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Tapping into the wearable device revolution in the work environment: a systematic review

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Abstract

Purpose – The purpose of this paper is to expand current knowledge about the recent trend of wearable technology to assess both its potential in the work environment and the challenges concerning the utilisation of wearables in the workplace.

Design/methodology/approach – After establishing exclusion and inclusion criteria, an independent systematic search of the ACM Digital Library, IEEE Xplore, ScienceDirect and Web of Science databases for relevant studies was performed. Out of a total of 359 articles, 34 met the selection criteria.

Findings – This review identifies 23 categories of wearable devices. Further categorisation of the devices based on their utilisation shows they can be used in the work environment for activities including monitoring, augmenting, assisting, delivering and tracking. The review reveals that wearable technology has the potential to increase work efficiency among employees, improve workers' physical well-being and reduce work-related injuries. However, the review also reveals that technological, social, policy and economic challenges related to the use of wearable devices remain.

Research limitations/implications – Many studies have investigated the benefits of wearable devices for personal use, but information about the use of wearables in the work environment is limited. Further research is required in the fields of technology, social challenges, organisation strategies, policies and economics to enhance the adoption rate of wearable devices in work environments.

Originality/value – Previous studies indicate that occupational stress and injuries are detrimental to employees' health; this paper analyses the use of wearable devices as an intervention method to monitor or prevent these problems. Introducing a categorisation framework during implementation may help identify which types of device categories are suitable and could be beneficial for specific utilisation purposes, facilitating the adoption of wearable devices in the workplace.

Keywords Benefits, Systematic literature review, Mobile communications, Occupational health, Work environment, Wearable devices, Business process improvement, Wireless technology, Work performance, IT-enabled social innovations, Wearable technologies, Wearable robotics

Paper type Literature review

1. Introduction

The evolution of technologies, such as computers and smartphones, has dramatically reshaped the work environment in recent decades. Many job descriptions have changed because work has shifted from manual labour to predominantly physically inactive duties (desk jobs, automated assembly lines, etc.) (Engbers, 2008). Potentially, this shift could have enormous effects on the physical well-being of employees, increasing the likelihood of occupational injuries and illness (Dembe *et al.*, 2005). Working long hours for long periods of time is associated with depression, anxiety, sleep disturbances, chronic heart disease (Bannai and Tamakoshi, 2014) and chronic stress disease (Muaremi *et al.*, 2013). According to Baka and Uzunoglu (2016),

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"Occupational accidents still occur, despite technical developments in the occupational safety field at large" (p. 69). Potential injuries occur in industrial environments because of complex, hazardous conditions (Kenn and Bürgy, 2014; Kritzler *et al.*, 2015; Baka and Uzunoglu, 2016) and fatigue. Studies conducted by various researchers and managers have generally recognised that health and well-being can negatively affect both workers and organisations (Danna and Griffin, 1999). Companies often suffer significant financial losses because of the illness and poor health of their employees (Kritzler *et al.*, 2015). Baka and Uzunoglu (2016) further stated that, "costs include lost production, negative impacts on staff morale, bad publicity, legal costs and the costs of replacing employees or equipment" (p. 76). Therefore, there is a need to improve health and safety to benefit both a company and its employees.

Companies have begun incorporating financial incentives (Baka and Uzunoglu, 2016) and approaches based on information and communication technology (ICT) into their health and safety promotion programmes; these approaches are designed to improve the health and safety of workers, while reducing healthcare costs (Cook *et al.*, 2007; Sole *et al.*, 2013a; Loeppke *et al.*, 2015). Currently, organisations are moving toward modifying their concepts of well-being by changing their healthcare technology into "wearable" types (Ferraro and Ugur, 2011). Wearable technology has gained traction in recent years to track data about everyday life and physical well-being for personal use. Following the same model, wearable technology could be immediately useful in work environments.

Wearable devices are smart electronic devices available in various forms (Liu *et al.*, 2016) that are used near or on the human body to sense and analyse physiological and psychological data (Spagnolli *et al.*, 2014), such as feelings, sleep, movements, heart rate and blood pressure (Sole *et al.*, 2013a; Yang *et al.*, 2015; Fang and Chang, 2016), via applications either installed on the device or on external devices, such as smartphones connected to the cloud (Muaremi *et al.*, 2013). Some wearable technology provides new opportunities to monitor human activity continuously through miniature wearable sensors embedded in garments (Ching and Singh, 2016). A key benefit of wearable technology is the potential for improving productivity, efficiency, connectivity, health and wellness (PricewaterhouseCoopers B.V., 2014).

To fully understand the potential benefits of wearables in the workplace, it is necessary to first discover what types of wearable devices can be used in work environments, and how these devices can be integrated into day-to-day business activities (i.e. to increase safety and levels of physical activity, to reduce stress and to enhance productivity and efficiency). Based on previous research, this systematic literature review (SLR) is guided by Kitchenham and Charters (2007) and provides an overview of trends and patterns related to both the research about and the usage of wearable technologies in work environments from 2000 to 2016. The review begins by examining related work already done by other researchers. The research methodology section focusses on how the research was conducted and how relevant studies were gathered. The findings section presents the findings of this study and an interpretation of the results. A discussion concludes the findings.

2. Related work

This section details both the benefits and negative implications of wearable technology discussed in recent years by other researchers. Dunne *et al.* (2007) suggest wearable devices can beneficially improve health, safety and well-being in the work environment. Many researchers' currently conducting studies have focussed exclusively on evaluating commercial off-the-shelf (COTS) or proof of concept (PoC) wearable devices to understand their advantages compared to existing programmes.

Glance *et al.* (2016) demonstrated the impact of a wearable digital activity tracker in the workplace on health and well-being. Results from their study show that participants increased their level of activity and maintained at least 10,000 steps a day during the study period. Lavallière *et al.* (2016) state, "Quantified-self and wearables can leverage interventions to improve health, safety and well-being" (p. 38). Muaremi *et al.* (2013) assess the stress experiences of 35 employees over a period of four months using wearable chest belts and a smartphone application. The study concludes that the use of wearable devices and smartphone applications can ensure better results than asking people about their moods in interviews or letting them fill out questionnaires. Similarly, Zenonos *et al.* (2016) evaluate Toshiba Silmee wristbands and chest sensors, which collect psychological data to predict mood in the work environment. The results show that these devices can help employers make better decisions about how to reduce the stress and fatigue of their employees. Chu *et al.* (2014) conducted research to assess how wearable robots can improve the health of employees and increase work efficiency. The study concludes that wearable robots effectively improve the health and safety of employees while assisting them in the shipbuilding work environment. Baka and Uzunoglu (2016) show that wearable safety devices can monitor electrical voltage and warn workers if it is too high, helping prevent occupational injuries.

While considering potentially negative implications of wearable technology in the workplace, however, Marcengo and Rapp (2014) point out that "quantified-self" can raise concerns about privacy risks and ethical issues if used in a mass environment such as a workplace, as the technology for collecting, analysing and visualising data is still immature. Similarly, Lupton (2014) states that self-tracking through wearables in the workplace can have political and social justice implications because employees must participate in the imposed self-tracking. Moore (2015) says, "Wearable and other self-tracking devices are part of an emerging form of Neo-Taylorism which risks subordinating workers' bodies to neoliberal, corporeal capitalism" (p. 8). Both Moore (2015) and Lupton (2014) argue that the benefit of quantification lies with employers rather than employees because employees have control over both the data and the devices. Regarding wearables as intervention tools promoting health, Lupton (2013) points out that such interventions can raise significant implications for employees in terms of individual responsibility, self-belief, invasion of privacy and discrimination. In another study, Lupton (2015) discusses the social and political implications caused by digital health promotion, noting that wearable devices offer interesting possibilities if utilised correctly; if not, the author feels these technologies can cause social disadvantages and poor health outcomes.

Previous studies indicate that different types of wearable devices can influence health awareness, safety and well-being at work, for better or worse. There are also some negative implications to utilising wearable devices. Previous studies show limited insight into the types of wearable devices and their advantages and challenges in the work environment. To further complicate this, nearly all previous studies use different types of wearable devices to explore their benefits and only a few studies have discussed their negative implications. No review studies have yet looked at how these wearable devices can be used to reduce challenges such as privacy, information ecology and increasing satisfaction and engagement. This in-depth SLR explores the most important phases in the wearable technology implementation process and the potential use of that technology in the work environment. In this study, the first step is to build the categorisation framework and identify the various wearable device types and their potential uses.

3. Methods

This study adopts and applies a SLR approach based on the guidelines provided by Kitchenham and Charters (2007) and the recommendations of Petersen *et al.* (2008). Kitchenham and Charters (2007) define a SLR as a "means of identifying, analysing and interpreting all available data relevant to the particular research question (RQ) or topic area, or phenomenon of interest" (p. 3) in an unbiased way. Steiger *et al.* (2015) assert that, "conducting a systematic literature review is an efficient way to select the best available research and facilitates research approaches by identifying current existing research gaps and study limitations" (p. 21). The guidelines suggest that researchers should utilise three phases to streamline the SLR approach: planning the review, conducting the review and reporting the review. In this study, reporting the review is mentioned as result instead. The following section explains how this SLR adopted this approach.

Planning the review

The stages associated with planning the review and how that planning was implemented within our research are presented in the following sections.

Identifying the need for the review. The guidelines recommend that, prior to the SLR, researchers must determine if there is a real need for the review. Then, they must formulate the RQs that will guide the research. In recent years, the research community has addressed the benefits and possible implications of using different types of COTS and PoC wearable devices in the work environment. Searches were conducted via online databases, such as IEEE, ACM and Web of Science, using the terms "wearable*", "work environment" and "systematic literature review" to find any existing SLRs summarising different categories of wearables and their mode of use. These search results indicated that there was no specific summary about the current state of the research concerning work environments, types of wearables, the specific purposes of those wearables and any benefits of utilising wearables in specific workplaces. Therefore, a SLR to summarise the types of wearable technologies that can be utilised in the work environment, determine whether these technologies can be beneficial for different stakeholders (internal and external) and fill the gaps in current research was needed.

RQs. Following the determination of need, RQs based on the objectives of the study were formulated. In the medical field, the population, intervention, control and outcome (PICO) criteria approach is widely used for formulating RQs. Petticrew and Roberts (2006) and Kitchenham and Charters (2007) both suggest using the PICO framework to formulate the SLR RQs. According to Greenes (2007), "The PICO review criteria serve as a sieve through which only the studies most likely to be relevant will be retrieved and analysed" (p. 252). The general idea of PICO is to organise the search strategy; however, previous studies have discarded some PICO elements depending on the nature of the research (James *et al.*, 2016; Oriol *et al.*, 2014). Oriol *et al.* (2014) discarded comparison as it was not suitable for their research approach. They stated, "The comparison is more a kind of general analysis of the field, since we do not aim at ranking the proposals found or to compare to some other existing approach" (p. 1170).

For our purposes, population was the work environment and the employees within it, whereas intervention was the wearable technology. The present study aimed to find the types of wearable devices and their benefits, but not to compare the devices themselves. Therefore, a comparison was outside of the current study's scope and was omitted. Finally, the outcome from this SLR was the summary of the current trends in the research community in types of wearable devices, their benefits and their challenges. Given this, three RQs, each with a rationale, were developed in order to obtain an inclusive overview of the topic:

RQ1. What types of wearable technology for use in the work environment does the literature mention?

RQ2. How do companies and employees benefit from the use of wearable technology?

RQ3. What challenges to the use of wearable devices remain, and what areas require further investigation?

Conducting the review

Performing a search for articles and primary studies by using search strings on scientific libraries and databases was necessary. Utilising tools such as the Network Analysis Interface for Literature Studies bibliometric software (Knutas *et al.*, 2015) refined the research terms. Kitchenham and Charters (2007) guidelines point out the importance of screening an initial set of articles by applying inclusion criteria (IC) and exclusion criteria (EC) to determine if a study should be included and also how to classify the articles based on the keywords from the abstracts. Classifying and categorising articles based on the final set of keywords is crucial in identifying relevant primary studies. The following section presents the steps taken while conducting the review.

Identification of research. The first step was initiating a search strategy to identify the primary studies through search terms (STs). The search strategy was composed using the four phases described in Figure 1:

In Phase 1 of the search strategy, the STs were formulated based on the RQs already determined by following the PICO criteria[1]. Phase 2 included the identification of possible synonyms, acronyms or alternative words for the initial STs. For example, "wearable", "wearable device", "wearable computing" and "wearable technology"; "work environment" and "work"; and "benefit" and "advantage". In Phase 3, all identified synonyms, acronyms and alternative words of STs were merged using the Boolean "or". Finally, in Phase 4, all the major terms were connected to form the final search string using the Boolean operator "AND" as ("wearable*" or "wearable device*" or "wearable computing" or "wearable technology*") AND ("work environment*" or "work") AND ("benefit*" or "advantage*") AND ("publication year > 2000").

In the second step, the search for primary studies began with the use of search strings in online search databases. The following electronic databases were searched: ACM Digital Library, IEEE Xplore, ScienceDirect and Web of Science. These databases were chosen because of their relevance to the field of information technology. Once papers were identified, citations within the papers were also manually browsed (Webster and Watson, 2002).

After formulating the final search string and utilising the search utilities of the digital databases, an initial search was conducted in March 2016. The final set of searches was performed in June 2016.

Article selection process. The aim of article selection process in this study was to extract publications relevant to the objective of this SLR based on certain IC and EC. Thus, the following sets of IC and EC were applied:

- IC1: publication date between 1/1/2000 and 06/30/2016;
- IC2: includes answers to at least one of the RQs, determined by reading the title and abstract;
- IC3: includes if the conducted study was related to using wearable technology in a work environment;
- IC4: written in English;
- EC1: limited discussion about wearables, which was determined by reading the title and abstract;
- EC2: not covering the enhancement of work environment productivity; and
- EC3: technical documentation or reports.

The initial automated search retrieved 359 articles (see Figure 2) from the following sources: IEEE Xplore, 166; the ACM Digital Library, 7; Science Direct, 181; and Web of Science, 5.

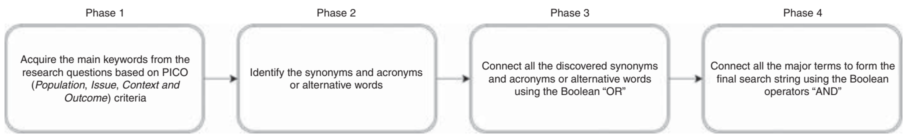

Figure 1. Search string formulation process

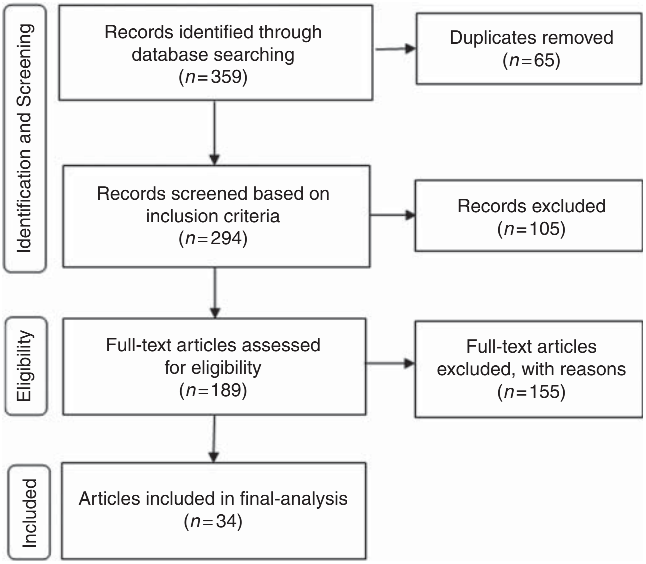

Figure 2.
Flow diagram of the search procedure

After refining the results based on the above-predefined criteria, 34 studies were selected for data extraction (DE) and analysis.

DE. Using a template, the relevant data from the final set of reviewed articles were registered. The DE process included the following input from each selected primary resource:

Metadata:

- The study ID (S1, S2 […],), the author(s), the year of publication, the paper title, the name of the conference or journal in which the study was presented, keywords, topic and the database in which the study was found.

The data were also analysed regarding the RQs and were extracted as follows:

- *RQ1*: types of wearables, utilisation and wearing position; *RQ2*: benefits of wearables in the workplace; *RQ3* challenges of wearables in the workplace.

Extracted data were recorded into 12 data fields described in more detail online in Table AI (https://doi.org/10.5281/zenodo.834232).

4. Results

Petersen *et al.* (2008) recommend researchers do SLRs to investigate and make use of alternative ways of presenting and visualising their results. The results of the present review were consolidated from the relevant articles and are presented in this section in the form of graphs and tables with analysis.

The data from 34 articles were gathered and analysed (see Table AI). Based on the analysed data, this section presents the results related to this SLR. Even though the search was limited to the years between 2000 and 2016, relevant articles only began to appear around 2009. More specifically, as shown in Figure 3, out of the 34 articles, 23 studies came from conferences, nine were from journals and the rest were from other sources (i.e. peer-reviewed magazines). This seems to indicate that, in recent years, there has been growing interest among researchers concerning this topic. Hosseini *et al.* (2015) also assert

Figure 3. Descriptive statistics on types of articles, publications and domains of the selected papers

that "The significant number of papers in conferences and journals is an indicator that the concept has started to get consolidated" (p. 51).

The analysis (Figure 3) shows that 20.59 per cent of studies were conceptual articles primarily focussing on theoretical advances without relying on data (Yadav, 2010). Research articles (67.65 per cent), reviews (5.88 per cent) and others (5.88 per cent), such as viewpoint articles (i.e. contributions presenting an insightful, thoroughly documented viewpoint on a topic), made up the remaining study sample. Further analysis showed that 50 per cent of the research articles came to empirical conclusions through experimental results. The majority of examined articles used methods such as experiments, mixed methods and case studies.

Analysis of the primary studies showed, surprisingly, that wearable technology has been widely discussed in various industry sectors. Over 29 per cent of the primary studies were focussed on wearable technology in office environments, compared to 17.65 per cent focussed on the construction industry. The manufacturing and marine sectors also received attention from researchers. The number of results related to the agriculture, retail, design, electrical and mining industries were limited.

The following section highlights the important results:

RQ1. What types of wearable technology for use in a work environment does the literature mention?

According to Yang *et al.* (2015), because of the commercial perspective "nearly all of the popular wearable devices and mobile apps in the market focus more on personal fitness and exhibit a lack of compatibility and extensibility" (p. 2309). Therefore, it was necessary to find out what types of wearables could be used in a work environment. The main objective of this RQ was to identify the range of wearable technologies so extensively mentioned in recent years and to determine how their use has been categorised. The search led to the identification of 23 types of wearable device categories in relevant papers. These identified devices are shown in Table I.

For this SLR, utilisation of wearable technologies in the work environment were categorised five ways (i.e. monitoring, assisting, augmenting, tracking and delivering content). These ways are discussed below.

Monitoring

Using wearable devices has the potential to engage employees through user engagement features such as data, gamification and content (Asimakopoulos *et al.*, 2017), at the same time making them collectors of quantified self-data, such as weight, diet, exercise routines or sleep patterns and heart rate and blood pressure skin conductance (Milosevic *et al.*, 2012; Lavallière *et al.*, 2016). Potentially, this gives employers opportunities to monitor the work-related stress, mood (Setz *et al.*, 2010; Milosevic *et al.*, 2012; Muaremi *et al.*, 2013; Shirouzu *et al.*, 2015; Lavallière *et al.*, 2016), individual and social behaviour (Kim *et al.*, 2009; Lavallière *et al.*, 2016) and progress (Chen and Kamara, 2011) of employees. For example, Zenonos *et al.* (2016) uses wearable fitness and activity monitoring sensors in conjunction with external devices (i.e. smartphones) with associated applications (i.e. the HealthyOffice smartphone application) for mood recognition of employees in the work environment through a mood recognition framework. The study identifies five intensity levels for eight different moods (i.e. tiredness, happiness, excitement, boredom, stress, sadness, calmness and anger), in two-hour time intervals, with 70.6 per cent accuracy, among employees in an office environment, to benefit employee's health and productivity. Furthermore, they state, "The employer can use this information to understand the general feeling of the work-environment at any given time without explicitly asking any employees. Based on this information, the employer can take decisions to increase positive (e.g. happiness) and reduce the negative moods of the employees (e.g. stress and tiredness)" (p. 5). Similarly, Milosevic *et al.* (2012) state, "Real-time wearable monitoring of occupational stress of nurses or nursing students may facilitate objective assessment of physiological changes and facilitate collection of subjective responses about the source of stress in the workplace" (p. 3775).

Assisting

A study conducted by Mänty *et al.* (2015) shows that "repeated and increased exposure to adverse physical working conditions was associated with a greater decline in physical health functioning over time" (p. 511). Another study conducted by Andersen *et al.* (2016) shows that frequent occupational lifting and consecutive workdays are associated with increased lower back pain among workers. Farioli *et al.* (2014) find that active and high-strain jobs – both categorised by high job demand control – are associated with musculoskeletal pain. These problems are alleviated by utilising assisting wearable devices in the work environment. Assisting wearable devices are external tools provided by employers worn by employees on the body to control posture or lift heavy items. Some of the reviewed studies analyse hydraulic- and electric-powered exoskeletons that assist workers with lifting heavy loads (Chu *et al.*, 2014) and control workers' posture (Luo and Yu, 2013). An exoskeleton is defined by de Looze *et al.* (2015) "as a wearable, external mechanical structure that enhances the power of a person" (p. 196).

Wearable categories	Availability Commercial off the shelf (COTS)	Proof of concept (PoC)	Wearing position	Study citations
Smartwatch	x		Wrist	Kritzler *et al.* (2015), Yang and Shen (2015)
Implantable (e.g. artificial pancreas)	x		Stomach	Nadeem *et al.* (2015)
Performance monitor (e.g. Zephyr BioHarness 3)	x		Chest	Milosevic *et al.* (2012)
Smart clothing (e.g. electronic shirt, sensorised Lycra garment)	x	X	Upper part of the body	Pioggia *et al.* (2009), Yang and Shen (2015)
Blood pressure monitor (e.g. blood pressure sensor node)	x		Arm	Nadeem *et al.* (2015)
Emotion measurement (e.g. emotion board)		X	Arm	Setz *et al.* (2010)
Heart rate monitor (e.g. wahoo chest belt)	x		Chest	Muaremi *et al.* (2013)
Electroencephalogram (EEG) monitor (e.g. EEG device)	x		Head	Dubinsky *et al.* (2014), Durkin and Lokshina (2015)
Electromyography (EMG) monitor (e.g. EMG sensor node)		x	Thigh	Nadeem *et al.* (2015)
Digital pedometer (e.g. Toshiba Silmee W20/W21, Fitbit, Nike + Fuelband, Jawbone UP and Misfit)	x		Wrist	Singh *et al.* (2015), Glance *et al.* (2016), Zenonos *et al.* (2016)
Body motion monitor/tracker (e.g. Inertial sensor node, Wearable Inertial Monitoring Unit (WIMU), BTS FREEEMG for sEMG)	x	x	Waist, thigh, knee, ankle, upper back	Pioggia *et al.* (2009), Nadeem *et al.* (2015), Yang and Shen (2015), Yang *et al.* (2016)
Pulse oximetry (e.g. Pulse oximetry sensor node)	x		Finger	Nadeem *et al.* (2015)
Wearable ECG and acceleration monitor (e.g. MBIT)		x	Chest	Shirouzu *et al.* (2015)
Head-worn terminal/body motion monitor (e.g. smart safety helmet combined with EEG sensors and inertial measurements unit)		x	Head and chest	Lavallière *et al.* (2016)
Heartbeat authenticator (e.g. ECG device, Nymi band)	x		Wrist	Dubinsky *et al.* (2014)
Fitness and activity tracker/monitor (e.g. Toshiba Silmee Bar Type sensor, RFID "UBI Tags")		x	Chest, pocket	Moran and Nakata, (2010), Moran *et al.* (2013), Sole *et al.* (2013a, 2013b), Zenonos *et al.* (2016)
Blood sugar and cholesterol monitor (e.g. blood sugar and cholesterol sensors)	x		Arm	Hamper (2015)
Chest-mounted display		x	Chest	Chen and Kamara (2011)
Eyewear (e.g. wireless personnel supervision system (WPSS) with AR, smart glasses with AR)		x	Eye, head	Leinonen *et al.* (2013), Alam *et al.* (2015)
Heads-up display (e.g. head-mounted display (HMD))	x		Head	Chen and Kamara (2011), Nee *et al.* (2012), Kenn and Bürgy (2014)
Stooped device (e.g. wearable stooping assist device (WSAD))		x	Over the body	Luo and Yu (2013)
Wearable robot (e.g. eectro-hydraulic wearable robot, electric wearable robot)		x	Over the body	Chu *et al.* (2014)
Human behaviour tracker (e.g. Sociometric badge)		x	Neck	Kim *et al.* (2009)

Table I.
Categories of wearable technology for use in the work environment

Augmenting

Wearable computing is a way to explore augmented reality (AR) and it begins to fulfil the promise of a truly personal digital assistant (Starner *et al.*, 1997). Wearable computing allows employers to deliver digital information such as images, text and videos, to head-mounted displays (HMDs) or glasses as the wearer views the real world. Experiments conducted by Lavallière *et al.* (2016) and Leinonen *et al.* (2013) find employers can improve employee performance by initiating training tools with augmenting devices. Employers can also use the AR devices for productivity (Lavallière *et al.*, 2016; Leinonen *et al.*, 2013), remote guidance (Ranatunga *et al.*, 2013), health and safety improvement (Alam *et al.*, 2015), industrial design (Leinonen *et al.*, 2013; Nee *et al.*, 2012) and maintenance work (Alam *et al.*, 2015).

Tracking

Physical inactivity and sedentary behaviour are health risks (Commissaris *et al.*, 2016) for employees and an economic burden to employers. One of the ways to reduce physical inactivity and sedentary behaviour in the work environment is via intervention with wearable devices to track the daily activities of employees. Studies conducted by Pina *et al.* (2012) and Pioggia *et al.* (2009) use devices (i.e. digital pedometers) to increase physical activity and track employees' sedentary behaviour, whereas Yang *et al.* (2016) and Baka and Uzunoglu (2016) point out these devices can be used to track workers and inform them about dangerous areas to avoid. Through these devices, employers can track the position and movement of workers with devices deployed on the body (e.g. arm movement or distance travelled). The tracked physical activity data helps employers with the early detection of work-related issues such as negative moods (e.g. stress and tiredness) (Zenonos *et al.*, 2016). In addition, the expansion of these tracking devices allows employees to monitor their health and fitness and employers to identify health issues among employees in order to offer specialised prevention programmes (Nikayin *et al.*, 2014).

Delivering content

Wearable devices allow employers to deliver materials, and enable users to read, listen to or watch content provided by third parties. In addition, these devices allow employees working in technical fields to read manuals or sets of diagrams while performing repairs or assisting customers with issues. Based on Chen and Kamara (2011), a wearable can provide just-in-time information currently impossible with paper, on-site construction processes.

Of the devices studied, 18 types of wearable devices were used for monitoring, two types were used for assisting, two types were used for augmenting, five types were used for tracking and two types were used for delivering content. Five of the device categories were used for multiple purposes. Based on these findings, a usage framework of wearables in work environments was created (see Figure 4).

Studies show that simpler devices such as digital pedometers (Singh *et al.*, 2015; Glance *et al.*, 2016) and smartwatches (Kritzler *et al.*, 2015; Yang and Shen, 2015) help employers obtain minimal data from tracking the activities of their workers, whereas advanced technologies such as EEG devices (Dubinsky *et al.*, 2014; Durkin and Lokshina, 2015) and EMG sensor nodes (Nadeem *et al.*, 2015), help employers compute a many-devices index (SI) score through employee assessment (Peppoloni *et al.*, 2014), allowing them to create and deploy effective physical well-being strategies. Some wearable devices, such as HMDs (Chen and Kamara, 2011; Nee *et al.*, 2012; Kenn and Bürgy, 2014), EEG devices (Dubinsky *et al.*, 2014; Durkin and Lokshina, 2015) and digital pedometers (Singh *et al.*, 2015; Glance *et al.*, 2016) can be utilised for multiple purposes, while others are suitable for a specific purpose only:

RQ2. How do companies and employees benefit from the use of wearable technology?

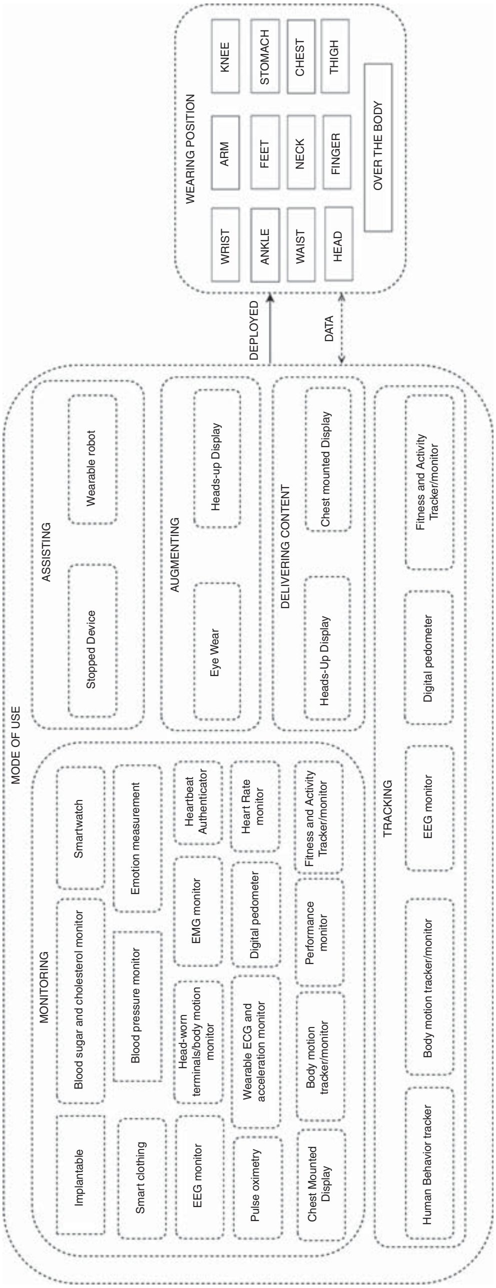

Figure 4.
The categorisation framework of wearable technology types

As mentioned in the previous section, some wearable technologies can be utilised for multiple purposes. The benefits of wearable technology are being actively researched worldwide. This section analyses how wearable technologies can be beneficial, providing long-lasting effects in the workplace:

- Monitoring psychological and physiological factors of employees: many employers remain unaware of the physio-social and physical stress levels of their employees, and the effects these have on the work environment. As Spath (2009) states, “if you can’t measure it, you can’t manage it” (p. 29). This applies to the work environment. Unless employers monitor working environments, it is difficult for them to know if the performance levels of their employees are increasing or decreasing. Wearable technology can be a valuable tool in the workplace to monitor and refine wellness initiatives. Many devices are used for monitoring physio-social stress, such as stress in the work environment (Setz *et al.*, 2010; Milosevic *et al.*, 2012; Muaremi *et al.*, 2013; Shirouzu *et al.*, 2015; Lavallière *et al.*, 2016); physical stress, such as stress caused to the body by contact with heavy equipment (Luo and Yu, 2013; Chu *et al.*, 2014; Peppoloni *et al.*, 2014); or tracking the physical activities of workers (Singh *et al.*, 2015; Glance *et al.*, 2016; Zenonos *et al.*, 2016). A significant benefit of wearable technology involves actively monitoring employees and having access to the data collected by those devices (Kritzler *et al.*, 2015). With the collected data, employers can understand the general feeling of the work environment at any given time without explicitly asking any employees (Zenonos *et al.*, 2016); encourage employees to be more active in their day-to-day life by generating personalised recommendations/prescriptions, utilising gamification or encouraging various well-being incentive programmes (Singh *et al.*, 2015); and predict the health issues of employees and take active steps toward assisting them via specialised prevention programmes (Nikayin *et al.*, 2014).
- Enhancing operational efficiency: employers can utilise wearable devices to deliver content, such as documentation and schematics, either remotely or from a device’s (i.e. HMDs or smart glasses with AR) storage (Nee *et al.*, 2012; Leinonen *et al.*, 2013; Ranatunga *et al.*, 2013; Alam *et al.*, 2015). Employees can then easily access the delivered content in various media forms, allowing them to look up information, answer customer questions, identify faults or make decisions on location or in remote settings.
- Collaborating: wearable HMDs (e.g. smart glasses, Microsoft HoloLens) can be utilised in the workplace to collaborate on projects with employees working in other locations, to find experts or to provide remote guidance to answer questions throughout the work environment (Nee *et al.*, 2012; Ranatunga *et al.*, 2013). Nee *et al.* (2012) reports that when using an HMD for remote guidance, a user’s hands can be free and the user’s vision is unobstructed. The person giving guidance can see the same things as the one being guided through the camera in the mounted device. This means the one giving guidance can see both the real world and the created 3D images from the camera. The images can be imposed on real-world surfaces for the guided person to see and interact with using diverse types of touch gestures (Ranatunga *et al.*, 2013).
- Promoting work environment safety and security: employee safety is always important, but it is especially critical for employees with hazardous jobs, such as those working in mines, operating heavy machinery or dealing with high voltage electricity. In many different sectors (e.g. healthcare and social services), workers may also encounter dangerous people or customers. A number of devices have been developed for safety monitoring, such as detecting falls and relaying alarm messages to caregivers or emergency response teams (Patel *et al.*, 2012). This literature review

discovered that safety and security can be improved with accurate monitoring through the use of wearables. Yang and Shen (2015) found it is possible to detect dangerous working spots (places with the most near-miss falls) using data collected from wearable devices. Another study conducted by Sole *et al.* (2013a) indicates that radio-frequency identification tags can be used to improve work environment safety and limit false alarms. Baka and Uzunoglu (2016) explain that wearables can be used to detect and warn users when a voltage hazard exists. Two sensors (transducers) that detect the user's body current can be attached to a user's feet so the sensors are in contact with skin. When a user approaches a dangerous zone, the device warns the user. This shows that wearables can improve work environment safety for employees.

- Performing industrial design: wearables integrating AR technology can provide new levels of exposure to industrial designing, for example, creating construction plans, blueprints, building information modelling (Leinonen *et al.*, 2013) and aircraft cabins (Nee *et al.*, 2012). Tasks can be done virtually, without incurring extra costs like overhead or travel. (Nee *et al.*, 2012) add, "With virtual information augmented onto a real scene, AR can improve a user's perception of the real world and facilitate human-computer interactions" (p. 662). Nee *et al.* (2012) show that AR can be used in manufacturing workplaces to help with maintenance and measuring the wires for vehicles before installation, leading to time and cost savings.
- Improving workers' health: maintaining a correct working posture is essential in many jobs. Computer-related jobs, construction work and mining are examples of jobs with a lot of physical strain that can cause back problems. When a worker's posture is bad for years, it is highly likely they will experience lower back problems. This strongly supports the need for devices that can improve employee health. In their study, Luo and Yu (2013) developed a wearable stooping-assist device for stooped work. As the name implies, this device reduces the strain from a stooping posture and prevents the risks of having a lower back disorder. Chu *et al.* (2014) experimented with wearable robots (exoskeletons) to improve workers' health while shipbuilding. They used exoskeletons to decrease the muscle strain on lower limb muscles and support vertical load. In the study, two different prototype exoskeletons were tested for several hours to determine their mobility and usability. Although the exoskeletons have certain limitations, such as lifting capacity and maximum walking speed, the workers confirmed that the devices improved work efficiency and seemed to help prevent muscular issues:

RQ3. What challenges to the use of wearable devices remain and what areas require further investigation?

The reviewed studies show that wearable devices may have benefits in the work environment. However, the adoption of wearable devices in the workplace faces the following five challenges:

- Technological challenges: device characteristics, such as size, battery life, modalities, accuracy and processing capabilities (Alam *et al.*, 2015; Chen and Kamara, 2011; Kritzler *et al.*, 2015; Nadeem *et al.*, 2015; Sole *et al.*, 2013b) are the most discussed challenges limiting the ways users in the work environment can interact with wearable technology. For example, Chen and Kamara (2011) mention that current the battery life of a device does not sufficiently last the period of time a user is on the construction work site. This limits the usability of the devices in the work environment. Lavallière *et al.* (2016) address the current size, weight and poor interface of wearable devices. Furthermore, they state, due to the aging of the workforce, there is need for wearable technologies that fulfil the requirements of all age groups, which means any device designed for all age groups might provide other usability challenges. Similarly, Kritzler *et al.* (2015) report, employees are concerned "the screen on the watch would likely break and the beacons, which are quite bulky, would eventually fall off" (p. 216).

Although wearable sensor technology has advanced, technological readiness is another challenge identified in the study because PoC devices use various sensors and prototypes. Nee *et al.* (2012) indicate that the current use of AR in the design and manufacturing work environment still lacks precision and accuracy. Luo and Yu (2013), conclude that, as a stooped human body model is different for each individual, a more precise wearable stooping assistance device model should be designed considering spinal stability and lumbar viscoelastic characteristics for better control over the amount of support provided by the devices. Similarly, Yang *et al.* (2016) find that although wearable sensors have advanced, currently these sensors are incapable of addressing different kinds of environments. For example, near-miss fall detection accuracy varies when the experiment is conducted in two different settings (i.e. laboratory and outdoor settings). They further state the signals from the wearable sensors may be affected while carrying symmetrical or asymmetrical loads, or while completing a diversity of construction job tasks. Durkin and Lokshina (2015) report that, in the future, data security may be a primary concern for both employees and employers because of potential cost savings for enterprises, mobile workforce opportunities and increase in Bring Your Own Device strategies.

- Social challenges: many studies identify violation of privacy as a major issue (Kritzler *et al.*, 2015; Lavallière *et al.*, 2016; Moran *et al.*, 2013; Zenonos *et al.*, 2016). Kritzler *et al.* (2015) state, that workers have concerns about how the features wearable technology has (e.g. monitoring heart rate, number of steps and GPS location) can be accessed and used without their knowledge. Furthermore, Lavallière *et al.* (2016) state that some older individuals unfamiliar with technology are concerned about privacy in the work environment, saying "great efforts and research should be undertaken in the domain of privacy concerns and willingness to use these devices among older individuals" (p. 41). Nikayin *et al.* (2014) points out that if wearable device providers such as employers or insurers have access to the data it raises ethical questions about whether having that information might influence hiring, firing or accepting employees. In addition, they state, "If employers access their employees' medical information, the employees could be concerned that the employer will use such data to discriminate against employees in the workplace" (p. 330).
- Previous studies identify factors, such as users' technological skills, privacy concerns (Nikayin *et al.*, 2014), and user requirements such as security and ease of use (Nadeem *et al.*, 2015), that can influence the adoption of wearable devices. For example, Nikayin *et al.* (2014) point out that the inevitable sharing of personal health data between collaborators compromises privacy. They state, "This may not only inhibit the acceptance of the programme, but could also provoke a conflict of interest between employer and employees" (p. 330).
- Policies and standards set by regulators: governments should provide strategic policy frameworks for the acquisition and use of IT for social and economic growth (Ejiaku, 2014). For example, Nikayin *et al.* (2014) state that providing services based on wearable technology would likely require relations with other actors, such as insurers and government institutions. They further note that this creates new challenges in finding out how institutional settings can influence the implementation and adoption of the services based on wearable technology.

- Economic challenges: the research community raises some concerns about the complexity and cost of integrating wearable devices with existing systems. For example, Chen and Kamara (2011) assert that cost is one of the factors that may affect the implementation of computing devices on construction sites, including organisational information systems related to specific construction projects. They further state that for companies it is necessary that the return on investment exceeds the cost of obtaining information wirelessly. Chan *et al.* (2012) assert "the high cost of current wearable system services limits their expansion" (p. 150). Nikayin *et al.* (2014) state that using wearables in the work environment requires collaboration between multiple service providers, which could change the business model, requiring the conceptualisation of a new business model more likely to succeed.
- Data challenges: Nikayin *et al.* (2014) state that wearable devices generate a large amount of health-relevant data that can be collected and analysed by different service providers such as employers and insurers. Furthermore, "Collecting health-relevant data raises concerns over data ownership, privacy and the role of the employer. For the case discussed, issues of data ownership and who has the right to use data in which way still have to be dealt with" (p. 331).

5. Discussion and research agenda

Having healthy employees is important for companies and being healthy is obviously desirable. As research reviewed in this work indicates, monitoring can be used to determine the causes of stress and to limit them by understanding the general feeling of the work environment at any given time without explicitly asking any employees (Zenonos *et al.*, 2016). By monitoring physical changes in the body, it may be possible to detect illnesses (Chan *et al.*, 2012) and obtain proper treatment before those illnesses progress. The use of wearable devices can improve the safety of work environments (Baka and Uzunoglu, 2016) and increase productivity. However, this SLR revealed that challenges – technological (i.e. usability, technology readiness and security), social (i.e. privacy and adoption), policy-related, regulatory, economic and data-related – remain.

The SLR revealed that several COTS and PoC (see Table I) wearable categories, such as smartwatches (Kritzler *et al.*, 2015; Yang and Shen, 2015), digital pedometers (Nikayin *et al.*, 2014; Singh *et al.*, 2015; Glance *et al.*, 2016), smart clothing (Pioggia *et al.*, 2009; Yang and Shen, 2015) and HMDs (Chen and Kamara, 2011; Nee *et al.*, 2012) that are used for entertainment or lifestyle purposes can also be used beneficially in the work environment. However, it may not always be possible to use COTS devices in work environments due to the context of the work and potential technological challenges. For example, Kritzler *et al.* (2015) find that a smartwatch with an LCD display and attachable beacons does not withstand harsh industrial environments. Similarly, Chen and Kamara (2011) point out that not all kinds of available devices can be used in the construction industry because of various physical conditions found there, such as extreme temperatures, humidity and dust; there are also usability issues related to such devices' characteristics, such as battery life. This means organisations have to employ rugged devices suitable for harsh environmental conditions, which may be costlier than normal COTS devices, increasing the cost of the implementation and limiting the feasibility of expansion (Chan *et al.*, 2012).

In addition to usability, wearability is an important characteristic of wearable devices. For example, employees working with: wearable robots on the body, for either long or short time periods, need devices that are relatively safe and comfortable; HMDs or eyewear attached to the employee's head require devices that cause minimal symptoms of discomfort leading to cyber-sickness, such as nausea, sickness and headaches (Porcino *et al.*, 2017). Devices failing to incorporate adequate wearability characteristics can affect utilisation (i.e. monitoring, tracking, augmenting, delivering contents and assisting), ability, motivation and an employee's engagement with the device and any associated smartphone applications, leading to increased risk in the work environment. In his behaviour model, Fog points to motivation as being an important element, in addition to trigger and abilities that determines whether or not engaged behaviour happens in an individual (Hamper, 2015). Nafus (2013) points out that wearables' current design options have constrained the adoption of them because of negative societal effects, such as limiting the creation of new knowledge, increasing dependency on technology and experts, and demoralising users due to a lack of relevant information presented by interpreting quantified data and decreasing privacy. However, few studies have attempted to map wearability factors while designing wearable devices (Motti and Caine, 2014).

Although using wearable devices, such as exoskeletons, can be effective in preventing muscular diseases by lowering physical strain on the body and improving work efficiency (Chu *et al.*, 2014; Luo and Yu, 2013), one potential problem with wearable exoskeletons is that safety standards for their usage in work environments have not yet been formalised (de Looze *et al.*, 2015). Although development and deployment of such devices is still in the initial stages, safety needs should be considered from the beginning so they do not later become urgent concerns for either employers or employees.

Although there are demonstrable benefits for both employees and employers while utilising and adopting wearables in the work environment, challenges related to privacy, data and security may result from the utilisation of wearable devices, in both pushed self-tracking and imposed self-tracking contexts. Different forms of ICT, such as wearable devices, empower employers (Cuijpers, 2007) and technology designers (Nafus, 2013) to promote their own goals, motives, interests and personal characteristics (Simpson *et al.*, 2015). For example, to reduce costs and compete with other organisations, employers may cooperate with institutional third parties such as insurance companies to reduce premiums conduct round-the-clock by using anonymous monitoring, called sousveillance, or "watching from below: a form of inverse surveillance in which people monitor the surveillors" (p. 11) (Fernback, 2013), without employees' consent – either via pushed or imposed self-tracking – in order to gather biometrics and other health-related habits and data (Lupton, 2015). The data collected could include the number of steps taken, heart rate, any medical conditions (Martin *et al.*, 2000) and geo-data. Although geo-data tracing collects user data anonymously, it can still involve a breach of privacy, as the information can be associated with the identity of the individual (Paul and Irvine, 2014). Similarly, technology designers may employ the sensors of wearable devices and associated applications to understand employees' daily habits and health for their own competitive advantage in the market, such as designing the technology or applications to be more relevant to the designers' needs than the users' (Nafus, 2013). Furthermore, the implications of both designers' and employers' ability to access such data raises privacy concerns, affecting the beliefs and behaviours of employees towards both employers and wearable technology itself, potentially inhibiting technology acceptance in the work environment.

Wearable devices generate a large amount of data; if the data are not analysed, they have no use (Nafus, 2013). From this perspective, four challenges may arise, creating feelings of uncertainty among both employers and employees: information ecology: how data will be collected and for which purposes collected data will be used; data literacy: who has the skills and abilities to analyse, interpret quantified data and provide feedback to the employees. Nafus (2013) states, "exporting data into common formats is difficult for users without coding skills, and widespread awareness of what can and cannot be obtained from device providers is lacking" (p. 152); data ownership and sharing: who owns the data; are those data shared with any other parties?; and data security: what kind of security measures will be taken to protect against internally unauthorised access by other employees and to protect externally against hackers, as the data will be scattered in different machines and devices including servers and mobile devices during storage and analysing (Sun *et al.*, 2014). Such uncertainty may hinder both acceptance and implementation of wearable technology in the work environment. Delaney and Agostino (2015) state that "The uncertainty of what new technology means for employees' can trigger more resistance to their acceptance of it" (p. 9).

To conclude, the above discussion highlights significant research gaps, which could jeopardise the acceptance and utilisation of wearable technology in the work environment and affect the relationship between employees and employers. Keeping this gap in mind, new avenues for future research to advance this area are possible. Although a substantial research effort has been devoted to the benefits of the wearables in the work environment, less attention has been paid to the empirical analysis of employees' attitudes towards their employer's ability to access health-related data through tracking and monitoring, or their acceptance of wearable technology in the work environment. Taherdoost *et al.* (2012) states, "For novel technology development in any educated society, acceptance measurement is more significant than relevant advantages and usefulness" (p. 1792). Considering wearables to be a beneficial technology, attitude, social and convenience factors play important roles in acceptance of wearable technology leading to recommendation. One way of moving forward is to empirically examine which factors affect employees' acceptance of wearables in the work environment. Within this perspective, the empirically examined (Gao *et al.*, 2015) model, such as a combination of the unified theory of acceptance and use of technology 2, protection motivation theory (PMT) and privacy calculus theory, could be adopted as a baseline model to help determine the key factors associated with an employee's willingness to accept wearables in the work environment. Although (Gao *et al.*, 2015) model is focussed on understanding the acceptance of wearable technology in healthcare sector, it may provide a better baseline than other technology acceptance model, which are not tested for such purposes. In considering user acceptance of wearable technology in the work environment, this study encourages researchers to consider wearability factors as additional variables when conducting further research.

On the other hand, privacy concerns while using technology depends on how much the user trusts the observer's (Pavlou, 2003; Moran and Nakata, 2010) motivation. To advance research on both the employee acceptance and benefits of wearable technology, future research should seek (i) to determine which privacy concerns affect the employees and how these concerns influence their behavioural responses and (ii) understand how employees perceive their relationship with their employers with regards to health-related data collection. Thus, Fortes and Rita's (2016) model, which is the combination of theories of trust and risk, the theory of planned behaviour and the technology acceptance model or PMT alone may be used as the basis for understanding the employees' level of privacy concerns and their behavioural responses, whereas theories of social exchange, communication and interpersonal relationships could be the starting point to empirically examining the important factors that may affect employer-employee relationships. Further research should include empirical research to examine which of the three factors – the nature of the data, the technology involved and the voluntariness of handing over otherwise private information to third parties as stated by Cuijpers (2007) – are the most important for an employee's reasonable expectation of privacy.

In summary, to successfully utilise wearable technology in the work environment for purposes like physiolytics – the practice of linking wearable computing devices with data analysis and quantified feedback to improve employee performance (Wilson, 2013), a major research collaboration between researchers, technology designers and organisations is needed. Such a successful utilisation will require investing time in the creation of new policies and strategies to offset the discussed challenges (i.e. usability, wearability, accuracy, security, cost, adoption, privacy and data). Attempting to understand the stakeholders' relationships with these challenges could be explored in future research.

6. Conclusion

Utilising wearable technology in the work environment to improve the health and safety of employees is a relatively new concept, but the research has gained significant momentum over the last few years. This paper is the first SLR on the topic. The strength of this work lies in its attempt to analyse relevant earlier studies and identify current research trends, while also examining the future potential of wearable technology in the workplace. This review reveals that wearable technology is not only appropriate for personal use but also has the potential for use in the work environment. These devices may be used for real-time monitoring, tracking, designing and other purposes. Previous studies have described some of the potential benefits of using wearable devices in the workplace, including monitoring and improving employees' psychological and physiological health, enhancing operational efficiency and collaboration, promoting work-environment safety and security and implementing industrial design. Potential negative implications and challenges of wearables in the work environment are also discussed. Many of these wearables, including exoskeletons and smart clothing, are still in the initial stages of development, but initial indications show they may revolutionise the work environment for the mutual benefit of employees and employers.

Constraints relating to economic, technological, legal, social and organisational factors, as well as strategies, data and government rules and regulations must still be overcome. These concerns could have legal, social and ethical implications, which in turn could lead to reduced productivity and efficiency. It is imperative that any stakeholders involved must not take advantage of a wearable device's power to infringe on an employee's right to privacy at the risk of causing both direct and indirect psychological effects.

Note

1. PICO Criteria: http://learntech.physiol.ox.ac.uk/cochrane_tutorial/cochlibd0e84.php

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Appendix

Citation	Research focus	Types of wearables discussed	Utilisation	Wearing positon	Benefits
Alam *et al.* (2015)	Advanced system architecture for maintenance workers in extreme environments using augmented reality for accurate maintenance tasks.	Wireless personnel supervision system (WPSS) with AR	Augmenting	Head	Workplace health and safety
Baka and Uzunoglu (2016)	Protecting electricians from step-voltage hazards using wearable devices to detect step-voltages in industrial areas.				Workplace safety
Chen and Kamara (2011)	Introduces a framework for the implementation of mobile computing on construction sites and validates the result with case studies.	Head-mounted display, chest-mounted display	Delivering, Monitoring	Head, chest	Progress monitoring
Chu *et al.* (2014)	Experiments with a wearable robot for carrying heavy objects in shipbuilding works. Testing two types of wearable exoskeletons for industrial work. Testing the manoeuvrability and benefits of these robots.	Electro-hydraulic wearable robot and electric wearable robot	Assisting	Overall body	Improving worker health
Dubinsky *et al.* (2014)	Wearable-based mobile app to help with decision-making. Study identifies how wearable devices can identify situations involving cognitive dissonance.	ECG device, Nymi band,	Monitoring		
Durkin and Lokshina (2015)	Studies about the impact of integrated wireless and mobile communication technologies on the corporate world.	EEG device, ECG tracker to apps on external devices	Monitoring, Tracking	Head	Workplace health and safety
Glance *et al.* (2016)	Measures the health and well-being of workers through assessments and activity programs in the workplace.	Digital pedometer: Fitbit, Jawbone and Misfit	Monitoring, Tracking	Wrist	Monitoring physiological
Hamper (2015)	Discusses how to use context-aware applications to promote physical activity.	Blood sugar and cholesterol sensors connected to apps on external devices	Monitoring	Wrist	Monitoring physiological

Table AI.
Raw data collected from selected studies

(*continued*)

Citation	Research focus	Types of wearables discussed	Utilisation	Wearing positon	Benefits
Kenn and Bürgy (2014)	Information about an augmented reality-based wearable system and why further research of such a system is required.	Head-mounted displays and complete head-worn computing devices	Augmenting, Delivering	Head	Industrial designing
Kim *et al.* (2009)	Discusses sensor-based feedback systems in organisational computing and how such systems can improve the performance and satisfaction of workers.	Sociometric badge	Tracking	Neck	Monitoring physiological
Kritzler *et al.* (2015)	Discusses wearable technology as a solution for workplace safety, explaining the ideas for, and implementation of, a safety system for personal protective equipment (PPE), based on wearable sensors and wireless technology.	PPE with beacons, smartwatches and apps on external devices	Monitoring	Wrist	Workplace health and safety
Lavallière *et al.* (2016)	Explains how wearable technologies can be used to tackle the challenges faced by an aging work force.	Smart safety helmet combined with EEG sensors and an inertial measurements unit	Monitoring	Head, chest	Monitoring physiological
K Leinonen *et al.* (2013)	Information about the use of augmented reality in construction work.	Smart glass with AR	Augmenting	Head	Industrial designing
Luo and Yu (2013)	Discusses reducing physical strain on the lower back with the help of a wearable stooping-assist device (WSAD).	WSAD	Assisting	Overall body	Improve worker health
Milosevic *et al.* (2012)	Discusses conducting simulations for nursing students with different type of tasks. Students wear wireless sensors, which detect stress to determine which tasks cause the most stress.	Zephyr BioHarness 3	Monitoring	Chest	Monitoring physiological
Moran *et al.* (2013)	Discusses experiments on the effects of wearable tracking devices, comparing the reactions and attitudes of British and Japanese workers toward these devices.	RFID "UBI Tags"	Tracking	On the body	Monitoring physiological
Moran *et al.* (2012)	Discusses experiments on the effects of wearable tracking	RFID Wearable tags	Tracking	On the body	Monitoring physiological

(*continued*)

Table AI.

Citation	Research focus	Types of wearables discussed	Utilisation	Wearing positon	Benefits
	and performance monitoring devices in workplace.				
Moran and Nakata (2010)	Discusses ubiquitous monitoring in the office focussing on user perceptions of wearable monitoring devices.	RFID wearable tags	Tracking	On the body	Monitoring physiological
Muaremi *et al.* (2013)	Discusses experiments to determine the solution for assessing the stress experience of people using features derived from smartphones and wearable chest belts.	Wahoo chest belt with applications on external devices	Monitoring	Chest	Monitoring physiological
Nadeem *et al.* (2015)	Provides information on scenarios where Body Area Sensor Network (BASN) can be used for both application and technical aspects.	ECG sensor node, Pulse Oximetry sensor node, EMG sensor node, inertial sensor node, artificial pancreas, blood pressure sensor node	Monitoring	Chest, finger, thigh, ankle, stomach, arms	Monitoring physiological
Nee *et al.* (2012)	Discusses different applications for augmented reality in industrial work.	Head-mounted display with AR	Augmenting, Delivering	Head	Industrial design
Nikayin *et al.* (2014)	Presents an illustrative case of a primary prevention programme in Finland using wearable devices in the work environment.	Pedometers	Monitoring	Wrist	Monitoring physiological
Peppoloni *et al.* (2014)	Discusses experiments on supermarket cashiers monitoring the physical strain on their hands as they perform constant repetitive movements.	Wearable inertial measurements units (WIMU)	Monitoring	Arm	Monitoring
Pina *et al.* (2012)	Presents a system designed to leverage Fitbit's near-real-time, automated step-logging to detect sedentary behaviour and then prompt users to take walking breaks.	Fitbit+	Tracking	Wrist	Monitoring physiological
Pioggia *et al.* (2009)	Explains the platform that analyses and merges sEMG signals and kinematics variables to provide coherent, dynamic information about the acquired movements.	BTS FREEEMG for sEMG, and a sensorised-Lycra garment	Tracking	Waist, thigh, knee	Monitoring physiological

Table AI. (*continued*)

Citation	Research focus	Types of wearables discussed	Utilisation	Wearing positon	Benefits
Ranatunga *et al.* (2013)	Discusses using augmented reality to project 3D images on the surface of objects, and then manipulating those images with hand gestures.	Head-mounted display with AR	Augmenting, Delivering	Head	Improve workers' health
Setz *et al.* (2010)	Discusses finding the line between regular cognitive load and stress in work situations. The test subjects were given difficult tasks in an attempt to cause stress and monitor it.	Emotion board	Monitoring	Arm	Monitoring physiological
Shirouzu *et al.* (2015)	Discusses using wearable devices such as an ECG and acceleration measuring device to find the causes of stress among kindergarten teachers.	MBIT-wearable ECG and acceleration measuring device	Monitoring	Chest	Monitoring physiological
Singh *et al.* (2015)	Explains how heart rate sensing in the workplace environment can be beneficial.	Fitbit, Fuel band, Jawbone UP, Nike+	Monitoring, Tracking	Wrist	Monitoring physiological and physiological
Sole *et al.* (2013a)	Discusses using RFID tags to monitor the safety of employees and the correct use of safety devices.	RFID tags	Tracking	Chest, head, feet	Workplace safety
Sole *et al.* (2013b)	Discusses using RFID tags to monitor the safety of employees and the correct use of safety devices.	Passive RFID tags and sensors	Tracking	Chest, head, feet	Workplace safety
Yang *et al.* (2016)	Studies the reasons ironworkers fall. The collected data can be used to minimise the risk of falling or increase the safety of specific areas.	WIMU	Tracking	Any part of body	Workplace safety and security
Yang and Shen (2015)	Discusses using wearables to reduce the mental and physical stress of future employees and examining how such devices could bring aging populations back to work.	Smartwatch/electronic shirt	Monitoring	Wrist and body	Monitoring physiological

(*continued*)

Table AI.

Citation	Research focus	Types of wearables discussed	Utilisation	Wearing positon	Benefits
Zenonos *et al.* (2016)	This study focusses on the use of wearable technology embedded with physiological and movement sensors along with external devices (i.e. smartphone) and associated applications to recognise the moods of employees in workplace.	Toshiba Silmee, bar type, W20/W21 with apps on external devices	Monitoring, Tracking	Wristband	Monitoring physiological and physiological

Table AI.

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