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Application of wearable technology for the ergonomic risk assessment of healthcare professionals: A systematic literature review

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ABSTRACT

Healthcare professionals are exposed to multiple physical risk factors related to the development of work-related musculoskeletal disorders (WRMSD), which significantly affect their quality of life. Several ergonomic methods have been developed for identifying risk factors in the workplace. Among these, wearable devices that perform direct measurements have demonstrated outstanding potential in recent years to provide reliable, non-invasive, and continuous exposure assessment. Therefore, this systematic review aims to describe the use of wearable technology for the ergonomic risk assessment of healthcare professionals. Twenty-nine publications were selected following PRISMA guidelines based on the inclusion and exclusion criteria set. Most of the articles were published in the last three years, confirming a growing trend in the research on this topic. Most wearable devices, which were used isolated or combined, consist of inertial sensors used to measure and assess the exposure to awkward postures and sEMG sensors, which provide the measurement of muscle activity parameters related to the force applied while performing work activities. The main results and respective analyses provided insights into the strengths and limitations of using wearable technology to acquire data on several work activities performed by healthcare professionals. Future research is needed to widen and validate the applicability of wearable technology in support of ergonomic interventions aimed at preventing the development of WRMSD among healthcare professionals.

1. Introduction

Musculoskeletal disorders (MSD) are characterised as "impairments of body structures such as muscles, joints, tendons, ligaments, nerves, cartilage, bones, and the localised blood circulation system" (de Kok et al., 2019). The literature has acknowledged that these disorders are strongly work-related (Anderson and Oakman, 2016) and have a multifactorial nature, meaning multiple risk factors may contribute to their development or aggravation (de Kok et al., 2019). Such risk factors are commonly classified according to three categories: physical, physiological, and individual risk factors (Nunes, 2009; van der Beek and Frings-Dresen, 1998).

Work-related musculoskeletal disorders (WRMSD) are a major occupational health problem, affecting the quality of life of three out of five European workers (de Kok et al., 2019). Moreover, WRMSD represents a financial burden to organisations due to costs related to increased absenteeism and decreased productivity among the workforce (Bevan, 2015; Nunes, 2009).

Because of the physical demands of their work environments, healthcare professionals are at a considerable risk of developing WRMSD (Andersen, 2020). According to the World Health Organization (WHO), healthcare professionals "maintain health in humans through the application of the principles and procedures of evidence-based medicine and caring. Health professionals' study, diagnose, treat and

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prevent human illness, injury and other physical and mental impairments in accordance with the needs of the populations they serve." (WHO, 2013). This occupation usually includes hospital, medical practice, and dental practice activities, as well as other activities performed by allied health professionals (such as occupational therapists, physiotherapists, and paramedics), but it does not include caregivers (Gupta et al., 2011; WHO, 2013; de Jong et al., 2014). The work tasks are frequently performed in a standing position while also bending and twisting the torso and involve repetitive lifting, transferring, and repositioning of patients (Anderson and Oakman, 2016; Rezaei et al., 2021). Numerous studies concerning this topic (Anderson and Oakman, 2016; Dias and Nunes, 2012; Dong et al., 2019; Ribeiro et al., 2017; Serranheira et al., 2015) have demonstrated that the prolonged exposure of healthcare professionals to risk factors, such as posture, force, and repetition, is a cause of the development of WRMSD. Thus, these authors report that the prevalence of WRMSD among healthcare professionals is more frequent in the upper body regions, mainly on the back, neck, and shoulders. Therefore, performing regular risk assessments in healthcare facilities (e.g., hospitals, dental clinics, and operating rooms) is crucial for monitoring and preventing the occurrence of WRMSD in workers of this occupational group (Andersen, 2020; de Jong et al., 2014).

Multiple risk assessment methods have been developed to provide reliable workplace exposure measurements (Eliasson et al., 2019). These methods can be classified into three main categories: self-reports, observational, and direct measurements (David, 2005). Many WRMSD studies described in the literature regarding the healthcare sector have been performed using self-reported questionnaires, mainly with the application of the Nordic Musculoskeletal Questionnaire (Anderson and Oakman, 2016; Blume et al., 2021; Weitbrecht et al., 2022). However, these methods, along with the ones which rely on visual observations and video recordings of the workplace, may fail to provide accurate data due to the risk of individual bias and intra- and inter-observer variability (David, 2005; van der Beek and Frings-Dresen, 1998). Furthermore, in a hospital environment, there are also ethical problems associated with the collection of video recordings, as mentioned by Nicoletti et al. (2014).

On the other hand, direct measurements rely on sensors applied directly to the worker's body, which record the work activity's exposure variables (e.g., physiological and biomechanical data) (David, 2005). In the past decade, substantial technological advances have improved wearable devices in terms of accuracy, miniaturisation, and connection to smart devices (Ranavolo et al., 2017). Currently, these represent a new solution to address the needs of numerous industries (Perez and Zeadally, 2021). According to Wright & Keith, wearable devices are described as electronics and computers integrated into clothing and other accessories that can be worn comfortably on the body (Wright and Keith, 2014). Wearable sensors have been pointed out as particularly interesting to support ergonomic risk analysis due to their ability to precisely and continuously monitor human activity with minimal disturbance (Stefana et al., 2021), as these devices do not interfere with workers' typical movements (Ranavolo et al., 2018a,b).

In recent years, scientific studies have enhanced the potential of technology to estimate the risk associated with biomechanical overloads (Ranavolo et al., 2017; Ranavolo et al., 2018a; Bezzini et al., 2023). While some authors focus on ergonomic risk assessment by digital human modelling tools (Boros and Hercegfi, 2020), others are exploring the impact of human activity recognition on ergonomic risk assessments (Abdullah et al., 2023; Carnazzo et al., 2023; Sabino et al., 2024).

Two software programs in digital human modelling tools stand out: ViveLab Ergo and JACK. Both simulation software uses traditional ergonomic evaluation methods to estimate the risk (Babicsne-Horvath and Hercegfi, 2019; Bednář et al., 2023). JACK software has also been connected to a Kinect V1 to perform real-time ergonomic assessments of a manual lawn mower (Kumar et al., 2022).

Due to technological advances, most recent studies use human activity recognition for risk assessment. The impact of human activity recognition can also be driven by combining wearable sensors with traditional risk assessment methods, such as the NIOSH Lifting Equation. Wearable sensor networks have been considered a valid strategy to increase work efficiency due to their ability to support human activities and improve workers' well-being (Stefana et al., 2021; Donisi et al., 2021, 2022a).

There are many recent reviews about using wearable devices for ergonomic purposes.

A systematic review conducted in 2019 focused on the validity and reliability of inertial measurement sensors. They included different body joints as well as different complexities of the tasks. In conclusion, they suggest that IMUs can be an alternative to optical Mocap systems when the objective is to study human motion. However, the authors address two main issues: the calibration process must be defined in future studies and testing outside the laboratories should be performed (Poitras et al., 2019).

Two years later (2020), a review about the use of wearable technology for ergonomic purposes (Stefana et al., 2021) confirmed the growing trend observed in literature regarding this topic at the time, with most of the articles being published in 2019 and 2020. These authors concluded that the population of focus for the ergonomic assessment has mainly been construction personnel and industrial workers. Other previous review studies have also focused, for instance, on the potential use of wearable sensors for quantitative biomechanical risk assessments (Ranavolo et al., 2018a,b), on motion capture in occupational ergonomics research (Lim and D'Souza, 2020), and on industrial applications (Menolotto et al., 2020).

A review conducted in 2021 distinguished the studies about the effectiveness of wearables inertial sensor technology feedback on upper body kinematics in occupational activities. However, the results are generalised since they did not cover a specific occupational activity. Despite that, authors suggest using this technology improves upper body posture (Lee et al., 2021).

The impact of human activity recognition can also be driven by combining the previous approach with artificial intelligence (Donisi et al., 2022a, 2022b; Bezzini et al., 2023). Some authors have focused on combining wearable devices with artificial intelligence for human-activity recognition (Jin et al., 2020; Donisi et al., 2022; Fernandes et al., 2023; Hu et al., 2023).

Literature reviews about wearable robotics (e.g., exoskeletons) are also common (Li and NG, 2018; Dittli et al., 2021). Nevertheless, this type of wearable is used to assist the user and does not help in ergonomic risk assessments.

Finally, the digital health technologies for COVID-19 applications are another topic covered by at least one literature review (Naik et al., 2022). Despite the focus on the healthcare context, this type of review is not limited to wearable devices; it is not related to ergonomic risk assessments.

Regarding the application of wearable technology in the healthcare sector, Li et al. (2021) analysed its application for the measurement of consumers' health-related parameters, a topic discussed in a review regarding recent advances in wearable sensing technologies (Perez and Zeadally, 2021). Hence, as far as the authors know, the use of wearable sensors for the ergonomic risk assessment of healthcare professionals has not yet been reported systematically.

This literature review aims to describe and analyse the wearable technologies used to conduct ergonomic risk assessments of healthcare professionals in their workplace and offer a perspective of the capabilities and limitations of their application to this specific group of professionals. The motivation for this work is related to the relevance of the sector under study, which is reported to have a high prevalence of WRMSD among its workers as they perform a variety of physically demanding work tasks (Anderson and Oakman, 2016; Dong et al., 2019; Krishnan et al., 2021). As this is a professional group whose observational access is limited and may condition its performance, it was considered relevant to identify what has been done at a technological level to analyse the prevalence of WRMSD.

2. Methodology

The methodology adopted in this systematic review was the Preferred Reported Item for Systematic Reviews and Meta-Analyses (PRISMA), which was first published in 2009 (Moher et al., 2009) and recently updated with new reporting guidelines (Page et al., 2021).

2.1. Eligibility criteria

A set of inclusion and exclusion criteria were defined to restrict the search and simplify the selection of articles. The significance of the articles, according to the matter of the review, was based on the following inclusion criteria:

- Papers written in English;
- Papers published in scientific journals or conference proceedings;
- Papers published in the last ten years (i.e., from 2012 onwards);
- Papers in which the ergonomic risk assessment aims to analyse the impact of ergonomic interventions in the prevention of WRMSD.

The following exclusion criteria were applied:

- Review Papers;
- Papers in which the data extracted from wearable devices are not used to perform an ergonomic risk assessment of healthcare professionals;
- Papers that focus on applying wearable sensors for the risk assessment of non-healthcare professionals (e.g., caregivers). This occupation is differentiated from healthcare professions since caregivers assist individuals unable to care for themselves due to sickness, disability, or old age. Caregivers usually refer to family members of the patient or anyone in the community and typically work in people's homes (de Jong et al., 2014; Karo et al., 2019);
- Papers that apply wearable technology but consist of protocol studies and, therefore, only provide predictions of possible outcomes of the study in a work context;
- Papers that propose the use of wearable devices as assistance for healthcare workers in patients' care;
- Papers in which the sample of the study is not representative of healthcare professionals (i.e., participants who do not practice the studied healthcare profession).

2.2. Search strategy

A literature search was performed in November of 2022 on Pubmed, Scopus, and Web of Science electronic databases. According to the focus of this systematic review, the most appropriated keyword combination was defined to be used in the literature search. They were categorised into four groups: (1) healthcare workers, healthcare professionals; (2) wearable, sensor; (3) ergonomic/ergonomics; and (4) musculoskeletal,

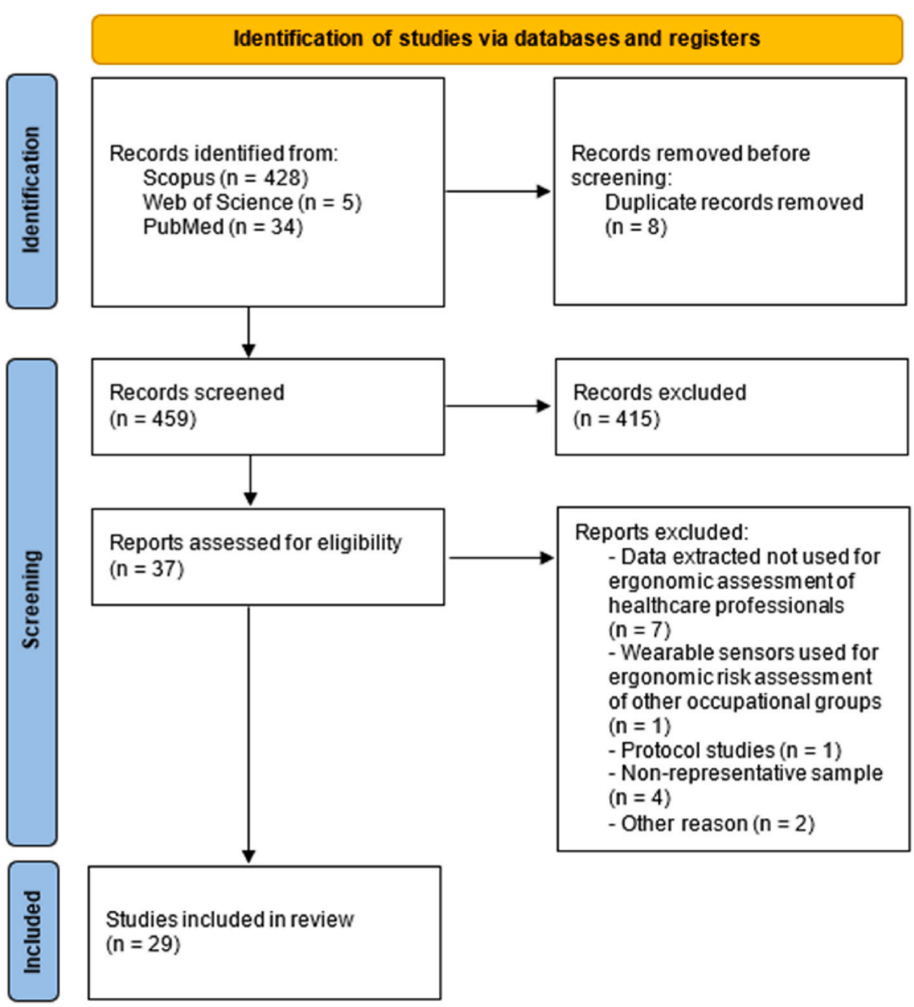

Fig. 1. PRISMA flowchart diagram (adapted) for the paper selection process.

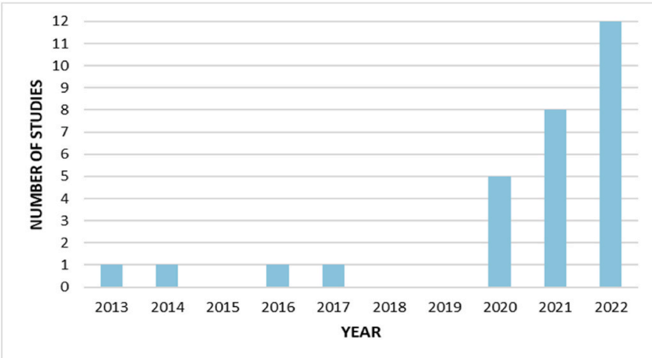

Fig. 2. Number of publications per year.

risk. It should be noted that a variety of other keywords combinations were tested, namely specific healthcare professions such as "nurses" and "physicians". However, hundreds of results were obtained with these combinations, and it was verified that a low percentage of these studies met the inclusion criteria defined for this systematic review.

The search string was comprised of the mentioned terms and Boolean operators (AND, OR, *). 'AND' and 'OR' were applied to combine the groups of keywords. This string consisted of the following: ("healthcare workers" OR "healthcare professionals") AND (wearable OR sensor) AND ergonomic* AND (musculoskeletal OR risk). All Fields' option was used for all three databases to obtain the maximum number of relevant results possible. Concerning the search undertaken in PubMed, this string was customised to include, besides the predefined keywords, 'Medical Subject Headings' (MeSH) terms. These are used for indexing articles for PubMed and allow for the automatic inclusion of keyword synonyms into the search.

3. Results

This search generated a total of 467 results. Among these, 34 were obtained from PubMed, Scopus identified 428 results, and the search in Web of Science retrieved five papers. As specified by the PRISMA guidelines, duplicated files were removed, and the remaining papers were screened. Afterwards, the articles' eligibility was determined based on their titles and abstracts, according to the previously mentioned criteria. Finally, 29 papers were selected to be included in this systematic review after screening their full text (Fig. 1).

According to the information chosen to be analysed and compared, given the focus of this systematic review, the following characteristics were extracted from each retrieved paper:

- Authors and year of publication;
- Country;
- The healthcare profession, i.e., among the healthcare sector, the profession represented by the study's sample;
- Purpose of the study and if its application is performed through experimental tests (i.e., in an environment controlled by the researcher) or in a real work environment;
- The wearable technology applied and respective risk factor or factors analysed;
- Ergonomic criteria used to support the analysis of the recorded data; and
- The study's main findings, which are divided into risk assessments of work activities (RW) and implementation of ergonomic interventions (EI), are categorised according to the context of the study.

3.1. Year and country of publication

The first included study was published in 2013. An analysis of the distribution over time of these studies, displayed in Fig. 2, shows that most of the results are from the last three years. Furthermore, a growing trend is observed in this period (2020–2022), as the year with the most studies retrieved is 2022. Consequently, it is possible to confirm the previous tendency observed in this area of research, noted by Stefana et al. (2021), as well as the relevance of the present literature review.

The graph presented in Fig. 3 offers a perspective of the authors' countries that, according to the results obtained in this review, were involved in the research topic of employing wearable technology to assess healthcare professionals' work conditions. It is observed that the USA, with a total of 12 papers, has the highest number of publications, followed by Germany (6 papers). Except for one of the USA's papers (published in 2017), the remaining publications of both countries are from the last three years. The following European and Asian countries are included: Italy, Spain, and Denmark, as well as Japan, China, Malaysia, and Thailand. Spain, where a paper from 2014 was published, is the only country among the ones displayed that is not represented in recent documents addressing the use of wearable sensors for the risk assessment of healthcare professionals' work activities.

3.2. Wearable technology

Different wearable devices are used regarding the technology mentioned in the studies identified in this review. Furthermore, the wearable technologies described in the selected papers are shown in Fig. 4, reflecting their frequency of employment. Coloured in blue are the ones used isolated, while in purple are the ones referring to studies in which a combination of two different technologies was applied. It is important to note that the present section uses the sensors' designation adopted by the authors of each study.

As observed in Fig. 3, inertial measurement units (IMU) and motion capture (MoCap) systems represent wearable technologies frequently used for healthcare professionals' risk assessment. Menolotto and colleagues define motion capture as "the process of digitally tracking and recording the movements of objects or living beings in space," including many techniques developed with this aim, namely optical cameras or inertial sensors (Menolotto et al., 2020; Kim et al., 2021). The inertial sensors include accelerometers, gyroscopes, and magnetometers, described as sensing technologies that use the inertia principle. This principle states that a free mass with resistance to moving (a property also referred to as inertia) can be accelerated if acted upon by an external force or torque (Ranavolo et al., 2018a,b). An IMU combines information obtained from these sensors, thus enabling the measurement of linear acceleration (triaxial accelerometer) and angular velocity (gyroscope) of the sensor concerning gravity. The IMU can, additionally, embed magnetic sensors to estimate the heading of the sensor for the Earth's magnetic polarity (Lim and D'Souza, 2020).

By placing IMU on particular body segments (using straps), it is feasible to estimate relevant biomechanical parameters for ergonomic

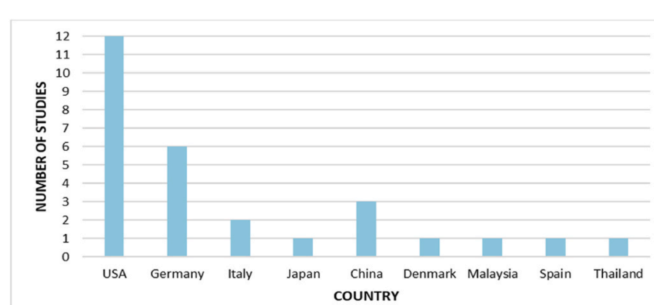

Fig. 3. Number of publications per country.

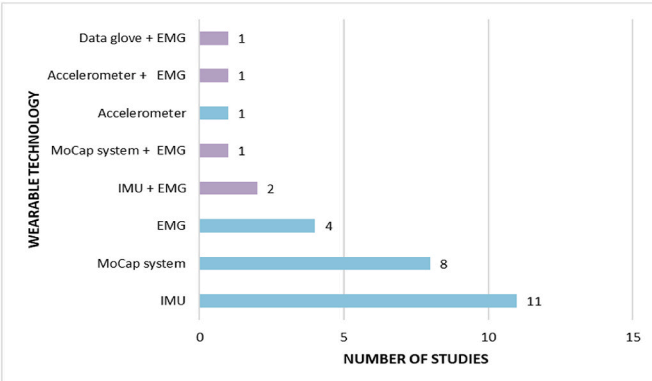

Fig. 4. Wearable technologies applied. Blue bars: used isolated; Purple bars: combined wearable technologies (IMU - Inertial Measurement Unit; MoCap - Motion Capture; sEMG - Surface Electromyography).

purposes, such as body segment orientations and body postures. The IMU used in the 13 papers are commercially available solutions (e.g., Xsens MVN, Xsens MTW, APDM Opal wearable sensor) previously validated and/or employed in similar studies. Furthermore, four MoCap systems were used in nine studies, briefly described in Table 1. As can be observed, the four systems are based on the IMU technology.

Regarding the technology of wearable inertial sensors, two papers reported risk assessment studies only using an accelerometer. Vinstrup et al. (2020) utilised a Noraxon DTS accelerometer sensor to quantify trunk inclination. In a separate study, Kokosis et al. (2022) had participants wear a posture-correcting device (LumoLift, commercially available by LUMO Body Tech, Inc.), which contained an internal accelerometer to monitor changes in posture.

Surface Electromyography (sEMG) systems are also frequently used for the risk assessment of healthcare professionals' work activities and are usually combined with inertial sensors. sEMG measures electrical activity during muscle contraction (Kuruganti, 2019). Therefore, various parameters related to muscle activity can be obtained, such as amplitude (maximum values, average rectified values, and root mean square or RMS) (Ranavolo et al., 2018a,b). These measurements are

Table 1
Brief description of the MoCap Systems used in the analysed studies.

Ref.	MoCap System	Brief description
[1]	CUELA Measurement System (IFA; Sankt Augustin/ Germany)	Kinematic reconstruction of movement through data recorded from gyroscopes, acceleration sensors, and potentiometers. Includes a software system that interprets the data automatically according to ergonomic and biomechanical criteria.
[2] [3] [4] [5] [6]	MVN System (Xsens Technologies B.V; Enschede, Netherlands)	Each sensor includes a 3D linear accelerometer, a gyroscope, a barometer, and a magnetometer. The software records, monitors, and reviews the kinematic data acquired[a].
[7] [8]	MyoMOTION System (Noraxon; Scottsdale, AZ, USA)	IMU enable a synchronised analysis of the kinematic parameters (such as orientation and velocity) through the associated software. It can also include sEMG sensors[b].
[9]	X–BUS System (Xsens Technologies B.V; Enschede, Netherlands)	The data captured by IMU can be output for storage on a laptop computer.

Study authors: [1] - (Anne et al., 2020); [2] - (Blume et al., 2021); [3] - (Holzgreve et al., 2022a); [4] - (Holzgreve et al., 2022b); [5] - (Weitbrecht et al., 2022); [6]- (Zhang et al., 2022); [7]- (Man et al., 2022); [8] - (Matsumoto et al., 2016); [9] - (Szeto et al., 2013).
[a] Information obtained from the website: www. movella.com/products/xsens.
[b] Information obtained from the website: www.noraxon.com.

frequently performed by placing skin surface electrodes (according to standardised techniques) over the target muscles. These have to be previously identified according to their known roles in the work activities analysed (Baird et al., 2021).

Another study combined measurements from a sEMG and a data glove (CyberGlove). Data acquired by the CyberGlove was converted to wrist angle values through software (Pérez-Duarte et al., 2014). The data glove can be classified as a smart garment (e-textile), as it quantifies different hand and wrist positions.

3.3. *Analysed risk factors and ergonomic criteria*

All retrieved papers describe risk assessments performed by quantifying the exposure to physical risk factors, namely posture, force, and repetition.

Regarding the postural risk assessments, one paper uses an accelerometer to quantify trunk inclination (Vinstrup et al., 2020). Kokosis and colleagues describe a wearable posture-correcting device that is programmed to vibrate when its internal accelerometer measures, for over 1 min, a change in the angle of the neck bigger than 30° (Kokosis et al., 2022). Moreover, the data acquired in the totality of the studies employing IMU was used for the measurement of joint angles, most of them to identify and analyse postural risk factors associated with the development of WRMSD.

After acquiring the data and assessing the parameters obtained, it is important to analyse the quantified exposures. In general terms, within the context of these articles, an assessment requires a comparison of such exposures with established "absolute" limits or thresholds or with "relative" terms (Lim and D'Souza, 2020). Most papers, including the measurement of kinematic parameters through IMU, classified the acquired data based on RULA (McAtamney and Nigel Corlett, 1993) and/or REBA (Hignett and McAtamney, 2000). These methods assign scores to body regions according to predefined thresholds of joint angles. Therefore, angle values are evaluated using ergonomic criteria to attribute a risk level to the recorded body postures. However, RULA and REBA were initially developed as observational methods. Therefore, some adjustments might have to be made to apply these tools to evaluate objective data. This approach is verified in seven articles, in which a modified version of RULA for the classification of demanding postures (Blume et al., 2021; Davila et al., 2021; Holzgreve et al., 2022a; Pérez-Duarte et al., 2014; Weitbrecht et al., 2022; Yang et al., 2020, 2021) was employed. Moreover, an automated WRMSD ergonomic assessment system, developed and validated by Huang et al. (2020), allows biomechanical and postural analysis of the data acquired from a MoCap system. Such analyses are performed by calculating RULA and REBA scores (Zhang et al., 2022).

Different approaches for the analyses of the kinematic data obtained are verified in four papers. In a recent study by (Anne et al., 2020), the recorded postures are classified according to the standards defined in ISO 11226 (ISO, 2000) and DIN EN1005-1 (DIN, 2003). Porta et al. (2022) classified the measured joint angles into three classes according to the guidelines of a document provided by the National Institute for Occupational Health and Safety (NIOSH). One of the studies computes the joints' angle data using amplitude probability distribution functions (APDF), resulting in three parameters of the 10th, 50th, and 90th percentiles of the APDF (Szeto et al., 2013). Thus, the 50th percentile data indicates the average postural angle. The range of motion implied in a specific task is calculated as the difference between the 10th and the 90th percentiles. Lastly, the MyoMOTION Analysis System is applied in one paper to measure and compare body segments' range of motion (ROM) (Matsumoto et al., 2016). This parameter is determined based on the data acquired by IMU sensors placed on two contiguous body segments, similar to the joint angles. A second study applying this MoCap system measured peak flexion and extension angles to assess the risk (Man et al., 2022). Nevertheless, it is also possible to analyse postures by performing measurements with sEMG, although not directly. This conclusion is presented in one study, noting that adopting a bad posture is associated with significantly higher muscle activity compared with good postures (Baird et al., 2021).

In total, nine reviewed articles measure sEMG data, and all normalise these data to each participant's maximum voluntary contraction (MVC), representing the maximum amplitude of electrical activity within a muscle. MVC is measured separately for each muscle and performed through tests. The participants are asked to perform exercises with different characteristics in these tests. For instance, in the study by Sirisawasd and colleagues, the MVC test is performed for approximately 5 s, with manual resistance from the experimenter, and is repeated three times (Sirisawasd et al., 2022). In another paper, the MVC test for the *erector spinae* muscles is performed in the Biering-Sorensen position (Vinstrup et al., 2020).

Afterwards, the raw EMG data is measured and reported as a percentage of each muscle's MVC (%MVC), allowing an ergonomic analysis of the force exerted. The authors of two studies defined any contraction of the muscles greater than 10% of the MVC as a demanding use of such muscles (Athanasiadis et al., 2021; Monfared et al., 2022). Furthermore, through MVC data measured twice in the morning and twice in the afternoon, Vinstrup et al. produced conclusions regarding the accumulation of fatigue at the end of the workday (Vinstrup et al., 2020).

Finally, two studies identified repetition as the most relevant risk factor in tasks based on data obtained regarding movements' frequency, as frequency indicates the number of movements per time unit (Blume et al., 2021; Weitbrecht et al., 2022).

3.4. Healthcare profession

A variety of healthcare professions are represented in these 29 studies. As shown in Fig. 5, surgery, nursing, and dentistry were the healthcare professions most frequently studied.

It should be noted that, in one of the papers, the authors were not specific about the healthcare professions of the participants, only mentioning that they were "from different departments" (Vinstrup et al., 2020). Thus, this article was included in the "Other Healthcare Professions" category. This category also includes neurology (Anne et al., 2020; Porta et al., 2022), physiotherapy (Man et al., 2022), rehabilitation therapy (Matsumoto et al., 2016), and physical therapy (Zhang et al., 2022).

Four tables summarising general information on the 29 selected papers are presented below. Table 2 refers to the studies focusing on the assessment of surgeons, whereas Table 3 and Table 4 refer to nursing and dentistry, respectively. Table 5 addresses papers attributed to the other healthcare professions category. Each table allows an analysis of the studies according to the main characteristics extracted from them (previously described). Thus, it is also possible to understand the contexts in which these wearable technologies were applied. It is noteworthy that all studies included in this literature review are exploratory; however, they do not describe the duration of data collection. For that reason, these characteristics were not included in the tables.

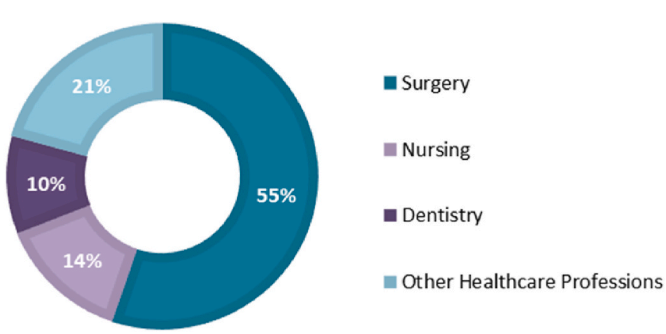

Fig. 5. -Distribution of the healthcare professions presented by each study's sample in the analysed studies.

3.4.1. Surgery

In 16 out of the 29 studies, the authors conducted a risk assessment of surgical work activities. This number represents 55% of the papers selected for this review, as shown in Fig. 4. A variety of surgical specialities are included in this sample, namely otolaryngology (Arrighi-Allisan et al., 2021; Baird et al., 2021), vascular (Davila et al., 2021; Norasi et al., 2021), orthopaedic (Haffar et al., 2022), plastic (Kokosis et al., 2022), oral and maxillofacial (Weitbrecht et al., 2022), and urology (Yu et al., 2017).

Twelve of these studies occur in operating rooms during the performance of real surgical procedures. The remaining four studies occur in experimental conditions, as participants perform tasks in simulators (Baird et al., 2021; Moss et al., 2020; Pérez-Duarte et al., 2014; Weitbrecht et al., 2022).

3.4.2. Nursing

Nursing is the second healthcare profession with the most publications (cf. Fig. 4). All of these studies focused on work activities related to patient handling, such as patient transfer (Brinkmann et al., 2022; Law et al., 2022), manual height adjustment of the hospital bed (Sirisawasd et al., 2022), and wound-dressing (Szeto et al., 2013). Most of these studies were performed through experimental testing with simulated patients. (Szeto et al., 2013) include a real work setting for the assessment.

3.4.3. Dentistry

All three papers related to dentistry (Blume et al., 2021; Holzgreve et al., 2022a, 2022b) are part of the SOPEZ study. SOPEZ is a recent project designed to investigate from an ergonomic point of view and in a laboratory environment (with a dummy head) the work activities performed by dentists and dental assistants (Ohlendorf et al., 2020).

3.4.4. Other healthcare professions

Concerning the category of other healthcare professionals, Anne et al. (2020) provided a detailed insight into the work routine of assistant physicians in Neurology, while Porta et al. (2022) and Vinstrup et al. (2020) recorded healthcare professionals' parameters during their work. In the other three papers, the authors apply experimental tests involving physiotherapy professionals (Man et al., 2022), physical therapy students (Zhang et al., 2022), and work activities related to patient transfers (Matsumoto et al., 2016).

4. Discussion

4.1. Main findings

Despite the few studies found, results suggest that wearable technology is a possibility to provide objective and feasible data for ergonomic risk assessments within healthcare professionals. It corroborates other literature reviews about the application of wearable sensors in other occupational areas. However, more studies in clinical context are needed to support this assumption.

The results also confirm that healthcare professionals frequently adopt demanding postures and exert high levels of force while performing work activities such as surgical procedures and patient handling tasks, which puts them at significant risk of developing WRMSD. Therefore, the need for ergonomic interventions in their working conditions was demonstrated, as proposed in several studies. Wearable sensors also allow the analysis of the effectiveness of preventive measures, such as protocols and assistive devices, in reducing these workers' exposure to risk factors during work activities.

The search strategy employed included the keywords "healthcare professionals" and "healthcare workers" to retrieve the maximum number of relevant papers for this systematic review. As previously

Table 2
Analysis and comparison of the studies regarding surgery.

Author, Year	Country	Application	Population	Purpose	Wearable Technology	Risk Factor	Ergonomic Criteria	Main Results
Arrighi-Allisan et al. (2021)	USA	Real work environment	6	Risk assessment of the posture adopted by trainees and attendings during FESS	IMU	Posture	REBA	Trainees performed the surgery by adopting neck and back positions associated with high risk for WRMSD.
Athanasiadis et al. (2021)	USA	Real work environment	20	Risk assessment of trainees and attendings during laparoscopic surgery	IMU sEMG	Posture Force	RULA	A considerable proportion of each surgery revealed demanding muscle activity for all surgeons. Trainees and attendings were exposed to a similar risk of exposure to awkward joint postures.
Baird et al. (2021)	USA	Experimental tests	8	Risk assessment of the posture adopted during ALS	sEMG	Posture	–	Patient positions relative to the surgeon were proposed, resulting in a lower RULA score and the least amount of muscle activity.
Carbonaro et al. (2021)	Italy	Real work environment	1	Development and preliminary test (during a laparoscopic and a mini-laparotomy procedure) of a wearable sensor-based platform for posture assessment	IMU	Posture	RULA	The ergonomic risk index estimated by the proposed system regarding spine and neck positions was high. It revealed the need for an ergonomic intervention in the surgeons' work conditions.
Davila et al. (2021)	USA	Real work environment	16	Risk assessment of the posture adopted during open and endovascular procedures	IMU	Posture	Modified RULA	Considering the neck, torso, and shoulder, the neck was associated with a higher postural risk for both surgical procedures, especially in open procedures.
Haffar et al. (2022)	USA	Real work environment	1	Risk assessment of the posture adopted during rTKA and cTKA procedures	IMU	Posture	RULA	Considering joint angles of the neck, lumbar, and shoulder and the respective percentage of time spent in demanding positions, rTKA demanded less postural strain.
Hallbeck et al. (2020)	USA	Real work environment	4	Risk assessment of two different mastectomy procedures	IMU	Posture	RULA	Significant risk exposure for WRMSD was quantified in both procedures, especially in the left upper arm.
Kokosis et al. (2022)	USA	Real work environment	5	Use of a posture-correcting device for the risk assessment of plastic surgery procedures	Acc	Posture	–	The device vibrated six to ten times in 40% of the procedures. It showed potential for adjusting postures adopted by trainees.
Monfared et al. (2022)	USA	Real work environment	20	Risk assessment of robotic and laparoscopic procedures	IMU sEMG	Posture Force	RULA	Significantly more static neck postures were measured for robotic procedures, although these were associated with less time spent performing demanding muscle activity.
Moss et al. (2020)	United Kingdom	Experimental tests	4	Assessment of the muscle activity required to perform MI laparoscopic and robotic procedures in patients with normal and high BI	EMG	Force	–	More demanding muscle usage was verified in the performance of robotic procedures, particularly with a high BI patient.
Norasi et al. (2021)	USA	Real work environment	16	Risk assessment of vascular surgery	IMU	Posture	RULA	The neck and lower back were exposed to a higher risk for WRMSD
Pérez-Duarte et al. (2014)	Spain	Experimental tests	14	Risk assessment of LAP and LESS surgical procedures	Data glove sEMG	Posture Force	Modified RULA	LESS procedure was associated with more significant muscle activity, although it resulted in a better wrist position and decreased joint flexion.
Weitbrecht et al. (2022)	Germany	Experimental tests	15	Risk assessment of standardised work activities	MoCap system	Repetition Posture	Modified RULA	Most work time was spent in postures with a RULA score of 7 (77.54%) and 6 (20.79%)
Yang et al. (2020)	USA	Real work environment	53	Risk assessment of surgical procedures	IMU	Posture	Modified RULA	Open operations were associated with more demanding neck, torso, and right upper arm postures.
Yang et al. (2021)	USA	Real work environment	24	Risk assessment of open and laparoscopic surgery	IMU	Posture	Modified RULA	Postures were classified as high-risk for the neck (66%) and the torso (24%).

(*continued on next page*)

Table 2 (*continued*)

Author, Year	Country	Application	Population	Purpose	Wearable Technology	Risk Factor	Ergonomic Criteria	Main Results
Yu et al. (2017)	USA	Real work environment	10	Risk assessment of RARP procedure	IMU	Posture	RULA	Assisting surgeons were exposed to a higher risk for WRMSD, especially regarding the adoption of awkward neck postures, in which they spent 58% of the total time.

Abbreviations: ALS - Awake Laryngeal Surgery; FESS - Functional Endoscopic Sinus Surgery; IMU - Inertial Measurement Unit; REBA - Rapid Entire Body Assessment; RULA – Rapid Upper Limb Assessment; sEMG – Surface Electromyography.
Abbreviations: Acc – Accelerometer; IMU - Inertial Measurement Unit; rTKA - Robotic-assisted Total Knee Arthroplasty, cTKA - Conventional Total Knee Arthroplasty; RULA – Rapid Upper Limb Assessment.
Abbreviations: BMI – Body Mass Index; IMU - Inertial Measurement Unit; LAP – Traditional Laparoscopy; LESS – Laparoendoscopic Single-Site; MI - Minimally Invasive; RULA – Rapid Upper Limb Assessment; EMG – Electromyography.
Abbreviations: IMU - Inertial Measurement Unit; MoCap - Motion Capture; RARP - Robotic-Assisted Radical Prostatectomy; RULA – Rapid Upper Limb Assessment; sEMG – Surface Electromyography.

Table 3
Analysis and comparison of the studies regarding nursery.

Author, Year	Country	Application	Population	Purpose	Wearable Technology	Risk Factor	Ergonomic Criteria	Main Results
Brinkmann et al. (2022)	Germany	Experimental tests	11	Risk assessment of the use of a robotic system designed to provide physical relief to nurses	sEMG	Force	–	EI: Using the robotic system reduced maximum force exertion by up to 51%.
Law et al. (2022)	Malaysia	Experimental tests	7	Risk assessment of patient transfer tasks with the use of a sliding board and the MTPD	IMU	Posture	REBA	EI: Using the MTPD resulted in a significant decrease in the mean peak REBA score measured for the performance of tasks with the sliding board.
Sirisawasd et al. (2022)	Thailand	Experimental tests	11	Proposal of an extensive device for manual adjustment of the hospital bed and analysis of its efficiency in preventing exposure to risk factors associated with LBP	sEMG	Force	REBA	EI: Using the assistive device resulted in a decrease in the majority of the muscles' activity when compared with the use of the hand crank.
Szeto et al. (2013)	China	Real work environment/ Experimental tests	19	Analysis of the performance of wound-dressing tasks and its association with the exposure to risk factors for the development of LBP	MoCap system	Posture	–	RW: Measured movements of the spine showed exposure to risk factors regarding developing LBP.

Abbreviations: EI – Ergonomic Interventions; LBP – Low Back Pain; MTPD – Motorized Patient Transfer Device; REBA – Rapid Entire Body Assessment; RW – Risk assessment of Work activities; sEMG – Surface Electromyography.

Table 4
Analysis and comparison of the studies regarding dentistry.

Author, Year	Country	Application	Population	Purpose	Wearable Technology	Risk Factor	Ergonomic Criteria	Main Results
Blume et al. (2021)	Germany	Experimental tests	15	Risk assessment of standardised work activities	MoCap system	Repetition Posture	Modified RULA	RW: 79% of the time was spent in a RULA score of 7, showing that these professionals are exposed to a considerable risk of developing WRMSD due to the posture adopted in the workplace.
Holzgreve et al. (2022a)	Germany	Experimental tests	30	Risk assessment of work activities and comparison of the ergonomic risk for dentists and dental assistants in each field	MoCap system	Posture	Modified RULA	RW: All fields of dental specialisation assessed reached moderate to high-risk RULA scores.
Holzgreve, et al. (2022b)	Germany	Experimental tests	17	Analyses of the effect of a trunk-oriented resistance training program in reducing musculoskeletal pain	MoCap system	Posture	RULA	EI: No significant changes in the participants' body posture were verified after the program.

Abbreviations: IMU - Inertial Measurement Unit; IE – Implementation of Ergonomic Interventions; MoCap - Motion Capture; RULA – Rapid Upper Body Assessment; RW – Risk assessment of Work activities.

mentioned, caregivers do not fulfil the requirements for inclusion in this occupational group. However, a considerable portion of the articles excluded focused on the risk assessment of work activities performed by caregivers. This finding can be justified because this group's daily activities are similar to those of healthcare professionals since they mainly require patient handling.

A high percentage of the papers included in this systematic review were published in the last three years, with 2022 reaching approximately 40% of the publications considered. Thus, an apparent growing trend regarding interest in this topic is verified. It is also evident that most of the research has been done in developed countries, especially in the USA (12 out of 29 studies). This observation can be attributed to the

Table 5
Analysis and comparison of the studies regarding other healthcare professions.

Author, Year	Country	Healthcare Profession	Application	Population	Purpose	Wearable Technology	Risk Factor	Ergonomic Criteria	Main Results
Anne et al. (2020)	Germany	Neurology	Real work environment	9	Risk assessment of daily work activities	MoCap system	Posture	ISO 1126 DIN 1005-4	RW: "Measures on patients" were frequently carried out in awkward postures. "Office activities" were performed more frequently and associated with a high risk for WRMSD.
Man et al. (2022)	China	Physiotherapy	Experimental tests	20	Ergonomic assessment of a passive exoskeleton as a tool for a transfer task	MoCap system sEMG	Posture Force	–	EI: Using the passive exoskeleton resulted in a significant decrease in muscle activity.
Matsumoto et al. (2016)	Japan	Nursing and rehabilitation therapy	Experimental tests	10	Risk assessment of the use of a robotic and a conventional wheelchair for patients' transfer	MoCap system	Force Posture	–	EI: Using the robotic wheelchair resulted in a significant decrease in the peak ROM for shoulder flexion and ankle abduction and in the activity of back muscles.
Porta et al. (2022)	Italy	Neurology, general surgery, cardiology, gastro-rheumatology, general medicine, and emergency medicine	Real work environment	39	Assessment of the risk of developing LBDs to which workers in three groups, formed according to their MAPO index, are exposed	IMU	Posture	MAPO	RW: Workers assigned to the red MAPO index group (general and emergency medicine) spent significantly more time exposed to trunk postures associated with moderate and severe risk for WRMSD.
Vinstrup et al. (2020)	Denmark	Professionals from different departments	Real work environment	52	Risk assessment of the performance of patient transfer with or without the use of assistive devices	Acc sEMG	Posture Force	–	EI: The use of more technically-advanced assistive devices resulted in lower muscle activity levels and a lower degree of trunk flexion.
Zhang et al. (2022)	China	Physical therapy	Experimental tests	23	Risk assessment of representative manual tasks in physical therapy	MoCap system	Force Posture	RULA REBA	RW: Three transfer tasks were classified, using RULA, as high risk. Patient transfer and mobilisation tasks were attributed to low to medium REBA scores. Limitations to the use of NIOSH LE in asymmetric lifting tasks were identified.

Abbreviations: EI – Ergonomic Interventions; MoCap - Motion Capture; RW – Risk assessment of Work activities sEMG – Surface Electromyography.
EAbbreviations: Acc – Accelerometer; EI – Ergonomic Interventions; MoCap - Motion Capture; MAPO – Movement and Assistance of Hospital Patients; REBA – Rapid Entire Body Assessment; RULA – Rapid Upper Body Assessment; RW – Risk assessment of Work activities; LE – Lifting equation; sEMG – Surface Electromyography.

fact that wearable sensors represent a costly and more complex solution for the performance of risk assessments compared to the traditional ergonomic methods available (such as questionnaires and observational methods). Besides the initial investment needed to acquire these devices, it is also necessary to maintain them and to ensure that these are effectively used, which requires employing technically trained staff (David, 2005).

The results show that the most adopted solutions include inertial sensors. Out of the 26 papers focusing on assessing the exposure to the Posture risk factor in the healthcare sector, 22 papers identify the use of this type of wearables. Although some authors use the term MoCap systems based on IMU, they rely on IMU technology. As previously mentioned, Motion Capture systems can be based on optical markers or inertial sensors (Kim et al., 2021). The present study evidenced that all MoCap systems used for ergonomic risk assessments of healthcare professionals rely on the second type of technology, as shown in Table 1.

IMU devices are reported to be more suitable for exposure assessment studies since combining information from multiple sensors (e.g., accelerometers, gyroscopes, and magnetometers) allows for using the strengths of each sensor to help compensate for the limitations imposed by another (Lim and D'Souza, 2020; Schall et al., 2016). For instance, it has been observed that accelerometer-based estimations may be associated with poor accuracy when used for more dynamic and complex work tasks and that gyroscope-based estimations may have a limitation related to the duration of the precision of the data collected (Schall et al., 2016), which are characteristics of the work tasks performed by healthcare professionals (Anderson and Oakman, 2016; Ribeiro et al., 2017; Serranheira et al., 2015). For estimating and monitoring muscle activity, sEMG sensors are also frequently used to perform assessments related to the exposure to the Force risk factor. Together with repetition - assessed in two papers - force and posture are generally recognised as the most significant risk factors contributing to the development of WRMSD.

Moreover, as underlined by Yang et al. (2020), the wearable sensors employed measure "highly accurate information with detailed time patterns of mechanical exposure compared with questionnaires or observational methods". In one study, the authors could confirm previously existing results, mainly based on information from questionnaires, by performing an ergonomic risk assessment based on kinematic data (Blume et al., 2021). Additionally, in a different study, including a recording of the work activity allowed an analysis of the percentage of time each subject spent on each RULA score (Holzgreve et al., 2022a). Over time, the relative average risk score enables a more reliable complete assessment of the exposure, representing an advantage compared with the primary application of RULA through observation. The determination of the time spent relatively on RULA scores is included in seven more articles (Blume et al., 2021; Davila et al., 2021; Holzgreve et al., 2022a; Pérez-Duarte et al., 2014; Weitbrecht et al., 2022; Yang et al., 2020, 2021).

Various properties of wearable sensors contribute to several strengths identified in the studies. The increased battery life and continuous monitoring capability over long periods, as mentioned in a review by Lim and D'Souza (2020), allowed the performance of measurements throughout an entire workday of healthcare professionals in one paper (Vinstrup et al., 2020). Considering the aim of that study, which required analysing real working scenarios, the use of a wearable device was essential for the success of the results. Yu et al. (2017) further discussed the possibility of continuous posture tracking, stating that it facilitates the quantification of angles that do not belong to the range of recommended postures and identifies areas needing ergonomic interventions. Furthermore, Anne et al. (2020) mention that IMUs connected via flexible cables cause minimal workflow disruption, which can also be verified for wireless IMUs. This non-invasiveness allows the assessed participants to perform movements in all dimensions, which is relevant because it contributes to a more reliable evaluation, as well as to the comfort of the worker. In four studies, wireless sEMG sensors were applied to participants (Man et al., 2022; Monfared et al., 2022; Moss et al., 2020; Vinstrup et al., 2020).

As far as the authors are concerned, few studies address the application of wearable technology for the ergonomic assessment of healthcare professionals. Most studies on this topic - for instance, the ones published by authors Anderson and Oakman (2016), Dong et al. (2019) and Ribeiro et al. (2017) - use questionnaires based on self-reports from participants. As previously mentioned, applying direct and quantitative measurements using wearable sensors allows for the collection of accurate and reliable data (e.g., joint angles, trunk inclination, range of motion and muscle force), which provides relevant information with a significantly greater level of precision than the one obtained from this qualitative category of risk assessment methods.

4.2. Limitations regarding the application of wearable technology

The analysed papers used wearable sensors to perform ergonomic risk assessments of healthcare professionals. There is a strong tendency to use IMU sensors to accomplish this objective. In addition, most studies focused on the postural risk factor by applying RULA and REBA methods. By analysing the nature of the tasks, it can be a limitation, since some studies focused on lifting, but they do not cover methods (e.g., NIOSH Lifting Equation) to evaluate the associated risk. It is important to highlight that healthcare professionals perform different types of tasks, and, in many situations, they perform asymmetric lifting. In those cases, the use of methods such as NIOSH Lifting Equation may not be recommended (Behjati and Arjmand, 2019; Skals et al., 2021; Zhang et al., 2022).

The present review revealed that 55% of the studies focused on the ergonomic risk assessment of surgeons, with most of these assessments being performed in a real work setting (i.e., operating rooms), except for four of them. The particular focus on this target group can be attributed to the predominantly static nature of surgical tasks (Athanasiadis et al., 2021; Yu et al., 2017), in contrast with the dynamic ones usually performed by nurses (the healthcare profession represented by 14% of the papers) (Matsumoto et al., 2016; Sirisawasd et al., 2022; Szeto et al., 2013). The nature of the tasks may be a limitation since it is more difficult to perform precise measurements in more dynamic activities. One of the studies pointed out that surface electromyography (sEMG) measurement could interfere with nurses' schedules since it resulted in the employment of female healthcare students as nurse representatives (Sirisawasd et al., 2022). However, performing a real-time ergonomic risk assessment in an operating room may pose challenges related to devices' sterility. Hospital environments are very prone to viruses and bacteria. Sterilisation is a crucial step of clinal procedures, especially in surgical rooms. It may be a limitation for using additional devices not vital for the surgery, and it may compromise the integration of wearable devices for ergonomic risk assessment or monitoring healthcare professionals. For instance, in two studies, participants could not wear IMU in specific upper body segments due to the sensor's interference with sterile scrubbing (Arrighi-Allisan et al., 2021; Yang et al., 2021).

Nevertheless, Yang et al. (2021) highlighted that assessing the postures of such body parts may be relevant, as many surgeons report pain in these areas. Limitations were also identified in a risk assessment of surgeons through experimental tests, where the authors stated that the exercises were performed with short duration and in a specific order, contrary to what would happen in a real surgery. Furthermore, the model used to simulate the patient may not replicate the challenges the surgeons face during the actual procedure (Moss et al., 2020).

Several other limitations associated with the application of wearable technology are mentioned in the articles included in this review. One study reported the need to repeat the IMU's calibration every time the kinematic model had a slight orientation and postural drift (Law et al., 2022). As for sEMG, a restriction that compromised the sample representation was identified in two studies. The inclusion criteria for sEMG required Sirisawasd et al. (2022) to select participants with a body mass index (BMI) less than 23.5 due to interferences with sEMG's signal. This limitation is mentioned, as well, by Baird et al. (2021), which state that the variation in the BMI of the sample may have affected the generalizability of the recorded signal. These authors further state that slight variations may have occurred while applying the sensors to the target muscles, possibly interfering with the reliability of the measurements.

In addition, the electromagnetic interference to which the IMU's magnetometer component is subjected accounts for a significant limitation in the ergonomic analysis performed by Arrighi-Allisan et al. (2021). In this study, besides recalibrating each IMU before every recording and removing any source of interference (e.g., cell phones, pens, jewellery), the authors still had to exclude 12 out of 30 measurements, representing 40% of the results. Moreover, two articles underline the possibility that participants were more vigilant of their posture due to the awareness of the inertial sensors placed in their body segments, a phenomenon named the Hawthorne effect (Anne et al., 2020; Arrighi-Allisan et al., 2021). Concerning the validity and reliability of the data measured by these sensors, Szeto et al. (2013) acknowledge the possibility that the estimated joint movement ranges are not directly associated with a specific risk of developing WRMSD. These authors refer to factors such as individual movement habits as an important influence on measuring the values of joint angles. Furthermore, Vinstrup and colleagues question the application of an accelerometer to quantify the participant's trunk inclination (Vinstrup et al., 2020). Lastly, two recent studies mention that using IMU requires a trained researcher as a limitation of the current technology (Davila et al., 2021; Yu et al., 2017).

Overall, this systematic review shows that using wearable sensors allowed for overcoming some limitations imposed by self-reports and observational methods in assessing the work conditions of healthcare professionals. However, the number of studies retrieved indicates that the application of wearable technology to prevent the development of WRMSD in this occupational group is still limited. It is important to mention that this number may also result from the literature search employed. The keywords, inclusion and exclusion criteria used, and the three indexed electronic bases (Pub Med, Scopus, and Web of Science) chosen may have led authors to overlook other potentially relevant studies, which was an assumed risk taken for conducting this systematic review.

Nevertheless, this number of retrieved studies can also be explained by research and development in wearable sensing technology, which have improved only in the last decade. Thus, compared with the most traditional risk assessment methods, wearable devices still represent a more complex and costly solution for preventing or reducing the prevalence of WRMSD in a particular occupational group. This approach can also be associated with an initial lack of acceptability from workers since it represents a new and innovative technology. More specifically, and given the focus of this systematic review, using wearable sensors to perform an ergonomic risk assessment in the healthcare sector may impose several limitations due to various factors related to the dynamic and complex nature of healthcare professionals' daily work routines. Besides the limitations already described in this section of the discussion, these workers can also express reluctance in using the wearable sensors due to the fear of feeling uncomfortable or unable to perform their tasks correctly, as they probably won't be familiarised with these devices. It should be noted, as well, that collecting data in a clinical work environment can impose restrictions which may affect the precision of the data collected.

4.3. Future perspectives

Future research should focus on broadening the application of wearable technology in the healthcare sector. More specifically, it is important to take advantage of the strengths imposed by wearable sensors by using them to collect data on healthcare professions that were not included or were poorly represented in this review or to perform intensive studies on specific groups of work tasks. This way, it is believed that it will be possible to validate the application of wearable sensors for ergonomic risk assessments of healthcare professionals in multiple working conditions.

Research on this topic would also benefit from addressing the limitations mentioned in the studies retrieved for this review. Besides interfering with the feasibility and accuracy of the data acquired, these limitations may affect the cooperation and acceptance of wearable technology by healthcare professionals. It is essential to ensure that these workers do not perceive the application of wearable technology in their workplace as invasive and complex; otherwise, it will be more challenging to integrate wearable sensors as a solution to perform regular and objective ergonomic risk assessments.

The potential demonstrated by wearable technology should also be used to carry out extensive and comprehensive data collection sessions. The aim of these sessions could be, for instance, to obtain information for developing software (such as mobile applications) to perform ergonomic assessments in real-time by providing feedback to healthcare professionals on inadequate postures or tasks requiring excessive effort in terms of the muscle force applied. Innovative platforms allowing this type of monitoring have been recently proposed. For instance, Battini et al. (2022) describe a system that provides visual feedback to workers performing manual tasks such as picking, construction and assembly. Authors Cerqueira et al. (2020) developed a vest based on inertial sensors designed to provide haptic feedback to operators as a strategy for improving posture awareness. However, to the authors' knowledge, no papers propose a system in which healthcare professionals are defined as the group of end-users. It represents a gap in the literature that should be addressed.

The information obtained can also be used to define concrete and effective strategies for decreasing the risk of exposure to risk factors associated with WRMSD in the healthcare sector, including integrating different methods, guidelines or technologies. Additionally, it is believed that incorporating other types of wearable sensors would allow a more complete and detailed ergonomic assessment of healthcare professionals. For instance, insole pressure systems - which provide postural changes over time - could be integrated into the daily routine of these professionals since they are used on the foot. Eventually, the end goal should be to develop, validate and implement an interactive system that: (i) provides direct and effective feedback to healthcare professionals regarding the exposure to the most relevant risk factors and considers the variety of tasks performed; and (ii) allows the performance of periodic risk assessments to analyse whether the risk level to which the workers are exposed to is decreasing.

It is essential to highlight that, despite the increasing use of wearable devices in healthcare, there is still a long way to go, and many barriers must be overcome. First, this type of technology is sensitive, and sometimes, the sensors' positioning and calibration are time-consuming. A trained professional is always needed during data collection, which may compromise the studies since hospitals have many restrictions, particularly after COVID-19. It is important to continue the technological improvement of the sensors to simplify the process, let the healthcare professionals be capable of performing the acquisitions by themselves, and achieve better results. It would also contribute to improving the workers' acceptance. Another concern is the difficulty in guaranteeing the immobilisation of the sensors while workers perform movements. It seems the most challenging barrier because solutions for this problem are invasive and can compromise the workers' acceptance. At last, the infectious environment within hospitals must be recognised. The material handling of this type of device can represent an increased risk, especially inside surgical rooms. Addressing this limitation depends on training the workers and disclosing sterility practices.

5. Conclusion

This systematic review aims to provide a comprehensive understanding of the use of wearable technology for the ergonomic risk assessment of everyday working activities conducted by healthcare professionals, which is currently lacking in the literature. After a thorough selection process, 29 studies were identified and categorised based on their relevance to the review context. General information retrieved from these studies was summarised, and the positive outcomes and limitations of the proposed wearable devices were discussed in the work environment in which they were applied.

The results underline that the emergence of more developed and innovative technologies has increased interest in applying such sensors in healthcare work settings. More specifically, inertial sensors (i.e., IMU, accelerometers, and motion capture systems based on IMU) and surface electromyography sensors have allowed the performance of objective and reliable measurements of the participants' biomechanical parameters. Therefore, these technologies revealed the potential for performing valid risk assessments and supporting the guidance of corrective actions that mitigate the risks for WRMSD.

However, it was noted by multiple authors that, despite being associated with numerous and valuable advantages, these devices still have limited usage in the risk assessment of the healthcare sector in comparison with traditional subjective methods, such as questionnaires and observational methods. A large number of limitations related to the complexity of this technology and issues related to its application in specific work activities were identified in these studies. Therefore, further research and development must be undertaken to address these challenges and ensure the successful implementation of wearable technology in promoting the health and well-being of healthcare professionals, ultimately leading to improved patient treatment and a more sustainable healthcare system.

CRediT authorship contribution statement

Inês Sabino: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Maria do Carmo Fernandes:** Methodology, Investigation. **Cátia Cepeda:**

Validation, Conceptualization. **Cláudia Quaresma:** Writing – original draft, Validation, Supervision, Methodology. **Hugo Gamboa:** Validation, Conceptualization. **Isabel L. Nunes:** Writing – original draft, Validation, Supervision, Methodology. **Ana Teresa Gabriel:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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