (Ângelo and Chambel 2015; Thibaut 2017). Accordingly Craske et al. (2011), anxiety is defined as an individual's mood in preparation for possible adverse events to take place in the future. Depression is characterised by a mood disorder that causes feelings of sadness and unhappiness (Marcus et al. 2012). Fear is the response to the actual or perceived danger caused by that event. Several factors influence the mental health of firefighters (Craske et al. 2011).

Burnout is the result of work-related stress and is associated with decreased performance in the workplace. Many people who suffer from Burnout appear to have symptoms identical to those diagnosed with depression (Koutsimani et al. 2019). According to Wolkow et al. (2019), insomnia is related to the appearance of Burnout, in particular, in individuals who perform activities during the night shift caused by the short rest period. Insomnia is defined as the difficulty felt by the individual in sleeping. Insomnia is a disorder associated with a decrease in the individual's quality of life, which can impact work, causing more absenteeism rates and decreased concentration, among others. Insomnia is strongly associated with psychiatric illnesses (Roth 2007). Santos et al. (2018) report that some participants only sleep three or four hours a day in their sample of firefighters.

In addition, continued exposure to anxiety or traumatic events can lead to mental illnesses, such as Post-Traumatic Stress Disorder (PTSD). PTSD is characterised by symptoms of reliving traumatic events, commonly called nightmares and flashbacks. The tolerance to stress developed by individuals is related to symptoms of depression and PTSD (Ranney et al. 2020). The present review aims to assess the incidence of anxiety, Burnout, depression and PTSD in firefighters.

2 Materials and Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement was used to conduct the systematic review (Page et al. 2021; Shamseer et al. 2015). The present research results from a scooping review where the objective was to evaluate the psychophysiological variables during the activities of firefighters, as already reported (Teixeira et al. 2021). A short review summarised results considering all types of psychological and psychological issues of firefighters on duty are presented below. The research was conducted in SCOPUS, Web Of

Science, and Pubmed databases. The conjugation of the keywords used in the databases were: "*firefighters and anxiety*"; "*firefighters and hormonal responses*"; "*firefighters and mental demand*"; "*firefighters and cortisol*"; "*firefighters and cognitive performance*"; "*firefighters and memory*"; "*firefighters and cognitive function*"; "*firefighters and psychological responses*"; "*firefighters and psychophysiological responses*"; "*firefighters and selective attention*"; "*firefighters and cognitive responses*"; "*firefighters and mindfulness*"; "*firefighters and burnout*".

No date restrictions were applied to article selection, and published research papers and press articles were included. Theoretical articles such as literature reviews and conference papers were not considered. The research focused on samples of firefighters, and there were no restrictions on gender and age. The review consisted of articles written in English only.

3 Results

3.1 Study Selection

The total number of articles included in the scoping review was 75. However, only 53 articles were accepted for the present article.

3.2 Characteristics of the Studies

The articles were divided into two subthemes: Prevalence of Anxiety, Burnout and Depression; Prevalence of PTSD. Studies from 1994 to 2021 were included. Of the selected articles, 44 were related to the Prevalence of Anxiety, Burnout and Depression. 21 of the selected articles were related to the Prevalence of PTSD.

3.3 Summary of Results

In these two categories, there are repeated articles because they fit both, as shown in Fig. 1. It was found that there is a strong association between the prevalence of anxiety, Burnout and depression in individuals and the incidence of long-term PTSD.

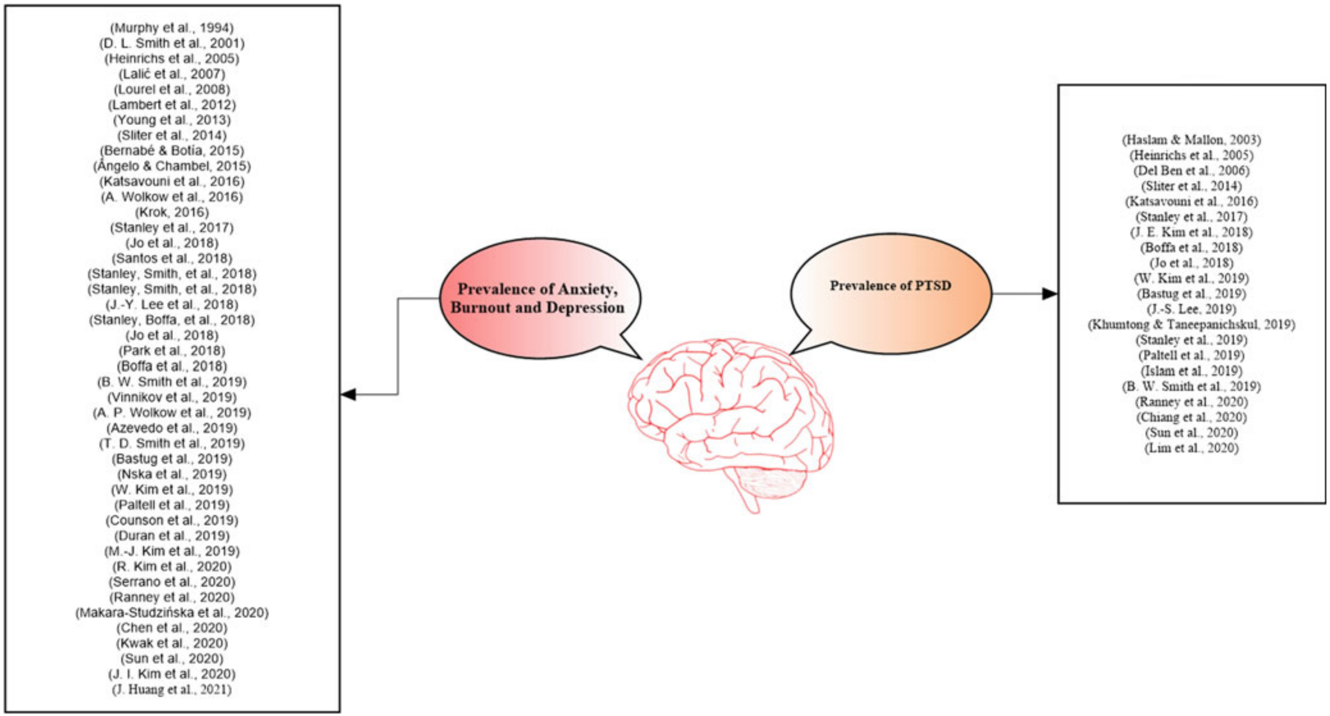

Fig. 1 Illness categories addressed

4 Discussion

4.1 Prevalence of Anxiety, Burnout and Depression

The activity performed by firefighters involves exposure to different traumatic events, making the stress rate higher (Kaikkonen et al. 2017). Young et al. (2013), when they are in a simulation of activities, reduce stress levels due to their perception. Workloads may vary depending on the activity performed and the existing workload. The tension, depression, and fatigue variables are significantly higher during a working day (Santo de Oliveira et al. 2012). It is essential to mention that work demands and exposure to trauma are related to psychiatric morbidity (Teoh et al. 2019).

Exposure to traumatic events can be associated with an increased anxiety disorder (Azevedo et al. 2019; Kim et al. 2020; Lee 2019). In 2017, anxiety had a prevalence of 7.3%, with a strong relationship between anxiety symptoms and depressive symptoms (Thibaut 2017). According to Smith et al. (2001), firefighters' anxiety increases 25% after testing structural fires. Lee et al. (2018), symptoms of anxiety and depression are predictors of perceived stress and two-dimensional exhaustion. When firefighters are more susceptible to depression and bullying, they show more incredible difficulty working as a team (Duran et al. 2019). In a study by Haslam and Mallon (2003), a group of firefighters indicated that they were emotionally disturbed when they remembered a traumatic event. The same group mentioned having difficulty falling asleep.

It should note that the symptoms of anxiety and depression can be related to the individual's age and the years of service as a firefighter (Counson et al. 2019). Chen et al. (2020) indicate that the time of experience and the activities developed as firefighters impact the psychological response. Groups of firefighters with more experience demonstrate greater significance in perceived stress (Makara-Studzińska et al. 2020), which may be associated with anxiety and depression (Lee et al. 2018). The mood of the individuals will be the primary influencer in the exposure to traumatic events and the symptoms of PTSD and Burnout (Sliter et al. 2014).

Some symptoms of Burnout seem to resemble symptoms of depression. Continued exposure to anxiety can lead to the appearance of Burnout syndrome (Koutsimani et al. 2019). Vinnikov et al. (2019) indicate that they are responsible for managing firefighting, which has the highest Burnout rate. This study contradicts another one carried out by Nska et al. (2019), indicating that stress and Burnout are found within limits.

Emotional exhaustion, often associated with Burnout, can be negatively related to the work practices of firefighters and their behaviours adopted in an emergency (Smith et al. 2018). In addition, the relationship of firefighters with co-workers and victims may be associated with feelings of harassment. These feelings influence the response to work-related stress (Duran et al. 2019) and may be related to professional exhaustion and the onset of post-traumatic stress disease (PTSD), Burnout, and absenteeism (Kim et al. 2019; Ranney et al. 2020; Sliter et al. 2014). Huang et al. (2021) indicates that individuals under 20 years of age have more significant emotional distress than older and experienced firefighters.

The repeated traumatic exposures inherent to fighting fires can increase susceptibility to suicide, anxiety and sleep disorders, depression, and occupational stress (Serrano et al. 2020; Stanley et al. 2018). Young et al. (2013) state that the fear of dying and anxieties do not correspond to reality in a fire simulation situation. The participants know that they are in a simulation situation and not in a real condition. According to Lalić et al. (2007), anxiety is moderately necessary as a personality trait in firefighting. In order to prevent emotional Burnout and the mechanisms that lead to it, Park et al. (2018) report the need to implement monitoring and support systems for firefighters.

4.2 Prevalence of PTSD

After exposure to emotional stress, firefighters are more fragile, needing more support to decrease the incidence of psychiatric disorders such as PTSD (Park et al. 2018) and other consequences, such as consuming illegal substances (Chiang et al. 2020). Lalić et al. (2007) mention the importance of training firefighters in activities to reduce work-related stress. Bullying and work-related Burnout can be indicators of higher levels of PTSD (Kim et al. 2019). Some traumatic events, such as witnessing people die, have already been identified as predictors of the appearance of PTSD (Sareen 2014). The most common events are witnessing the death of a person and perceiving the risk of living in a place, accident, or threat with a firearm (Sareen 2014). Firefighters' work seems to be a vital source of stress and mental tension, leading to the inevitability of PTSD (Lourel et al. 2008).

This information is in line with a study carried out by Del Ben et al. (2006), which indicates that the traumatic events most reported by a group of firefighters are the death of an adult (38% response rate) and followed by the death of a child (34% response rate). The death of children is also mentioned in a study carried out by Katsavouni et al. (2016). It knew that the more serious the traumatic event experienced by the firefighter, the greater the occupational stress. In a sample of firefighters, Kim et al. (2019) report that 70% of individuals have a prevalence of memories of a traumatic event, the most suitable being the treatment of fatal or injured victims.

In a study developed by Bastug et al. (2019), a 40% PTSD rate was reported in a sample of Turkish firefighters. The nature of traumatic events influences the incidence of PTSD (Kim et al. 2018). Rescue tasks indicate the most significant increase in PTSD levels (Jo et al. 2018). In addition to this, it is known that the quality of sleep is related to the symptoms of PTSD. In a sample of firefighters, 6.4% reported symptoms of PTSD, whereas 80% of this sample had poor sleep quality (Khumtong and Taneepanichskul 2019). Occupational stress may be related to the incidence of PTSD, as confirmed by Chiang et al. (2020). He found that higher levels of PTSD are associated with greater dissatisfaction with work. PTSD symptoms increase suicide risk among firefighters (Boffa et al. 2018; Stanley et al. 2017). One of the activities with a possible link to the appearance of PTSD and other mental illnesses is the fight against forest fires (Groot et al. 2019). This increased risk of suicide may be related to cognitive concerns and susceptibility to anxiety (Boffa et al. 2018). However, firefighters with a higher perception of skills are more resistant to psychological symptoms and work-related stress (Lambert et al. 2012).

In a sample of firefighters studied by Stanley et al. (2018), 8.2% of individuals are at significant risk of suicide. When the activities are carried out with conscious of the exposed dangers, there is an attenuation between the symptoms of PTSD and the risk of suicide (Stanley et al. 2019). When work equipment has problems or the working conditions present challenges, the PTSD level increases (Sun et al. 2020). Despite this, it is known that the greater the symptoms of anxiety and PTSD, the greater the risk of suicide, as confirmed by Boffa et al. (2018), in male firefighters. According to Kim et al. (2020), the high rate of PTSD in firefighters may be associated with an increased risk of depression, suicide, and problems related to the ingestion of illegal substances. Firefighters need to have meaning in life and find a reason for job satisfaction to avoid psychiatric symptoms (Krok 2016).

The relationship between psychiatric illnesses and decreased cognitive function seems to be strongly linked. In individuals with PTSD, there is a negative relationship with cognitive Assessment (Huang et al. 2019). Exposure to various sources of stress affects psychological well-being. Mindfulness can be a buffer against the effects of stress (Smith et al. 2019).

5 Conclusions

The tasks carried out by firefighters are mentally demanding as they face traumatic events daily. In the long term, even mentally healthy individuals are susceptible to developing psychological illnesses associated with the activity of firefighting.

Studies have already revealed the high prevalence of anxiety, Burnout, depression and PTSD among firefighters. However, there is still a need to relate these diseases to the types of tasks developed in firefighter activity. It is necessary to develop further studies in this area of research, finding ways to reduce the psychological impacts caused by the activity.

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Positive Impacts of Integrating Lean Methodologies and Ergonomics—A Literature Review

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Abstract In the last decades, more and more companies have adopted continuous improvement strategies to increase competitiveness. To that end, Lean Manufacturing is one of the most used approaches. However, the workload imposed by Lean manufacturing can be higher than the workers' capacity. Understanding how the workload demanded by the Lean models affects workers' health and well-being became highly relevant to the companies. This work carried out a literature review on the topic. It aims to clarify the actual impacts for companies of integrating Lean Methodologies with Ergonomics. Moreover, it is expected to enhance the most common ergonomic methods used. The research was performed on two highly regarded scientific databases, the Scopus and Web of Science, and included articles published between 2013 and 2022. A total of 16 articles were selected based on the inclusion criteria. Results show that a few studies focus on the relationship between Continuous Improvement and Ergonomics. Nevertheless, the articles analysed evidenced the positive effects of integrating the two areas, both for companies and workers. In addition, the integrated approach enables the identification of the risk factors imposed by the Lean methodologies and the definition of adequate strategies to mitigate the risk.

Keywords Lean · Ergonomics · Continuous improvement · Risk assessment

1 Introduction

Several companies worldwide have adopted Lean methodologies to improve operational performance (Sakthi Nagaraj et al. 2019). Lean Thinking focuses on eliminating everything that does not directly contribute to the added value of a product

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from the perspective of customer needs and requirements (Arezes et al. 2015). As a result, products have better quality at the lowest cost and with the shortest lead time by reducing the production flow, eliminating waste, and involving labor (Costa et al. 2019). This approach comprises four subsystems: Just-In-Time (JIT) manufacturing, Quality Management (QM), Total Preventive Maintenance (TPM), and Human Resources (HR) management practices (Longoni et al. 2013).

When well implemented, Lean provides benefits such as the possibility of task variety, job security, financial incentives, and worker autonomy (Tortorella et al. 2017). However, it is estimated that only about 10% of the companies that adopted Lean methodologies managed to implement them sustainably (Sakthi Nagaraj and Jeyapaul 2021). One of the reasons why results are not as good as expected is that many companies focus only on Lean tools and techniques, neglecting Human Factors and Ergonomics (Alsaffar and Ketan 2018a; Sakthi Nagaraj et al. 2019). Lean production is more demanding on a muscular, cognitive, and emotional level since it increases the pace and workload, leading to fatigue and stress (Nunes 2015; Stimec and Grima 2019; Vukadinovic et al. 2019; Colim et al. 2021).

The problem can be more significant if workers do not report their illnesses and refrain from reporting injuries or requesting sick leave, which is common when they suffer from pressure imposed by their colleagues (Koukoulaki 2014). In addition to this, there is a tendency for companies to neglect the comparison between the required workload and the actual workload, both psychologically and physically (da Silva et al. 2016).

The main objective of Ergonomics is to develop and apply techniques to adapt man to his work efficiently and safely, optimize well-being and consequently increase productivity (Santos et al. 2015).

To ensure companies' continuous improvement without compromising workers' health and well-being, integrating Lean Management techniques and ergonomic methods is extremely important. This integration may boost productivity, improve working conditions, and reduce worker absenteeism (Colim et al. 2021).

Several authors suggest different methodologies that intend to integrate Hard Lean, namely the production process, and Soft Lean, a practice related to humans and their interaction with the system (Sakthi Nagaraj et al. 2019). Although these methodologies come from different authors, they have the same goal to improve the physical and psychological aspects of workers' health while ensuring the company's economic success. Although there is a growing concern in several entities, this is still not considered a priority theme (Longoni et al. 2013).

A short literature review on the subject was developed to understand and identify what has been done in recent years regarding applying Lean methodologies and ergonomic assessment methods. To this end, two research questions (RQ) were formulated:

RQ 1: Which ergonomic methods have been applied to assess the risk imposed by Lean methodologies?

RQ 2: What are the positive impacts of integrating Lean Methodologies and Ergonomics?

The article is organized as follows: Section 2 describes the Research Methodologies where the research is described; Section 3 includes a detailed analysis of the selected articles; and Sect. 4 provides a Conclusion of the main findings.

2 Research Methodology

This research consists of a systematic literature review to evidence the work that has been developed in the recent years among the application of Lean methodologies integrated with Ergonomics. The study aimed to understand it by answering the two research questions described in the previous section.

While conducting the research, the following inclusion criteria were considered:

- Articles published between 2013 and 2022;
- Articles that are written in English;
- Articles that integrated Lean methodologies with Ergonomics.

The search was conducted using Scopus and Web of Science and combined four keywords: Ergonomics, Continuous Improvement, Lean, Kaizen and DMAIC.

Initially, 271 articles were found in the two research databases. After analyzing their titles, keywords, and abstracts, only 30 articles were selected to be deeply analysed. Finally, after a thorough screening, it was verified that only 16 articles followed the third inclusion criteria. Therefore, 16 articles were used to pursue this research work.

3 Results

The 16 articles carefully analyzed. Table 1 summarizes the articles and points out the associated benefits.

3.1 Model Proposal Through a Case Study

One of the studies consists of developing the Ergo-VSM tool in the textile industry. Authors initially defined a set of metrics related to the ergonomic aspects studied (e.g., psychological, and physical factors) and the Lean ones (e.g., cycle time). Measurements were taken to quantify the different Lean metrics. Subsequently, the operation under study was divided into different tasks to which ergonomic scores were assigned (obtained through observation and questionnaires). These were considered low, medium, or high risk depending on the score obtained. Thus, ergonomic measures were implemented according to the risk level. Finally, the parameters were

Table 1 Summary of the articles analysed

References	Study type	Ergonomic aspects	Aim of the study	Benefits of including the approach
Sakthi Nagaraj et al. (2019)	Model proposal through a case study	Physical Psychological Organizational Risks	Development of the Ergo-VSM tool, in the textile industry, to evaluate the risk level of each operation task. After the evaluation, a set of ergonomic measures were developed	Improved workers' quality of life and organizational performance Healthier organizations (for workers and management)
da Silva et al. (2016)	Model proposal through a case study	Physical Psychological	Development of a model, in the automotive industry, to identify the differences between estimated and actual work required at the ergonomic level	Understanding ergonomic factors in the implementation of Lean methodologies and where to act in the medium and long term
Botti et al. (2017)	Model proposal through a case study	Combining Ergonomics with Occupational Safety	The ILP model seeks to find the optimal sequence of an assembly line in a toolbox production. It includes an ergonomic evaluation using the OCRA index and two functions that drive its optimization: one addresses the Lean principles of JIT production and WIP reduction; another aims to reduce the overall cost of the hybrid assembly system	Respect for ergonomic principles of occupational health and safety Assembly line optimization WIP and cost minimization

(continued)

Table 1 (continued)

References	Study type	Ergonomic aspects	Aim of the study	Benefits of including the approach
Alsaffar and Ketan (2018b)	Model proposal through a case study	Musculoskeletal injuries	Development of a methodology, in the automotive industry, that combines Ergonomics principles, through job rotation, with Lean approaches, Muda waste and SS with DMAIC phases focused mainly on WIP efficiency and Ergonomics	Reduce waste, NVA, and musculoskeletal injuries Increased efficiency Improved ergonomic conditions
Alsaffar and Ketan (2018a)	Model proposal through a case study	Risks inherent to the workstation	Model applied in the automotive industry based on the integration of LSS and Ergonomics by designing a diagnostic ES that combines time-wasting-centric tools Mura and RULA. This identifies the risk level regarding posture as part of the Lean practice used at workstations	Simple methodology although highly efficient in the implementation of productivity measures and assessments and ergonomic actions Increased assembly line efficiency by reducing Mura waste

(continued)

Table 1 (continued)

References	Study type	Ergonomic aspects	Aim of the study	Benefits of including the approach
Vukadinovic et al. (2019)	Methodology development	Human Resources Management	Creation of the "Early Management and Human Resources development" technique that recommends 7 steps to be developed by companies. They claim that if the steps are carried out successfully then the workers will exhibit safer and more ergonomic behaviors without the need for training	Increased cooperation between companies and educational institutions New workers start working at 100%, without the need for training or eliminating the problem of inadequate preparation
Tortorella et al. (2017)	Model proposal through a case study	Physical Psychological	Use of questionnaires and a mathematical model to verify risks of Lean and Ergonomic methodologies applied in the automotive industry. Thus, it was possible to prioritize the improvement opportunities to be implemented according to the level of risk	Improving long-term ergonomic issues Identifying gaps in the Lean process by anticipating problems
Colim et al. (2021)	Methodology development	Musculoskeletal injuries	Evaluation of the effect of implementing robotic technology, in a board production, through KPI's related to Lean metrics and ergonomic characteristics	Reduction of production times, cycle times, and raw material consumption Improved ergonomic conditions and worker well-being

(continued)

Table 1 (continued)

References	Study type	Ergonomic aspects	Aim of the study	Benefits of including the approach
Longoni et al. (2013)	Methodology development	Combining Ergonomics with Occupational Safety	Development of a methodology, in the production of metal, plastics and furniture, based on a Service Profit Chain (SPC) model to verify the impact of implementing different Lean methodologies on ergonomics and occupational safety	Lean impact reduction in Ergonomics and Safety when the methodologies are applied in an integrated and correct way, with emphasis on human resources
Sakthi Nagaraj and Jeyapaul (2021)	Model proposal through a case study	Physical Psychological Organizational Risks	Through an SEM-based analysis it was possible to calculate the correlation between physical, psychological, management, workplace design, and cognitive factors with Lean performance and a positive influence was found	Relevance of considering human and organizational factors when implementing practices that achieve sustainable results

(continued)

Table 1 (continued)

References	Study type	Ergonomic aspects	Aim of the study	Benefits of including the approach
Nunes (2015)	Methodology development	Physical Psychological	Development of a DSS to assist managers with the activities required by each phase of the DMAIC cycle. This helps the choosing and application of the tools and methods used by the Ergonomics and LSS paradigms, in the integrated implementation of continuous improvement in enterprises	Integration of Ergonomics during LSS implementation Substantial productivity gains and improved working conditions
Brito et al. (2020)	Methodology Improvement	Combining Ergonomics with Occupational Safety	Improvement of ErgoSafeCI methodology adapting it to the plastic packaging sector, in which ergonomics was divided into Physical and Organizational and Cognitive. The software itself has been improved to make it more automated	Improved productivity and worker conditions Improved ErgoSafeCI tool making it easier to apply
Stimec and Grima (2019)	Interviews/Questionnaires	Occupational stress	Questionnaires and interviews were conducted to identify the relationship between Lean methodologies applied to production and the occupational stress caused by them	Positive effects on workers' stress and absenteeism Rapid identification or anticipation of work impeding factors

(continued)

Table 1 (continued)

References	Study type	Ergonomic aspects	Aim of the study	Benefits of including the approach
Santos et al. (2015)	Interviews/Questionnaires	Physical Psychological	Questionnaires and interviews were conducted in an automotive industry, to identify workers' opinion regarding the workstation, considering ergonomic factors and the application of methodologies to the production system. It is possible to verify where the company needs to act and how the working conditions must be improved	Top management awareness of workers' health Reduction of accident risk in the workplace Improved product quality
Afonso et al. (2022)	Model proposal through a case study	Musculoskeletal injuries	The proposed ESMED model successfully integrated SMED and ergonomics in a detailed and well-defined approach aiming the reduction of the risk associated with injuries and streamline setup processes	Reduction of the risk level of Work-Related Musculoskeletal Disorders Increased production efficiency
Mrugalska (2020)	Methodology development	Combination of ergonomic with lean competences	An integrated model of lean and ergonomic competencies is presented, and these initiatives are shown at different stages of their development	Organizational vision and focus on value systems, Creation of beneficial relationships, dynamic coaching and problem solving, Attempt for improvement and development

measured once again. Significant improvement was verified (Sakthi Nagaraj et al. 2019).

Another study focused on developing a tool that identifies the differences between estimated and actual work. First, different physical and psychological criteria were defined to be evaluated. Then, questionnaires and observations were performed to analyze the Lean production cells and their operations. Finally, the actual physical and psychological demands were classified, and the difference between these and those estimated by management was calculated (da Silva et al. 2016).

Integer Linear Programming (ILP) is another model that aims to find the optimal sequence for an assembly line. The model assigns workers or machines to each workstation given the characteristics of the assembly process and the working parameters of the machines. Each assembly sequence includes ergonomic risk assessment using the Occupational Repetitive Actions Index (OCRA) to meet occupational health and safety requirements. Two functions drive the optimization of this model. First, one addresses the Lean principles of JIT production and Work in Progress (WIP) reduction. Another aims to reduce the overall cost of the hybrid assembly system (Botti et al. 2017).

Finally, two other studies developed the "LSS + Ergo" methodology, starting by identifying the 7 Muda wastes in each workstation.

Subsequently, for the first study, two models were created:

- Efficient Process Flow and Time—to prevent Muda by implementing effective and appropriate Lean tools.
- Working Condition versus Ergonomics—assessment of losses from an ergonomic perspective.

Both models have been integrated into an Expert System (ES) that aims to facilitate the execution of the DMAIC cycle. Finally, it was possible to derive practices that should be implemented, such as job rotation, to reduce waste, NVA activities, and risks and injuries associated with the job (Alsaffar and Ketan 2018b).

The second study proposes the same ES; however, this one combine tools focused on time-wasting, such as Mura and Rapid Upper Limb Assessment (RULA). It identifies the risk level associated with postural movements as part of the Lean practice used at workstations. First, the ergonomic problems and risk factors associated with the workstations were identified. Then, RULA was used to calculate the risk level of musculoskeletal disorders. Finally, the results that correlate Mura waste with ergonomic working conditions were obtained along with the measures that should be applied (Alsaffar and Ketan 2018a).

The last case study reviewed proposes an Ergonomic solution based on Lean Manufacturing in the metalworking industry based on continuous improvement. Through the application of RULA, the need to make immediate changes in the process activities was found. Implementing a Lean practice made it possible to, after the integrated application of Lean and Ergonomic tools, verify an improvement in several metrics associated with them. This study has shown that the lack of an ergonomic analysis can be considered a waste within the Lean philosophy. When applied in organizations, it can increase efficiency and promote the continuous elimination of waste, ensuring financial and workers' health (Miguez et al. 2018).

3.2 Methodology Development

The first article in this section (Vukadinovic et al. 2019) was based on the creation of the "Early Management and Human Resources Development" technique, summarized as follows:

- Focus on training the company's human resources in Lean knowledge. Thus, in the recruitment process, they will be able to identify the characteristics of the candidates that are best suited for the job.
- They recommend a merger between companies and universities to train future candidates to use ergonomic guidelines when exposed to Lean methodologies.

Another study (Tortorella et al. 2017) shows that workers were exposed to Lean work practices; however, sustainable work was never adopted, especially regarding ergonomics. Thus, a method consisting of 3 steps was applied:

- Determination of Lean and Ergonomic practices adopted in the company through two questionnaires given to senior individuals.
- Through creating a mathematical model, it was possible to calculate the risk level of Lean methodologies.
- Consolidation and prioritization of improvement opportunities according to risk level.

Another methodology studied is related to the high manual work in the assembly of frames that causes musculoskeletal injuries. Implementing more ergonomic ways of working was necessary through more robotized work. Before and after implementing the robotic technology, the workstation was evaluated to understand whether the tasks brought value by measuring different key performance indicators (KPIs). Subsequently, an evaluation of the ergonomic characteristics was performed using three evaluation methods: RULA, Revised Strain Index (RSI), and Key Indicator Method for assessing physical workload during Manual Handling Operations (KMI-MHO). Finally, a questionnaire was conducted to assess workers' perceptions of the inclusion of a hybrid industry (human and robot labor) and the associated ergonomic improvements (Colim et al. 2021).

The Service Profit Chain (SPC) model (Longoni et al. 2013) is based on different industries, such as metal, plastics, and furniture manufacturing. The different phases that involved the creation of the methodology consisted of:

- Conducting interviews and sending anonymous forms to understand the previously selected companies better. In these forms, it was asked which Lean methodologies are currently applied.

- From the data collected, the companies were divided into four groups according to the 4 Lean methodologies considered most important to the researchers (JIT, QM, TPM, and HR).

The role of HR for Ergonomics and Occupational Safety was found to be vital when compared, for example, with companies that only implemented JIT (Longoni et al. 2013).

Another study performed a Structural Equation Modeling (SEM) analysis (Sakthi Nagaraj and Jeyapaul 2021). It was based on the following phases:

- Separating the subjects under study into six branches: physical, psychological, management, workplace design, cognitive factors, and Lean performance.
- Selection of 29 measurement items used to construct online questionnaires and telephone interviews to assess the six branches.
- Development of a measurement model after data collection allowed studying the correlation between physical, psychological, management, workplace design, and Lean performance factors, with a positive influence.

The last methodology studied consists of developing a Decision Support System (DSS) that allows managers to be assisted in the activities required by each phase of the DMAIC cycle. The objective is to help choose and apply the tools and methods used by the Ergonomics and Lean Six Sigma (LSS) paradigms in the integrated implementation of continuous improvement (Nunes 2015).

3.3 Methodology Improvement

The study is based on the improvement of the ErgoSafeCI tool. The objective was to improve ergonomic and safety conditions for workers while maintaining productivity and a focus on performance indicators. Firstly, all the issues belonging to the tool were analyzed to understand whether they should be adapted to the productive reality of the plastic packaging sector. Secondly, a literature review on Lean, Safety, and Ergonomics was done to improve the tool's questions. From this analysis emerged the separation of Ergonomics into three parts: Physical, Organizational, and Cognitive. In addition, some questions had to be added to the tool to improve the evaluation of the jobs. The third phase improved the software, mainly by automating as much as possible to make the tool easier to use. Finally, based on the results obtained, improvements were introduced to increase the productivity and well-being of the workers (Brito et al. 2020).

3.4 Interviews/Questionnaires

In the first phase, questionnaires and interviews were conducted to understand what happens on the "shop floor" (Stimec and Grima 2019). The goal was to identify the links between Lean (namely Continuous Improvement) and occupational stress based on three questions:

- Characterization of continuous improvement. This was defined based on training and education, management commitment and involvement, and worker participation and empowerment. It was found that the workers had already received the training. The remaining factors were evaluated based on the data collected. A panel of experts assessed the level of continuous improvement and Lean performance.
- Industrial performance: the expert group classified industrial performance into 3 levels.
- Occupational stress performance: the experts relied only on psychometric questionnaires.

Finally, in the last method analyzed, questionnaires and interviews were conducted to identify the workers' opinions regarding the workstation, considering ergonomic factors and the organization and application of methodologies to the production system. After collecting the data, it is possible to ascertain the situation regarding Lean concepts that have been applied to production correlated to Ergonomics and Working Conditions. In this way, it is possible to see where the company needs to act and how the working conditions need to be improved (Santos et al. 2015).

4 Discussion and Conclusions

Worldwide, several companies have started to adopt Lean methodologies to achieve excellent performance through a culture of continuous improvement in a very competitive environment. It happens because Lean methodologies, when well implemented, provide better operational and financial performance for a company.

However, although there is a concern with implementing Lean methodologies, the same concern is not witnessed for integrating ergonomic strategies from the initial stage. It can be seen by comparing many studies on Lean and the small number of studies that consider the integration of both topics.

This review article considers different methodologies and studies that demonstrate the importance of integrating Ergonomics with Lean and Six Sigma methodologies. Many include questionnaires, interviews, DSS, ES, and even mathematical models. The literature research developed focused on two research questions.

Regarding RQ1, it was verified that most authors had used questionnaires and interviews conducted primarily with engineering or Lean professionals. These are the primary purpose of obtaining the data needed to create the tools. Overall, we can say that the integrated ergonomic assessment methods depend on the type of Lean methodologies implemented by the companies since they may represent different risk factors and different risk levels. For example, if the focus is to quantify wasted time, combining the MURA reducing tools from Lean with the standard ergonomic assessment methods (e.g., RULA) is expected. Another example is robotization through Lean metrics but designed with ergonomic characteristics. This combination improved productivity and provided benefits for the worker as the monitoring and control of interfaces replaced manual and repetitive work.

In addition, the research demonstrated that many authors proposed and implemented integrated models that are very specific to a company or to a type of industry. A relevant topic for future studies would be identifying complementary criteria to ensure that the models could be used in different companies or contexts.

Regarding RQ2, the research showed that combining Lean methodologies and ergonomic principles can positively impact an organization. Through the 16 articles used in this research, it was possible to identify numerous benefits associated with this integration. Among the benefits, the following should be highlighted:

- Development of practices that benefit both Lean implementation and worker from an ergonomic point of view. An example is the job rotation that eliminates waste and reduces the risk of injury.
- Prioritization of opportunities for continuous improvement based on the ergonomic risk level obtained by specific methods; in this way, the organization realizes where it should act in the short and medium term.
- Improvement of workers' quality of life by reducing the stress and the risk of musculoskeletal disorders/work accidents.
- Improvement of the organization's performance by reducing production times, cycle times, and resources and, consequently, reducing costs and increasing productivity and quality.
- Increased awareness of top managers regarding workers' health.

As a result of this research, it can be concluded that the integration of Lean and Ergonomics is an asset for both companies and workers.

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