Chapter 3
Mental Workload Management and Evaluation: A Literature Review for Sustainable Processes and Organizations

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Abstract Current organizational and manufacturing processes imply high mental workload demands that can be evaluated through the construct of MWL (mental workload). This term is often used in new manufacturing and organizational environments, which have replaced physical tasks with cognitive activities involving a high MWL. By overusing the attentional resources given to the tasks, such work environments are placing high cognitive loads on operators, thus affecting their performance and causing them to experience mental fatigue. A formal evaluation of MWL offers the opportunity to prevent mental disorders and maintain mental health. On the other hand, the lack of evaluation and proper management of MWL in the industry can result in errors that create economic costs, accidents, injuries, or even deadly events. Finally, MWL assessment and management can be a human-oriented strategy designed to improve and sustain the future of an organization. Industries must find competitive advantages in sustainable processes from the economic, environmental, and social view. In this sense, this chapter aims to present a literature review to provide a comprehensive literature analysis of MWL evaluation and management for sustainable processes in the manufacturing industry, from a social perspective.

Keywords Mental workload · Sustainable process · Cognitive ergonomics

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3.1 Introduction

Workload has an impact on any kind of work, especially in performance. Gore (2018) classifies workload into a physical load, mental load, or the load associated with the effort required to meet task demands. Current workplaces in manufacturing organizations show a growing trend in the amount of mental workload (MWL) demand on workers, which has led researchers to focus on different ways of evaluating MWL (Estes 2015; Haji et al. 2015; Park et al. 2018).

3.1.1 Mental Workload Evaluation in Organizations

Several models have been proposed to evaluate MWL in a wide range of contexts. However, most of them have been applied and used in organizations. These models entail diverse techniques for conducting employees' MWL assessment; they can be classified into physiological, subjective, and analytical ones. This section describes its main characteristics, advantages, and disadvantages.

Physiological measures are based on the use of certain cognitive activities associated with physiological variations in people, where variation in the measurements is affected by the increase or decrease in the MWL generated by the working task. The main advantage of this kind of measurement is that they do not interfere with the performance of the primary task. Some disadvantages, however, are that they can be affected by the worker's health and that the equipment necessary for its execution can be expensive and/or difficult to manage.

In contrast, the subjective rating models analyze the worker's perception of the task's complexity and are usually performed once the task is executed. The advantages of these types of techniques are their ease of use, their short administration time, and their low cost. In contrast, they show certain disadvantages when the MWL rate correlates with workers´ performance. Additionally, the outcomes can be affected by respondents' factors such as partiality, response sets, errors, and attitudes of protest (Yan et al. 2017).

The analytical techniques to measure MWL are performed through mathematical modeling and computer simulation. One advantage is that computer systems are quite common and highly potent nowadays, which facilitates the work of math modeling and simulation significantly. A disadvantage, however, is that they are more difficult to understand and apply.

3.1.2 Techniques for Measuring Mental Workload

3.1.2.1 Properties of Techniques Used for Measuring Mental Workload

Wierwille and Eggemeir (1993) compile and determine the properties that any mental workload evaluation technique should comply with, and they are as follows:

- Sensitivity: the degree to which a given workload technique can distinguish differences in the levels of the load imposed on an operator.
- Intrusion: an undesirable feature in which the introduction of the MWL measuring technique causes a change in worker's performance.
- Diagnosticity: defined as the ability to distinguish the cause or type of MWL or the ability to attribute it to an aspect of the task.
- Global Sensitivity: the potential to reflect discrepancies in different types of resource expenditure or factors that influence MWL.
- Transferability: refers to the capability of a technique to be used in various applications.
- Implementation requirements: consist of any instrumentation necessary to present and analyze information or record data, including aspects such as time, data collection procedures, or subject training.

3.1.2.2 Physiological Measurement Techniques

The following physiological techniques to measure MWL can be highlighted:

- Heart rate (HR) is the number of times a person's heart beats per minute. The normal range for adults is 60 to 100 beats per minute but can vary from person to person. Several authors mention that heart rate increases when MWL appears (Fallahi et al. 2016; Yan et al. 2017).
- Heart rate variability (HRV) is a measure that indicates the variation in a person's heartbeat within a specific interval. When the intervals between the heartbeats are relatively constant, the HRV is considered low; if their length varies, the HRV is high. The spectral HRV analysis enables the break down into components associated with different biological mechanisms such as the low-frequency power/high-frequency power (LF/HF) ratio, the men inter-beat (RR), and the standard deviation of normal RR intervals (SDNN) (Yan et al. 2017). HRV decreases concerning MWL (Heine et al. 2017; Mandrick et al. 2016).
- Salivary cortisol: Cortisol (hydrocortisone) is a steroidal or glucocorticoid hormone synthesized by the adrenal gland, released in response to stress and responsible for the reduction of glucocorticoid levels in the blood. Cinaz et al. (2013) state that in some individuals, cortisol levels increase concerning MWL, while in other cortisol levels stay the same or decrease. These responses might be explained by the conclusions that uncontrollable and social-evaluative stressors are associated with the changes in cortisol.

- Blink rhythm and duration: Blinking is a semi-autonomic, rapid closing of the eyelid. Nowadays, researchers think blinking may help humans to disengage their attention as following blink onset, cortical activity decreases in the dorsal network and increases in the default-mode network, which can be associated with internal processing. Thus, eye blinking frequency and duration decrease with MWL (Yung and Wells 2017).
- Ocular fixation duration: This is the period when the eyes remain relatively static. Teo et al. (2015) reference that fixation duration is shorter when MWL is present.
- Pupil dilation (PD): The size of the pupil is controlled by the activities of two muscles: the circumferential sphincter muscle, found in the margin of the iris and innervated by the parasympathetic nervous system; and the iris dilator muscle, running radially from the iris root to the peripheral border of the sphincter. Yan et al. (2017) mention that human pupil dilation may be used as a measure of psychological load because it is related to the amount of cognitive control, attention, and cognitive processing required for a given task.
- Intraocular pressure (IOP) is a measurement involving the magnitude of the force exerted by the aqueous humor on the internal surface area of the anterior eye. Higher intraocular pressure values are associated with high workload levels (Jiménez et al. 2018; Vera et al. 2017).
- Electromyography (EMG) is a diagnostic procedure that evaluates the health condition of muscles and the nerve cells that control them. Fallahi et al. (2016) found a relationship between EMG amplitude increase and MWL.
- Electroencephalography (EEG) measures voltage fluctuations resulting from ionic current within the brain's neurons. EEG activity is often decomposed into frequency bands delta (up to 2 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–25 Hz). Charles and Nixon (2019) pointed out that brain activity establishes a promising indication of MWL; however, data measurement and analysis remain complex.
- Near-infrared reflectance spectroscopy (NIRS): A non-invasive technique uses light transmission and absorption to measure hemoglobin and mitochondrial oxygenation. Reduced cerebral blood oxygen saturation in the left prefrontal cortex (PFC) is associated with fatigue (Liu et al. 2016).
- Functional near-infrared spectroscopy (fNIRS) is the use of near-infrared spectroscopy with the objective of functional neuroimaging. Brain activity is assessed through hemodynamic reactions associated with neuronal behavior. Banville et al. (2019) point out that several fNIRS features correlate significantly with the temporal demand and performance dimensions of the NASA-Task Load Index (NASA-TLX) methodology to measure MWL.
- Respiration depth (RD) refers to the volume of the breath. Respiration volume decreases as MWL increases (Charles and Nixon 2019).
- Respiration rate (RR) accounts for the number of actions indicative of inspiration and expiration per unit of time. The normal respiratory rate for healthy adults is between 12 and 20 breaths per minute. However, RR increases as MWL increases, but it is also contingent on physical activity (Charles and Nixon 2019).

- Saccade rate (SR): The brain commands sent to the eye muscles result in the eyes making a rapid, step-like rotation following which the eyes remain stationary at their new position. These step movements are known as saccade eye movements, which increase with MWL (Cai et al. 2016).
- Systolic blood pressure (SBP) is the amount of pressure in the arteries during the contraction of the heart muscle. SBP increases with the difficulty of a task (Fairclough and Ewing 2017).
- Diastolic blood pressure (DBP) is the pressure in the arteries when the heart rests between beats. DBP increases with an increment in workload (Klonowicz 2015).
- Facial thermography: This technique detects heat patterns created by the branching of blood vessels and issued from the skin. Marinescu et al. (2016) mention that facial thermography is a good method for non-intrusive MWL measurement as temperature variations on some areas of the face appear to be strongly associated with the changes in MWL.
- Electrodermal activity (EDA) describes the phenomenon in which the skin momentarily becomes a better conductor of electricity when either external or internal physiologically arousing stimuli occur. The disadvantage is that they require the control of several factors such as temperature, humidity, time of day, emotional state, and irregularities in respiration (Charles and Nixon 2019).

3.1.2.3 Subjective Techniques

Concerning subjective techniques to measure MWL, fourteen methods can be mentioned:

- NASA-TLX: It is a subjective evaluation technique designed by Hart and Staveland (1988), divided into six subjective subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. In the first part of this test, each subscale is to be rated within a 100-point range with 5-point steps. These ratings are then merged to obtain the task load index. The other part of the test proposes to generate an individual weighting of these subscales by letting individuals equate them pairwise based on their perceived weight. NASA-TLX is currently one of the most widely used indices to evaluate subjective MWL (Bommer and Fendley 2018; Cowan et al. 2018; Galy et al. 2018).
- Workload profile (WP) is the label for a multidimensional MWL assessment tool, elaborated by Tsang and Velazquez (1996) and used to determine demand ratings imposed by a task on the eight following dimensions: perceptual processing, response selection and execution, spatial processing, verbal processing, visual processing, auditory processing, manual output, and speech output.
- Subjective rating of mental effort (SRME). It was developed by Paas (1992) as a unidimensional 9-point rating scale, which asks participants to rate how much mental effort they've invested in a task, ranging from (1) very, very low mental effort to (9) very, very high mental effort (Paas 1992).
- Modified Cooper Harper: The Cooper Harper Scale (Cooper and Harper 1969) is a decision-tree rating scale that was originally developed as an aircraft handling

measurement tool. The modified Cooper Harper scale is a unidimensional measure that uses a decision tree to elicit operators' MWL (Wierwille and Casali 1983) based on the assumption that there is a direct relationship between the level of difficulty of aircraft controllability and workload on the pilot (Wierwille and Casali 1983).

- Standardized Copenhagen Psychosocial Questionnaire II (COPSOQ II): It was developed by Pejtersen et al. (2010) because of the first version of the Copenhagen Psychosocial Questionnaire (COPSOQ I) failure to address important aspects relative to work. The COPSOQ II solved these limitations and incorporated aspects arising from the former questionnaire.
- Dundee Stress State Questionnaire (DSSQ): It was developed by Matthews and colleagues in 1999 as a questionnaire based on a factor model distinguishing eleven primary state factors that cohere around three higher-order dimensions: task engagement, distress, and worry (Matthews et al. 1999).
- Short State Stress Questionnaire (SSSQ) is a self-report measure of stress based on the DSSQ and developed by Helton (2004).
- Integrated Workload Scale (IWS): This is a scale for real-time assessment of subjective workload, initially designed to be used with train traffic controllers (Pickup et al. 2005). It consists of nine points that describe the degree of MWL and captures the multidimensionality of workload by integrating elements that reveal time, demand, and effort.
- State-Trait Anxiety Inventory (STAI): An assessment developed by Spielberger et al. (1970) and a Spanish edition the next year (Spielberger et al. 1971); it is used to measure trait and state anxiety through 40 items, 20 for assessing trait anxiety and 20 for state anxiety, all rated on a 4-point scale.
- Instantaneous self-assessment of workload technique (ISA): It is a unidimensional scale developed by the United Kingdom Civil Aviation Authority to provide subjective ratings of workload during air traffic control tasks. It uses five different ratings for perceived workload: excessive, high, comfortable, relaxed, and underutilized; Castle and Leggatt (2002) published the validity and reliability of the method.
- Subjective Workload Assessment Technique (SWAT): Reid and Nygren (1988) developed this tool, based on the thought that MWL is planned to be a multidimensional concept that can be largely explained by three factors: time load, mental effort load, and psychological stress load.
- Simplified Subjective Workload Assessment Technique (S-SWAT): SWAT presented two main problems: The first one is related to its lack of sensitivity for low MWL (Nygren 1991) and the second one to the time-consuming card sorting (Luximon and Goonetilleke 2001). The discrete SWAT subscale and the other four used the continuous SWAT subscale, resulting in the S-SWAT technique being more sensitive than the original SWAT scale (Luximon and Goonetilleke 2001).
- Verbal Online Subjective Opinion scale (VOSO): It consists of unidimensional rating systems, where subjects provide a verbal estimate of MWL on a scale

between 0 and 10. This scale is very sensitive to short periods of mental load (Miller 2001).

- For very particular investigations and in rare cases, researchers choose to develop their own assessment techniques that could be a direct interview with the subjects including very specific questions and recording to analyze emotions and gestures and/or assessments made specifically with the points related to the research on hand; an example is found in the research by Cruz Espinoza (2017).

3.1.2.4 Analytical Techniques

Additionally, five models related to analytical techniques for MWL measurement published from 2015 to 2019 were found:

- Improved Performance Research Integration Tool (IMPRINT): It is a human performance-modeling tool that uses discrete event simulation to predict MWL. The Human Research and Engineering Directorate (HRED) of the United States Army Research Laboratory (ARL) Combat Capabilities Development Center (CCDC). Data and analysis Center developed this tool. It was developed using the NET framework, which operates under the Microsoft Windows operating system to evaluate human-system function allocation, human performance, and MWL (Allender 2000).
- Model Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE): This is a biomathematical fatigue model developed by the US Army Research Lab. It analyzes an array of relevant sleep factors; among them are acute sleep interruptions, cumulative sleep debt, the consistency of sleep onset and wake times, and circadian disruptions that influence a change in cognitive function to accurately predict fatigue. Once this information is provided, the SAFTE Fatigue Model can accurately predict changes in cognitive effectiveness throughout the work hours (US Army Research Lab 2019).
- Adaptive Control of Thought-Rational (ACT-R): This cognitive architecture-based system stemmed from the assumption of a unified theory of mind. Simulations with ACT-R allow for the prediction of typical measures in psychological experiments such as latency, accuracy, and neurological data, which help understand human cognition. It was developed by John Robert Anderson and Christian Lebiere at Carnegie Mellon University (Anderson and Matessa 1998).

3.1.3 Issues, Controversies, Problems

3.1.3.1 International Businesses in the Mexican Manufacturing Sector

Mexico is a country that is offering significant advantages related to manufacturing, such as low labor rates, convenient localization, and transportation infrastructure with cheap transportation costs of raw materials, and the ability to incorporate important sustainable manufacturing strategies such as just-in-time, kaizen, lean, and ergonomics. Additionally, Mexico counts on a highly skilled and motivated workforce at every business level. Additionally, an important factor is the existence of the IMMEX program (maquiladora program) which allows foreign manufacturers to import raw materials and components into Mexico, tax and duty-free, under the condition that 100% of the product will be exported out of Mexico within a government-mandated timeframe. The program aims to modernize the globalization of Mexico's manufacturing infrastructure by bringing new, specialized technologies and knowledge to the region (Stanley 2020).

Recently, in January 2020, the president of the United States signed the new North American Free Trade Agreement call USMCA (United States-Mexico-Canada Agreement) with new laws on intellectual property protection, the Internet, investment, currency, and additional provisions designed to identify and prevent labor violations, particularly in Mexico, all this in pursue of better international business relations.

3.1.3.2 Ergonomics and Humanistic Management for Sustainable Processes

Sustainable development has become a relevant topic. It refers to the development that fulfills the needs of the present, without compromising future generations' capacity to meet their own needs (United Nations 1987). This approach grants importance not only to the environmental aspect, but also to sustainable socio-economic development, where production processes are involved and terms such as humanistic management. In this approach, people turn out to be a priority above other variables to have a sustainable process. On the other hand, Ergonomics is the scientific discipline that undertakes the understanding of interactions between humans and other elements of a system, as well as the profession that applies theory, principles, and design to optimize human well-being and total system performance (IEA 2019). Accordingly, Radjiyev et al. (2015) affirm that ergonomics can be a significant factor in the transition to the sustainable development of production processes having because of sustainable processes.

Accordingly, several studies that have addressed how significant knowledge of ergonomics, such as human behavior, performance, and interactions with technology, can play an important role in the systems of sustainable and socially responsible manufacturing that current trends require (Thatcher et al. 2018; Kujawinska et al. 2015). These human factors are also key in the man-machine systems that new manufacturing environments and advanced manufacturing technology involve. These new working conditions demand a greater mental (cognitive) workload from workers, while the physical load required by work activities has decreased significantly, leading to the search for sustainable processes where the MWL is greater than the physical one (Haslam and Waterson 2013).

This means that new problems regarding workers' health have emerged in the work environment. These are mainly related to mental well-being rather than physical conditions. In cognitive ergonomics, it is critical to understand the influence of MWL over workers' performance, as mentioned by Young et al. (2015) in their work "State of Science: Mental Workload in Ergonomics," and more importantly, the actions that ergonomists can take to lessen the negative effects of MWL.

Human factors, especially cognitive ergonomics, should focus on being an alternative to study and improve the variables in the new international business/sustainable processes that affect the workers' performance in the search of better labor conditions, fewer job-related accidents, continuous improvement, and more productivity.

3.1.4 Cognitive Ergonomics and Sustainability

It is important to mention that MWL is not a variable that occurs only in office work environments or in association with senior management positions; it is also present in all kinds of work activities. That is the reason why Apud (2012) recommends the implementation of ergonomics and its guidelines in all types of workstations. On the other hand, according to Nieto (2014), occupational injuries and diseases have increased with a significant differentiation among the types of work as the conditions currently faced by employees that are related more to the cognitive aspect of the job than to the physical one. Accordingly, the mental demand that new sustainable processes place on their workers is increased to meet quality and customer service expectations.

In fact, the term "psychosocial risks" is becoming more common concerning occupational health. Such risks have been grouped, according to Gil-Monte (2012), in five areas:

1. New forms of contracting distinguished by the emergence of less favorable work contracts in conjunction with phenomena such as production scheduling and outsourcing and insecurity in the workplace.
2. The risk associated with the working population's aging and the delay in retirement age.
3. The intensification of work activities characterized by the need to handle more information and greater workload along with increased pressure from chief executive officers (CEOs).
4. The strong emotional demands at work as well as the increase in psychological harassment in the workplace.
5. The imbalance and conflict between work and personal life.

It can be inferred that these emerging psychosocial risks result in a greater MWL.

In conclusion, if the new international business wants to have a sustainable process, they need to measure MWL in their workers and have changes in their processes to increase productivity and avoid health risks in their job force.

3.2 Methodology

The specific objective in the literature review was to answer the question: What variables are being considered when measuring MWL and how are these variables being measured? To achieve this goal, a systematic literature review was conducted in the following databases: Science Direct, Google Scholar, Taylor & Francis Group, and SAGE journals. Likewise, the following journals were selected as they were considered to be more closely related to the subject of this work: Ergonomics, International Journal of Occupational Safety and Ergonomics (JOSE), Human Factors, the Ergonomics Open Journal, Procedia Manufacturing, Consciousness and Cognition, the American Journal of Engineering Research (AJER) and Medicina y Seguridad del Trabajo. Research articles, literature reviews, and theses that were written in Spanish and English from 2015 to 2019 were reviewed.

The general inclusion-exclusion criteria included the focus on adult subjects, research articles, thesis, and book chapters or review articles published between 2015 and 2019. It was focused on manufacturing, monitoring, and/or controlling processes, and studies in relation to the medical field were excluded because the activities performed are too specific to this field and not to any other; experimental and quasi-experimental studies were accepted with randomized assignation.

To perform the literature review in relation to ergonomics and sustainable production, six (6) articles were found in the last five years, all of them highlighting the relevant impact of ergonomics on sustainable development. Regarding mental workload, 610 articles were found in English, out of which 93 were selected considering these ones are related to manufacturing processes or activities that can be related to manufacturing activities. A considerable number of articles were found in relation to mental workload in medical activities of doctors and nurses and other health professionals; none of these were selected, because they are very specific to this profession. Ninety (90) more were found in Spanish, from which 4 articles and 3 theses/dissertations were selected after applying the same aspects applied in the English ones.

The authors of this work resorted to the ScienceDirect, Taylor & Francis, and Sage Journals' databases to find results in English as a greater number of indexed journals focusing mainly on the area of engineering (ergonomics/neuroergonomics/human factors) and manufacturing are published in this language.

Once the databases to be used were established and based on each of their advanced search characteristics, including only from 2015 to date and the words: ergonomics, sustainable production, and mental workload were chosen that would be the basis on which the searches would be performed.

In the final phase, titles and abstracts were thoroughly analyzed concerning the questions stated before.

When utilizing the ScienceDirect database, the term used was "mental workload." Once articles and book chapters related to medical processes or those dated before 2015 were excluded, 2808 results since 1995 decreased to 925. Then, only those publications related to manufacturing, vigilant, or attention processes

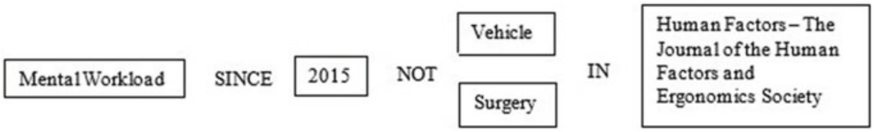

Fig. 3.1 Relationship between keywords and the logical operators for the SAGE database

with high mental workload were selected. We search in the following journals: Applied Ergonomics, Procedia Manufacturing, International Journal of Industrial Ergonomics, Accident Analysis & Prevention, Safety Science, International Journal of Human-Computer Studies, Neuroergonomics and Computer in Human Behavior excluding only IFAC-PapersOnLine and Transportation Research Part F: Traffic Psychology and Behavior, which reduced the number of articles to 308. Next, the 308 titles and their corresponding summaries were read, excluding those that did not seem to focus on the question "which are the variables to consider when measuring MWL, and how are these variables measured?" Eventually, only 56 articles were left to be included in the systematic review.

As for the Taylor & Francis database, 15,863 results were initially obtained using the term "Mental Workload." When excluding publications before 2015, the number lowered to 4,350. Then, the journals of Ergonomics and the International Journal of Occupational Safety and Ergonomics were selected because they focus on manufacturing or related processes and not medical, thus resulting in 247 publications being obtained, which were analyzed regarding the variables exposed before to end up with 27 articles significant to the research.

The SAGE database was searched through an advanced search using the term "mental workload"; 11893 results were found. When the search was refined to include only content published from 2015 to 2019 and to which the authors had full access, the number of results lowered to 3456, excluding the words "vehicle" and "surgery" in the journal "Human Factors—The Journal of the Human Factors and Ergonomics Society." The relationship in which these words and logical operators were used is shown in Fig. 3.1. The content of the remaining 55 articles was analyzed more thoroughly with a focus on the above-stated question, and in the end, only 10 articles remained.

3.3 Results

3.3.1 Summary of the Search in the Databases in English

A summary of the results obtained in the different phases of the systematic review is offered below.

In the first search, a total of 30564 articles were found. Table 3.1 shows the number obtained per database. During the second phase, all items that were not full

Table 3.1 Number of articles found by database in phase 1

Database	Number of articles
ScienceDirect	2808
Taylor & Francis	15863
SAGE Journal	11893
Total	30564

Table 3.2 Number of articles left by database after phase 2

Database	Number of articles
ScienceDirect	308
Taylor & Francis	247
SAGE Journal	55
Total	610

Table 3.3 Number of articles in the final selection

Database	Number of articles
ScienceDirect	57
Taylor & Francis	27
SAGE Journal	10
Total:	94

access articles, or book chapters, or were published before 2015 were eliminated. In addition, depending on the database, some journals were selected, while others were eliminated, after which keywords for further exclusion were used. Table 3.2 shows the results obtained after this process.

The final number of articles selected in each database is shown in Table 3.3.

3.3.2 Results of the Search by Keywords Related to Mental Workload Found in Spanish

When the words "Carga Mental," which is the Spanish term for "mental workload," were searched in Google Scholar, 2850 results were obtained. After filtering them by their title and publication date (2015 to present), the results decreased to 90. Finally, once those publications were analyzed concerning the question of variables and types of techniques related to MWL measurement, three thesis and four research articles remained.

3.3.3 Classifications of MWL Measurement Results

After this selection process, all one hundred and one items were reviewed in detail. As a result, they were classified in relation to their type of MWL measurement as shown in Fig. 3.2.

These articles feature a variety of different MWL measurements and techniques related to subjective measures. Their classification is shown in Table 3.4. In 41% of the studies, the NASA-TLX is used as a subjective measure for MWL; 15% use only subjective measurements; and from those, 53% use NASA-TLX alone. Although it can be concluded that the NASA Task Load Index is the most widely used measurement for subjective MWL in recent years, 35% of the studies use at least one subjective and one physiological method to determine MWL (see Table 3.5).

Eighty percent of the total studies found include at least one physiological measure (Table 3.6). Thirty-eight percent of the studies use only physiological methods to measure MWL. Fifty-two percent of the studies use an electrocardiogram in the subjects with measurements of heart rate (HR), heart rate variability (HRV), or the mean inter-beat-interval (IBI), this being the most widely used type of physiological methodology to find MWL. Finally, thirty-three of the studies used electroencephalography.

In relation to the analytical methodologies used to measure MWL (Table 3.7), of the eight studies found, five use already validated methodologies (IMPRINT, SAFTE, and ACT-R). The remaining three, on the other hand (Fang et al. 2015; Cai et al. 2016; Kostenko et al. 2016), propose new methods that require validation through further studies.

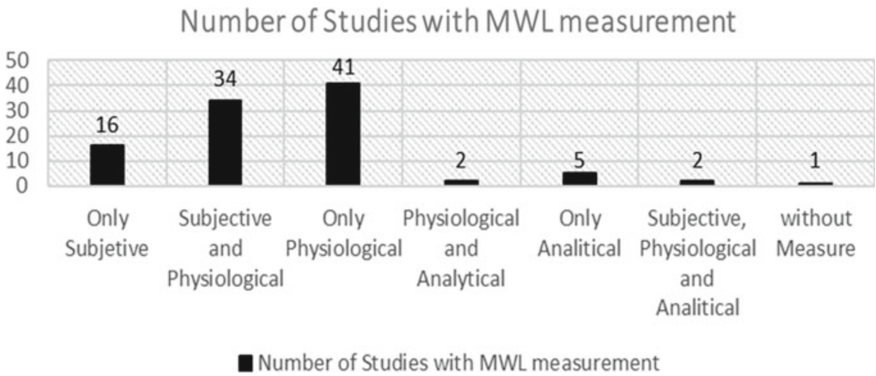

Fig. 3.2 Classification of studies from 2015 to June 2020 in relation to their type of MWL measurement

Table 3.4 Studies which employ subjective measures

Measure	Reference
NASA-Task load Index (NASA-TLX)	Chi et al. (2019), Dudek and Koniarek (2015), Jiménez et al. (2018), Bommer and Fendley (2018), Galy et al. (2018), Atalay et al. (2016), Mansikka et al. (2016), Yan et al. (2017), Alberdi et al. (2016), Claypoole et al. (2019), Ahmed et al. (2016), Banville et al. (2019), Boulhic et al. (2018), Cai et al. (2016), Darvishi and Melmanatabadi (2015), Causse et al. (2015), Fairclough and Ewing (2017), Fallahi et al. 2016, Faure and Benguigui (2016), Fernandes and Olivind Braarud (2015), Foy and Chapman (2018), García-Mas et al. (2016), Grassmann et al. (2017), Heine et al. (2017), Finkbeiner et al. (2016), Huggins and Claudio (2019), Jaquess et al. (2018), Mandrick et al. (2016), Marinescu et al. (2016), Morales et al. (2019), Mun et al. (2017), Ogawa et al. (2016), Orlandi and Brooks (2018), Shakouri et al. (2018), Shaw et al. (2018), Shuggi et al. (2017), Teo et al. (2015), Vera et al. (2017), Wang et al. (2015), Gore (2018), and Chen et al. (2019)
Workload Profile (WP)	Bommer and Fendley (2018)
Subjective mental effort rating (SRME)	Haji et al. (2015)
Modified Cooper Harper	Mansikka et al. (2016)
Standardized Copenhagen Psychosocial Questionnaire II (COPSOQ II)	Wixted et al. (2019)
Dundee Stress State Questionnaire (DSSQ)	Teo et al. (2015), Fairclough and Ewing (2017), and Claypoole et al. (2019)
Short State Stress Questionnaire (SSSQ)	Craig and Klein (2019) and Wixted et al. (2019)
Integrated Workload Scale (IWS)	Balfe et al. (2015)
State-Trait Anxiety Inventory (STAI)	Mandrick et al. (2016)
Instantaneous self-assessment of workload technique (ISA)	Marinescu et al. (2016) and Gore (2018)
Subjective Workload Assessment Technique (SWAT)	Dudek and Koniarek (2015)
Simplified Subjective Workload Assessment Technique (S-SWAT)	Fallahi et al. (2016)
Verbal online subjective opinion scale (VOSO	Marchitto et al. (2016)
Interview, questionnaire, assessment	Cruz Espinoza (2017) and Orsila et al. (2015)

Table 3.5 Studies which employ physiological measures and at least one subjective MWL measure

Measure	Reference
NASA-Task load Index (NASA-TLX)	Jiménez et al. (2018), Bommer and Fendley (2018), Mansikka et al. (2016), Yan et al. (2017), Ahmed et al. (2016), Banville et al. (2019), Cai et al. (2016), Causse et al. (2015), Fairclough and Ewing (2017), Fallahi et al. (2016), Faure and Benguigui (2016), Foy and Chapman (2018), García-Mas et al. (2016), Grassmann et al. (2017), Heine et al. (2017), Huggins and Claudio (2019), Jaquess et al. (2018), Mandrick et al. (2016), Marinescu et al. (2016), Morales et al. (2019), Mun et al. (2017), Ogawa et al. (2016), Orlandi and Brooks (2018), Shakouri et al. (2018), Shaw et al. (2018), Teo et al. (2015), Vera et al. (2017), Wang et al. (2015), Gore (2018), Chen et al. (2019)
Workload Profile (WP)	Bommer and Fendley (2018)
Modified Cooper Harper (MCH)	Mansikka et al. (2016)
Dundee Stress State Questionnaire (DSSQ)	Teo et al. (2015) and Fairclough and Ewing (2017)
Short State Stress Questionnaire (SSSQ)	Craig and Klein (2019)
State-Trait Anxiety Inventory (STAI)	Mandrick et al. (2016)
Instantaneous self-assessment of workload technique (ISA)	Marinescu et al. (2016) and Gore (2018)
Simplified Subjective Workload Assessment Technique (S-SWAT)	Fallahi et al. (2016)
Verbal Online Subjective Opinion scale (VOSO	Marchitto et al. (2016)
Interview, questionnaire, assessment	Orsila et al. (2015)

3.4 Solutions and Recommendations

Interest in mental workload evaluation has increased significantly in recent years. Companies are becoming aware of the diverse problems that result from dealing with high cognitive demands and significant MWL in the new manufacturing systems, which leads the researchers to recommend the inclusion of MWL in the design of the human-machine systems (job workstations) to help improve human performance and workers’ well-being.

Table 3.6 Studies which employ physiological measures only

Measure	Reference
Electrocardiogram (HR, HRV, and/or IBI)	Yan et al. (2017), Young et al. (2015), Ahmed et al. (2016), Cai et al. (2016), Foy and Chapman (2018), Grassmann et al. (2017), Huggins and Claudio (2019), Mandrick et al. (2016), Marinescu et al. (2016), Orlandi and Brooks (2018), Mansikka et al. (2016), Morris et al. (2018), Orsila et al. (2015), Zhang et al. (2018b), Boele-Vos et al. (2017), Charles and Nixon (2019), Cui et al. (2016), Gore (2018), Hidalgo-Muñoz et al. (2018), Hsu et al. (2016), Omurtag et al. (2019), Heine et al. (2017), Luque-Casado et al. (2016), Vera et al. (2017), Li et al. (2019), Singh and Bharti (2015), Fallahi et al. (2016), Teo et al. (2015), and Huang et al. (2018)
Salivary cortisol	García-Mas et al. (2016)
Pupil dilation	Yan et al. (2017), Chen et al. (2019), Jiang et al. (2015), Peysakhovich et al. (2015), Omurtag et al. (2019), Marquart et al. (2015), Kim and Yang (2017), Ke et al. (2015), Bernhardt et al. (2019), Kearney et al. (2019), Cai et al. (2016), and Jiménez et al. (2018)
Eye-tracking	Teo et al. (2015), Fallahi et al. (2016), Charbonnier et al. (2016), and Charles and Nixon (2019)
Blink rhythm and duration	Yan et al. (2017), Faure and Benguigui (2016), Ogawa et al. (2016), Yung and Wells (2017), Charles and Nixon (2019), Chen et al. (2019), Marquart et al. (2015), and Ohtsuka et al. (2015)
Ocular fixation duration	Marquart et al. (2015) and Ohtsuka et al. (2015)
Intraocular pressure (IOP)	Vera et al. (2017) and Jiménez et al. ()2018Jiménez et al.
Electromyography (EMG)	Zhang et al. (2018c), Zadry et al. (2016), and Fallahi et al. (2016)
Electroencephalography (EEG)	Cui et al. (2016), Borghetti et al. (2017), Wang et al. (2016, 2017), Roy et al. (2019), Omurtag et al. (2019), Kumar and Kumar (2016), Kosti et al. (2018), Horat et al. (2016), Fairclough et al. (2019), Di Flumeri et al. (2019), Cui et al. (2016), Chen et al. (2016), Charles and Nixon (2019), Charbonnier et al. (2016), Causse et al. (2017), Bernhardt et al. (2019), Zadry et al. (2016), Liu et al. (2016), Teo et al. (2015), Shaw et al. (2018), Orlandi and Brooks (2018), Mun et al. (2017), Morales et al. (2019), Jaquess et al. (2018), Fallahi et al. (2016), Fairclough and Ewing (2017), Causse et al. (2015), Banville et al. (2019), Young et al. (2015), Mun et al. (2017), and Shaw et al. (2018)
Near-infrared reflectance spectroscopy (NIRS)	Craig and Klein (2019), Liu et al. (2016), and Foy and Chapman (2018)
Functional near-infrared spectroscopy (fNIRS)	Roy et al. (2019), Causse et al. (2017), Liu et al. (2016), Li et al. (2019), Teo et al. (2015), Mandrick et al. (2016), and Banville et al. (2019)
Respiration depth (RD)	Cai et al. (2016)

(continued)

Table 3.6 (continued)

Measure	Reference
Respiration rate (RR)	Omurtag et al. (2019), Charles and Nixon (2019), Cai et al. (2016), Foy and Chapman (2018), Grassmann et al. (2017), Huggins and Claudio (2019), Grassmann et al. (2015), and Charles and Nixon (2019)
Saccade rate (SR)	Ohtsuka et al. (2015), Marquart et al. (2015), Biswas and Prabhakar (2018), Cai et al. (2016), Kearney et al. (2019), Biswas and Prabhakar (2018), and Marquart et al. (2015)
Systolic (SBP) or diastolic (DBO) blood pressure	Klonowicz (2015) and Charles and Nixon (2019)
Facial thermography	Marinescu et al. (2016) and Murai et al. (2015)
Electrodermal activity (EDA)	Foy and Chapman (2018), Huggins and Claudio (2019), Li et al. (2019), Ghaderyan and Abbasi (2016), and Ghaderyan et al. (2018)

Table 3.7 Studies which employ analytical methodologies to measure MWL

Measure	Reference
Improved Performance Research Integration Tool (IMPRINT)	Bommer and Fendley (2018), Borghetti et al. (2017), and Rusnock and Borghetti (2018)
Model Sleep, Activity. Fatigue, and Task Effectiveness (SAFTE)	Peng et al. (2018)
Adaptive Control of Thought Rational (ACT-R)	Park et al. (2018)
Observational	Fang et al. (2015)
Model	Cai et al. (2016) and Kostenko et al. (2016)

3.4.1 Recommendations and Strategies for MWL Management

Some research mentions that MWL in organizations can be managed and diminished in diverse ways. Among them are work activities reorganization, workstation, and infrastructure design, physical conditions improvement (noise reduction, proper lighting, and temperature control). Additionally, Technologies of Information and communication (TIC's) usage and more recent, work breaks which can be passive or active, and of different lengths of time, been a very effective way to reduce MWL (Zhang et al. 2018a; Rupp et al. 2017).

3.5 Future Research Directions

So far, there is no evidence of a model of work breaks focusing on the reduction of MWL—one that establishes the time when pauses should be implemented during the workday, as well as their duration, or whether they should be active or passive pauses. The lack of the above leads to excessive mental load in different work activities, which affects the workers' performance and directly influences the company's sustainable production goals.

Moreover, the literature shows that various authors, such as Apud (2012), Duque López (2015), and Nadima (2014), have addressed the issue of how the implementation of active pause models has had an impact on the decrease in physical load. However, the interruption of work with pauses designed to decrease MWL is considered a particularly important field of study, which has not been dealt with in a significant way to this day.

3.6 Conclusions

The objective of this chapter has been accomplished since international businesses face significant challenges to remain competitive in a global market. Thus, sustainability has become relevant in all senses. Global initiatives have considered humanistic management, which involves the quest for human employee's well-being. This aspect is essential to achieve sustainable operations. Actual organizational and manufacturing processes imply high mental work demands that can be evaluated through the construct of mental workload. Nowadays, work environments are placing high cognitive loads on operators, which affect their performance by overusing the attentional resources given to the tasks and causing workers to experience mental fatigue. Lack of evaluation and proper management of MWL in the industry can result in errors that can create economic costs, accidents, injuries, or even fatal events. MWL assessment and management can be a human-focused strategy designed to improve and sustain the future of the organization. Industries must find competitive advantages in sustainable processes from the economic, environmental, and social view.

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