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Jayden Khakurel

ENHANCING THE ADOPTION OF QUANTIFIED SELF-TRACKING WEARABLE DEVICES

LUT University

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Dissertation for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the lecture room 2303 at Lappeenranta University of Technology, Lappeenranta, Finland on the 19th of December, 2018 at noon.

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Abstract

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Over the past couple of years, quantified self-tracking wearable devices have become a promising emerging technology that can aid individuals in improving physical activities through behavior change. However, the adoption rate of these devices has not reached expectations, so researchers and practitioners have looked into ways to reduce abandonment, focusing on young or middle-aged individuals; yet little research exists on how to improve the adoption rate of wearables among older adults. Also, these wearable devices could be used as an interventional tool in an organizational context to reduce employees' sedentary behaviors. However, driven by the impression that the devices give access to health-related data to employers, employees may be reluctant to adopt wearable devices in the work environment. A more in-depth study is needed to explore on how to improve the adoption of quantified self-tracking wearable devices in both use contexts: individual and organizational.

Therefore, this thesis explores the needs for acceptance and continued use of quantified self-tracking wearable devices, from a device characteristic perspective among older adults in the individual context, while factors influencing adoption of these technologies in the long term by individuals in the organizational context. This study employs qualitative and quantitative research to gather data from a usability and behavioral perspective.

The findings show that for older adults, it is necessary to design the external context by understanding the demographic context, which could improve the internal context and the intention to continue using quantified self-tracking wearable devices (i.e., smartwatches and pedometers). Similarly, for organizational use, the findings indicate wearability and attitude factors have a direct effect on intention to use, whereas performance and effort expectancy have only a direct influence on attitude and intention. In addition, privacy concerns and social influence have a positive influence on the intention to use both directly and indirectly through attitude. The design and device characteristics have a significant negative influence on intention to use.

Overall, the findings show how to improve the effectiveness and efficiency associated with the use of quantified self-tracking wearable devices such as smartwatches and pedometers, as well as increase user satisfaction in both the organizational and personal use contexts, especially with older adults, where there is a current need to reduce the rate at which wearables are abandoned.

Keywords: Quantified self-tracking device, Older adults, Organizational use, Wearable devices, Wearable technologies IT-enabled social innovations.

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Jayden Khakurel
November 2018
Lappeenranta, Finland

"The broader one's understanding of the human experience,
the better design we will have."

Steve Paul Jobs

Contents

List of publications

This thesis is based on the following papers; the rights have been granted by publishers to include the papers in the current dissertation:

I. Khakurel, J., Porras, J., Melkas, H., and Fu, B. (2018) 'A Comprehensive Framework of Usability Issues related to the Wearable Devices', *(Submitted to Human-Computer Interaction, Taylor & Francis Group) (Under Review).*

II. Khakurel, J., Tella, S., Melkas, H., Penzenstadler, B., and Porras, J. (2017) 'Living with Smartwatches and Pedometers: The Intergenerational Gap in Internal and External Contexts', *in GOODTECHS Conference Proceedings. Pisa, Italy: Springer-Verlag in the Lecture Notes of ICST (LNICST),* pp. 31–41.

III. Khakurel, J., Knutas, A., Melkas, H., Penzenstadler, B., Fu, B., and Porras, J. (2018). Categorization framework for usability issues of smartwatches and pedometers for the older adults. *(In: Antona M., Stephanidis C. (eds) Universal Access in Human–Computer Interaction. Users and Context Diversity. UAHCI 2018. Lecture Notes in Computer Science, vol 10907. Springer, Cham)*

IV. Khakurel J., Knutas A., Melkas H., Penzenstadler B., Porras J. (2019) Crafting Usable Quantified Self-wearable Technologies for Older Adult. *(In: Ahram T. (eds) Advances in Human Factors in Wearable Technologies and Game Design. AHFE 2018. Advances in Intelligent Systems and Computing, vol 795. Springer, Cham)*

V. Khakurel, J., Melkas, H., and Porras, J. (2018) 'Tapping into the wearable device revolution in the work environment: A systematic review', *Information Technology and People*. Emerald, pp. 1–17.

VI. Khakurel, J. Knutas, A., Immonen, M., and Porras J., (2017) 'Intended use of smartwatches and pedometers in the university environment', in *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers on – UbiComp '17*. New York, New York, USA: ACM Press, pp. 97–100.

Author's contribution

For Publication I – Initially, the dissertation candidate presented this idea to the supervisor (i.e., second author) and discussed the methodology. In a later stage, the dissertation candidate was involved in the data collection and analysis and wrote the publications. The second and third authors supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

For Publication II – The dissertation candidate and all authors conceived, planned, and designed the measurements. The dissertation candidate conducted the survey and collected the data; the second and third authors analyzed and interpreted the data. The dissertation candidate wrote the publication. All authors discussed the results and commented on the publication.

For Publication III – The dissertation candidate and third and sixth authors conceived, planned, and designed the measurements. The dissertation candidate performed the experiment and collected and processed the experimental data. The dissertation candidate and second author performed the analysis, interpreted the results, and drafted the publication. All authors discussed the results and commented on the publication. The fifth author provided critical feedback for the final version of the publication.

For Publication IV – The dissertation candidate and third and fifth authors conceived, planned, and designed the measurements. The dissertation candidate performed the experiment and processed the experimental data. The dissertation candidate and second author performed the analysis and interpreted the results. The dissertation candidate wrote the publication. All authors provided the critical feedback for the final version of the publication.

For Publication V – Initially, Simo Pöysä and the third author conceived of the idea. The approval for the further rework was taken from Simo Pöysä. The dissertation candidate reworked the entire concept, conducted data collection, performed the analyses, and wrote the publications. The second and third authors supervised and contributed to the manuscript through their critical feedback.

For Publication VI – The dissertation candidate and fourth and fifth authors conceived, planned, and designed the measurements. The dissertation candidate carried out the experiments and wrote the publication. All the authors provided critical feedback and helped shape the research, analysis, and publication.

Nomenclature

Abbreviations

HMD	head-mounted device
COTS	commercial off-the-shelf
VR	virtual reality
UTAUT	united theory of acceptance and use of technology
TAM	technology acceptance model
SLR	systematic literature review
CAT	contextual action theory
UEM	usability evaluation method
CAT	contextual action theory
UEM	usability evaluation method

1 Introduction

Smart computing technologies—such as wearable devices (wearables) that can be comfortably worn on the body to measure and manage daily activities—have recently been introduced and enhanced by technology developers and researchers (Wright and Keith, 2014). Wearable devices represent an evolution in the expansion of sensors and are available in various forms (either on or near the human body) to sense and analyze physiological and psychological data, including feelings, sleep patterns, movements, heart rate, and blood pressure (Khakurel et al., 2018). Applications are either installed on the wearable device or external devices, such as smartphones, that are connected to a cloud service (Khakurel et al., 2018). The wearable device industry has evolved exponentially over the past few years in terms of the technology and design of wearables (Motti and Caine, 2014), which may partly be because of the recent conversion from the use of large, bulky, and user-unfriendly technologies (Wright and Keith, 2014) to those that are powerful, affordable, unobtrusive, and fashionable, which is partly thanks to the development of different categories of commercial off-the-shelf or proof-of-concept wearable devices. These categories include smart watches (Kritzler et al., 2015); implantable devices (Nadeem et al., 2015); smart clothing (Pioggia et al., 2009; Yang and Shen, 2015); pedometers (Zenonos et al., 2016); and head-mounted devices (Lavallière et al., 2016). Among these categories, quantified self-tracking wearable devices such as smartwatches and pedometers have been around since 2000 and are commercially growing as an extension of smartphones but with more intimate elements (Choi and Kim, 2016). These devices seem to have become mainstream among individuals who are taking part in the quantified self-tracking movement, in which individuals engage in the self-tracking of any kind of biological, physical, behavioral, or environmental information, such as continuous data about vital signs (e.g., heart rate, skin temperature) and environmental variables (e.g., movements) (de Arriba-Pérez et al., 2016; Swan, 2013).

The known benefits of wearable devices for individuals of all ages, regardless of for what purpose wearable is used, that is, for personal use or use at work, have been reported by many practitioners and researchers in recent years (Kritzler et al., 2015; Lauritzen et al., 2013; Luo and Yu, 2013; Malcolm et al., 2013; Moran et al., 2012; Muaremi et al., 2013; Rasche et al., 2015; Sin et al., 2014). Following technological advancements and the revolution of their design, wearable devices have acted as facilitators in personal and work environments in the following ways:

- To influence healthy lifestyle behavior in individuals through quantified self-tracking (Swan, 2013) and the interrelationship between them, that is, goal setting, feedback, connectivity, and intervention (Lentferink et al., 2017; Wu et al., 2016) so that individuals can become better versions of themselves (Lazar et al., 2015).
- To improve the mobility of older adults (i.e., via assistive support devices) (Kong and Jeon, 2006).

- Increase efficiency, productivity, and performance through real-time collaboration between and knowledge transfer among workers to enhance core business processes (Kalantari Mahdokht, 2017).
- To understand patient health conditions through the analysis of health data patterns and trends (i.e., algorithms) (Appelboom et al., 2014).
- To understand employee-related physiological stress through the analysis of daily quantified data (Zenonos et al., 2016).
- For use in daily pediatric surgical practice, photo and video documentation, and searches for unfamiliar medical terms or syndromes (Muensterer et al., 2014).

The benefits that wearables bring to individuals and organizations are expected to increase as different types of wearable device categories emerge and as global shipment opportunities rise. However, this also brings a dilemma: Which devices are suitable for which purposes? The widespread adoption of wearable devices is anticipated if the projections about the growth of this sector, its technological advances, the availability of devices in the market, and their known benefits are taken into consideration (Lazar et al., 2015). Indeed, the exponential growth of various categories of wearable devices has been supported by forecast data. Globally, the shipment of smart wearable devices is expected to total 98.0 million units in 2018 and reach 148.5 million units by 2021 (Statista, 2017).

However, it is intriguing to note that the actual adoption rate of wearable technology is not up to expectations (Jeong et al., 2017): individuals only use wearable devices for a short period immediately following their initial adoption, ultimately abandoning them. Wu et al. (2016) assert, “While the adoption rate has increased, the abandonment rate remains high” (pp.1068). Similarly, Hänsel et al. (2015) point out that ensuring long-term user retention is still a challenge; because these devices are still counted as emerging technology, research on these devices is at a nascent stage (Reeder and David, 2016). For example, the rate at which wearable devices such as smartwatches were abandoned was reported to be 29% (Gartner Inc, 2016), and nearly a third of people (30%) who started wearing pedometers stopped using them. It has been demonstrated (Shih et al., 2015) that 25% of the participants abandoned their pedometers after only 1 week of use, 50% did so after 2 weeks, and 75% after 4 weeks. Similarly, 80% of purchased devices, such as smartwatches and pedometers, were shown to be discarded within the first 2 months of use (Lazar et al., 2015). This means that among individuals, a positive first evaluation of an innovation is followed by commitment to use the innovation on all following occasions (Lee, 2014), but if the individual perceives challenges at this first evaluation, the individual will abandon the device.

Concern over the growing abandonment of wearable devices and the saliency of threats to their future have been expressed (Endeavor Partners, 2014; Gartner Inc, 2016; Lazar et al., 2015; Lee et al., 2016). The abandonment of quantified self-tracking wearable devices such as smartwatches and pedometers was recently attributed to the gap between the features desired by consumers and the capabilities of the device (Wu et al., 2016), as well as device breakage or loss and technical difficulties with the device or its accompanying software (Maher et al., 2017). Piwek et al. (2016) state, “Those who market and develop consumer level devices may underestimate the distance between designing a product that appears to be associated with a healthy lifestyle and providing evidence to support this underlying assumption" (pp.3). Because these quantified self-tracking wearable devices can also provide insights and support behavior changes within an individual by providing information on his or her performance, a lack of knowledge regarding what consumers want or need could jeopardize the future innovation and long-term retention of these devices, and individuals will remain unsure of whether to use them (Hänsel et al., 2015). In addition, short-term adoption also has a negative impact on the environment because of e-waste. Bhutta et al. (2011) point out, "A major driver of the growing e-waste problem is the short lifespan of most electronic products—less than two years" (p.2). Therefore, the current thesis seeks to fill this gap in the research on wearables by conducting usability and behavioral research on what individual's desire while using quantified self-tracking wearable devices so that these devices can be used for a longer period of time.

In recent years, to reduce abandonment, the adoption of wearable devices has been looked at, here focusing on young or middle-aged individuals or only on individuals who are already physically active (Seifert et al., 2017). This tendency to neglect older adults can also impact their access to and usage of recent technologies (Wu et al., 2015). Batsis et al. (2016) and Jeong et al. (2017) also assert that there is a need for research on older adult's experiences when it comes to adopting smartwatches.

Seen from a different angle, these quantified self-tracking devices can be utilized for the same purpose: to retrieve quantified self-tracking data and display these data on the user interface of the device or on an application installed on external devices, which can be done in both the individual and organizational context, as proposed in recent research (Ajana, 2017; Lupton, 2014). Although an individual context poses few issues, users might be reluctant to adopt wearable devices in a work environment because these devices expedite access to health-related data by employers and third parties, for example, insurance companies. Thus, it is potentially concerning that the use of wearable devices could negatively impact the privacy of employees if an organization employs mandatory and voluntary self-tracking (Lupton, 2015). There is growing interest among technology designers and developers to understand the influential factors in adopting these technologies in the long term by individuals in the organizational context (Kalantari Mahdokht, 2017). In light of the concerns regarding increases in the rate at which quantified self-tracking wearable devices are being discarded and the future challenges of these wearable devices, the objective of this dissertation is the following: *to bridge the gap of device users' needs and other stakeholders such as managers, technology designers, application developers, vendors, and the research community by addressing the factors that impact the acceptance of and the intention to continue to use quantified self-tracking wearable devices in both individual and organizational contexts.* However, based on previous studies (Batsis et al., 2016; Ehn et al., 2018; Hounsell et al., 2016; Jeong, Kim, Kim, et al., 2017; Seifert et al., 2017), there is a need for research regarding the acceptance of and intention to continue to use quantified self-tracking devices by older adults in terms of individual context. Therefore, this thesis focuses through Research

Question (RQ1) on older adults and their needs for acceptance and continued use of quantified self-tracking wearable devices, while factors influencing adoption of these technologies in the long term by individuals in the organizational context will be investigated through Research Question (RQ2).

The overarching questions that motivate our research are the following:

RQ1. For the target audience of older adults, what should technology designers, application developers, and the research community do to improve the acceptance of and intention to continue using quantified self-tracking wearable devices from the perspective of the usability of the device characteristics (i.e., hardware and software)?

RQ2. How can organizations implement and increase the acceptance of and intention to continue using quantified self-tracking wearable devices for different use purposes?

To answer these research questions, in the current thesis, the factors associated with the abandonment of quantified self-tracking wearable devices were identified from a usability and behavioral perspective by applying the contextual action theory (CAT) proposed by Stanton (1994) and usability evaluation method (UEM) (Ivory and Hearst, 2001) to a set of experiments among older adults; in addition, the united theory of acceptance and use of technology (UTAUT) as the baseline model (Venkatesh et al., 2003) was used with sets of quantitative data among individuals in organizational settings.

The contributions of the present thesis are as follows:

- An overview is provided of the usability issues affecting individuals' use of wearable devices for personal use.
- An overview of the wearable device categories that are the most suited to specific utilization purposes is given.
- The factors having a significant impact on the use of quantified self-tracking wearable devices such as smartwatches and pedometers are explored by using a qualitative and quantitative analysis based on the theoretical framework presented by Stanton (1994) and by applying a usability, attitudinal, and behavioral perspective.
- The factors that affect the intention to use quantified self-tracking wearable devices such as smartwatches and pedometers are also evaluated using a quantitative analysis that is based on a theoretical framework presented by (Venkatesh et al., 2003).
- Informal usability guidelines are recommended for technological designers and developers regarding how to improve the effectiveness and efficiency of quantified self-tracking wearable devices such as smartwatches and pedometers, as well as user satisfaction with them; here, the objective is to reduce the rate at which these devices are abandoned.

The current dissertation is divided into two parts. The first contains the body of research, and the second covers the "Appendices" (i.e., scientific publications and the survey and questionnaire used in the study). The body of research (part 1) comprises six chapters. The first chapter contains an introduction of the topic. The second chapter encompasses the background and existing work relating to wearables; an explanation is also provided of the key concepts required to understand the remaining chapters. The research objective and methodology are explained in detail in the third chapter. The fourth chapter is devoted to a summary of the publications that are detailed in "Appendix 1," along with a brief description of each research publication. The results are presented in the fifth chapter, and this is followed by a discussion of the theoretical and practical findings; this chapter includes a section on the limitations identified in the research and recommendations for future research, especially in relation to proposals for future research, and these are followed by a conclusion in the sixth chapter.

2 Background

This chapter discusses the key concepts of the topic and its history in the scientific literature, including related work on improving the adoption of quantified self-tracking wearable devices in the following areas: a focus on wearable technologies; the classifications of wearables; the adoption of wearables for use in certain contexts, that is, individual and organizational.

2.1 Wearable Technology

The definition of wearable technology has been defined extensively by various researchers and covers a vast range of wearable devices. In some research, the words "wearable technology," "wearable devices," "wearable computing," "wearable sensor," "wearable," "wearable electronics," and "wearable biomedical sensors" are used as synonyms. Table 1 summarizes the useful definitions of wearable technologies in the literature.

Table 1: Definitions of the wearable technologies in the literature

Study	Definition
(Raskovic et al., 2004)	"Wearable computers are an intelligent medical monitoring device providing real-time feedback to patients, athletes during training and healthy users about their physiological state." (p.495)
(Wright and Keith, 2014)	"Electronics and computers that are integrated into clothing and other accessories that can be worn comfortably on the body." (p.204)
(Starner, 2014)	"Any body-worn computer that is designed to provide useful services while the user is performing other tasks" (p.10)
(del Rosario et al., 2015)	"Wearable sensor is an electronic device that can be attached to the body or embedded in a clothing garment and is able to record information about the user's body movements by analysing the signals produced by the device's transducers." (p.18902)
(Mewara et al., 2016)	"A wearable device is a computer that is subsumed into the personal space of a user, controlled by the user, and has both operational and interactional constancy, i.e., is always on and always accessible." (p.59)
(Lunney et al., 2016)	"A category of devices that can be worn by a consumer and often includes tracking information." (p.114)

(Gao et al., 2016)	"Wearable electronics are devices that can be worn or mated with human skin to continuously and closely monitor an individual's activities, without interrupting or limiting the user's motions." (p.2)
(Aliverti, 2017)	"Wearable biomedical sensors are therefore the subset of devices that are able both to measure physiological parameters and to be worn." (p.2)

Currently, the literature lacks a clear definition of exactly "what wearable device means." For example, the definition from Raskovic et al. (2004) uses the term wearable devices but does not specify which categories of wearable devices measure and provide real-time feedback to users about their physiological states; in addition, this definition does not specify which sort of physiological data wearables provide. Similarly, all the definitions summarized in Table 1 contain phrases such as "what wearable devices can do" and "where it can be worn" but do not cover how the data obtained from the devices can be managed by users. For example, wearable devices come in various categories, for example, implantables, optical head-mounted devices (OHMD) and quantified self-tracking devices such as smartwatches and pedometers (Khakurel et al., 2018). Each of these categories may have the physical components, *which consist of the product aesthetics and relate to the external look and feel,* the internal components, *with sensors, processor, and memory supply,* user interface aspects, *which relate to parts through which users interact with the computing device,* or only the physical components without the user interfaces, hence requiring the external devices to work together to deliver the quantified data (Ally and Gardiner, 2012; Liu et al., 2010, 2016). Because there does not seem to be a standard definition of wearable devices, for the purpose of the current thesis, the term "wearable devices" is defined as the following:

> A smart electronic device that is available in various categories, such as quantified self-tracking devices, (Heikkilä et al., 2018). These devices are placed on the human body to sense and analyze quantified biological, physical, behavioral, or environmental self-data (Spagnolli et al., 2014; Swan, 2013), such as feelings, sleep, movements, heart rate, and blood pressure (Fang and Chang, 2016; Sole et al., 2013; Yang et al., 2015); this monitoring is conducted through applications either installed on the device or on external devices, such as smartphones connected to the cloud (Muaremi et al., 2013).

2.2 Rise of wearable technology

For decades, wearable computers have been researched from different angles in both academia and industry contexts. The roots of this research can be traced back to the twentieth century. Throp (1998) conceived of the first wearable computer in 1955 to predict roulette; however, in 1960–61, the idea grew into a joint effort with Claude Shannon at M.I.T. to experiment with a "gambling shoe" (Mills et al., 2016). Later, Mann

(1997) designed and developed an existential computer in the late 1970s and early 1980s for applications used in the visual arts, in particular still-life and landscape imaging. Further, in 1989–90, Schoening and other researchers envisioned and designed a small wearable computer that was integrated with a wireless link and HMD, including software for creating reports and displaying battlefield situation maps to help soldiers on the front lines (Zieniewicz et al., 2002). During this time, these devices were extremely limited regarding their functionalities, were not very comfortable to wear, and were used for a particular scenario. Furthermore, in the 1980s, the Finnish company Polar introduced the world's first wireless heart rate (HR) monitor that consisted of a chest strap transmitter with a wrist-worn receiver; this project was done in cooperation with top-level athletes and world class trainers (Czinkota and Ronkainen, 2007), and the goal was to measure and provide athletes with real-time feedback during exercise.

In 2000, the technical advancements of sensors and evolution in the design of the characteristics of the devices (i.e., both hardware and user interface) led to the introduction of Linux-based smartwatches with a high resolution display (Narayanaswami and Raghunath, 2000), which was later followed by Fitbit fitness bands in late 2009. Since then, 9 out of 10 smartphone vendors, such as Apple, Samsung, Sony, and others (e.g., Misfit and Polar) have entered the wearable device market and brought with them advanced connectivity features and diverse styles of wearable devices (Jung et al., 2016; del Rosario et al., 2015; Yang et al., 2016), enabling individuals to adopt a quantifiable living style (Wu et al., 2016). Statista (2017) forecasts that the penetration rate of consumer wearable technology is to accelerate to 42.5 million units of basic wearables and 148.5 million smart wearables units, with a total of 221 million units worldwide, by 2021.

2.3 Goal of wearable devices

A wearable computer must work to satisfy three goals. i) Mobility: wearable devices must be mobile, meaning these devices go with user; ii) Augment reality: enhance the real environment with the digital information; and iii) Context sensitivity: the device can be made aware of the user’s surroundings and state and must be able to easily access an application, which includes the gamification of activity with competitions and challenges, publication of visible feedback on performance utilizing social influence principles, or reinforcements in the form of virtual rewards for achievement that can increase the intimacy between human, computer, and environment (Billinghurst and Starner, 1999; Piwek et al., 2016).

With the evolution of wearable technology, users' perceptions of the adoption of wearable devices have evolved. Researchers and vendors have identified what wearables must satisfy to increase adoption rates, including fashion-ology (i.e., the fashion aspect, such as pleasing aesthetics, wearability, expressiveness, etc.) (Adapa et al., 2017; Kuru and Erbug, 2013; Rauschnabel et al., 2016), compatibility (Choi and Kim, 2016), technology novelty (Adapa et al., 2017), privacy and security (Goh, 2015; Motti and Caine, 2015; Paul and Irvine, 2014; Sheng et al., 2008), and minimum manual input (Rhodes, 1997).

2.4 Classification of wearable devices

Most of the existing studies on the categorization of commercially available devices are exploratory. Table 2 summarizes how wearable technologies have been classified by the research community.

Table 2: Classification of the wearable technologies in the literature

Study	Classification
(Lunney et al., 2016)	▪ Notifiers, *which give information about the world to individuals, such as the case with smartwatches* ▪ Glasses, *which use eye glasses to create augmented virtual reality* ▪ Trackers, which *use sensors to record data*
Mewara et al. (2016)	▪ Product forms *(i.e., head mounted, body dressed, hand worn, and foot worn)* ▪ Product functions *(i.e., well-being, information consulting, etc.)*
Çiçek (2015)	▪ Wearable health technologies ▪ Wearable textile technologies ▪ Wearable consumer electronics
Reeder and David (2016)	▪ Consumer grade ▪ Developer device ▪ Experimental prototype

Table 2 shows that researchers have classified wearable devices in terms of their forms, functions, specific domains, and availability of the devices in the market. In fact, the core classification does not include which form of devices could be utilized in what type of environment. For example, Mewara et al. (2016) classify wearable devices in terms of their functions and forms but fail to classify which devices could be adopted in harsh or not usage environments or which ones are better suited for personal purposes. Thus, wearable devices could also be classified in terms of *forms, functions, domain specific, and availability of the devices in the market, along with the user environments and conditions*. To demonstrate, in the case of smartwatches such as Apple Watch, these devices could be hand worn, their functions could be well-being through quantified data, the availability could be consumer-grade devices, and domain could be either health technologies or consumer electronics, depending on the user's usage.

2.5 The benefits and challenges of wearables

With the variety of form factors that wearable technologies can adopt and with the promise of wearables being used for different use purposes in both individual and organizational settings (Aleksy and Rissanen, 2014; Motti and Caine, 2015), Mills et al. (2016) assert, “Wearables are arguably the most personal and intimate IT devices of all, portending enormous benefits of all kinds of individuals and organizations alike” (pp.616).

2.5.1 Individual

Commercial off-the-shelf (COTS) wearable technologies such as smartwatches and pedometers, which are also mentioned in the literature as “quantified self-tracking devices” or “self-tracking devices,” “personal health information device,” “activity tracker,” and “self-monitoring technologies” have dominated the use context in the individual landscape (Altenhoff et al., 2015; Jung et al., 2016; Lentferink et al., 2017; Lunney et al., 2016; Rasche et al., 2015; Reeder and David, 2016). Given this use context, examples of use for individuals include the following: underused as fashion accessories (Rauschnabel et al., 2016) and engaged in the self-tracking of any kind of physical or behavioral actions to better understand daily life (Swan, 2013; Wu et al., 2016). Many researchers have discussed the benefits of wearable technologies for all demographics (i.e., age). Table 3 summarizes the identified benefits of wearable technologies in the literature.

Table 3: Summary of the benefits of wearable technologies in the literature (individual use)

Study	Benefits
Reeder and David (2016)	“Smart watches have the potential to support health in everyday living by: enabling self-monitoring of personal activity; obtaining feedback based on activity measures; allowing for in-situ surveys to identify patterns of behavior; and supporting bi-directional communication with health care providers and family members” (p.270).
Wu et al. (2016)	“By recording and reporting activities like sleep patterns, calorie intake, and steps taken, fitness tracking devices play an important role in educating and motivating people to live healthier” (p.1068).
Maher et al. (2017)	Participants improved their physical activity (51–81%) more commonly than they could their diet (14–40%) or sleep (11–24%) when using wearables.

O'Brien et al. (2015)	In the study, 95% of the participants experienced a decrease in waist circumference when using wearables ($p > 0.009$); however, no change in self-efficacy was concluded regarding if activity trackers could be useful for monitoring and promoting physical activity and improving older adults' health.
Mercer et al. (2016)	Trackers can be useful in promoting self-awareness and motivation.
Gualtieri et al. (2016)	Older participants used pedometers over a 12–14-week time frame; the results showed that there were improvements among the participants, with significant positive outcomes being found. For example, participants i) lost an average of 0.5 lbs per week (SD 0.4), with a mean total weight loss of 5.97 lbs (P=.004) and had a 9.2% decrease in Low-density lipoprotein (LDL) levels (P=.038) and ii) reported an increase in well-being and confidence in their ability to lead more active lives.
Ehn et al. (2018)	This study investigated how older adults experience using activity trackers as support for physical activities. The study concluded that quantified self-tracking wearable devices can increase senior users' awareness of their own physical activity behavior and that there were no problems related to integrity when using the devices.

Given the numerous benefits shown in Table 3, quantified self-tracking wearable devices have been shown to be beneficial for engaging individuals, irrespective of their age, in self-tracking, improving their awareness of the need for physical activities and helping them better understand their daily lives. Despite these benefits for all the demographics, reports (eMarketer, 2017; The NPD Group Inc, 2015) indicate user demographics, such as age, income, and gender, vary greatly among wearable devices owners. For example, a report from the NPD Connected Intelligence (The NPD Group Inc, 2015) shows that less than 30% of older adults (age 55+) reported owning pedometers, whereas less than 10% reported owning smartwatches, compared with 69% of all younger people who reported owning a smartwatch. Reports show that quantified self-tracking wearable devices have lower adoption rates among older adults, even though these wearables offer greater potential for older adults beyond the use cases generally directed at the entire population (Kunze et al., 2014). Ehn et al. (2018) and Maher et al. (2017) point out that the currently available quantified self-tracking wearable devices in the market are not ideal for broader groups of older adults. This may be because the quantified self-tracking wearable devices are either designed to attract a young, sporty, and technically savvy group of people, because of the rapid nature of the development of wearables, or because of the time to market pressure and fierce competition between product manufacturers (Maher et al., 2017; Piwek et al., 2016; Tedesco et al., 2017).

2.5.2 Organizational environment

There has been significant interest in the use of wearable devices in the organizational environment, which includes applications in several domains, ranging from entertainment to medicine to safety critical systems (Motti and Caine, 2014), all of which increase efficiency by conducting hands-free operation (Albrecht et al., 2014), increase productivity by helping better design a product (Nee et al., 2012), and support user interaction and communication (Motti and Caine, 2016).

In contrast to the Internet and mobile-based cognitive behavioral therapies, wearables have a broader scope. Numerous studies report there are positive attitudes toward the use of wearables in work environments (Alam et al., 2015; Bhattacharjee, 2014; Glance et al., 2016; Muaremi et al., 2013; Zenonos et al., 2016). Spagnolli et al. (2014) state that wearables can be an ideal component of a symbiotic system (i.e., systems that record and interpret a user's cognitive and affective states and respond accordingly). Bernaerts et al. (2014) point out that the office environment is an interesting space to utilize smartwatches that support and digitally augment interactions to help perform common actions without losing too much time. Similarly, Aleksy and Rissanen (2014) say that wearable computing may provide considerable improvements to the aforementioned areas of industrial service. Table 4 summarizes the benefits of the use of wearables in organizational settings through the other researcher's point of view.

Table 4: Summary of the benefits of wearable technologies in the literature (organizational use)

Study	Benefits
Zhang (2017)	Utilizes HMDs for an intuitive virtual reality (VR) training system to instruct trainees and evaluate the effects of each mining training system. The study concludes that 9 out of 10 students found VR to be more immersive, intuitive, interactive, and easy to use, and they would prefer to use it for training experiences in the future.
Grabowski and Jankowski (2015)	Show that participants felt positively about training with VR devices after 3 months. The authors further report that "it encouraged owners of training facilities cooperating with polish mines to introduce VR training to basic training for youngest miners" (pp.310).
Papi et al. (2016)	Assess clinicians' views of health-related wearable technologies in the context of supporting the long-term management of osteoarthritis (OA); the study concludes

	that wearable technologies could positively complement health professionals' role and enhance their relationship with patients while monitoring progress, evaluating treatment options, monitoring compliance, and informing clinical decision making.
Nwosu et al. (2017)	Utilize smartwatches to examine their potential use to support the care of people living with advanced illnesses. The study concludes that collected sensor data, such as such as movement, HR, and the activities of daily living are beneficial for determining how symptoms (such as pain) affect the function and quality of life and assist in the monitoring and management of symptoms.

From Table 4, it can be seen that wearable technologies could be beneficial for both employers and employees if implemented properly for organizational use; these technologies could be used to increase efficiency and productivity and reduce operational costs, depending on the form, functions, domain specific, and availability of the devices in the market and the user environments and conditions. In addition, a recent study points out that wellness programs have started incorporating emerging wearable devices such as Fitbit, Nike+ Fuel Band, and Jawbone UP as effective tools for detecting the various ailments of employees, such as the anxiety, stress, and cardiovascular diseases (Singh et al., 2015); the researchers further explain that wellness programs use these devices to sense physical activity, sleep patterns, HR, and so on, and after obtaining the data, the employees are encouraged to be more active in their daily lives through the generation of personalized recommendations and prescriptions, gamification, and various incentive programs.

In summary, the literature shows there are a range of commercially available, proof-of-concept wearable devices that could be utilized in organizational settings. Identifying the correct devices for implementation is of great importance; however, this is still missing. This may cause organizations to identify and then adopt the wrong devices for different utilization purposes, leading to the abandonment of devices by employees in the long run. Chu et al. (2014) point out that the work environment in which the devices are utilized should be identified, and then, the context of their use should be identified.

Additionally, as more organizations begin utilizing wearables in the work environment because of the benefits of quantified self-tracking wearable technology, employers will increasingly be collecting, using, and possessing much of the same sensitive personal health information as medical providers, including quantified self-tracking data, including the temporal (i.e., characteristics related to the timing of a behavior, such as the exact start time of a behavioral episode), physical (i.e., the physical environment in which a behavior occurs, such as the location and objects at the location), psychological (i.e., the psychological state of the user during the behavior), and social (the social environment in which a behavior occurs, which could include who the user was with when the behavior occurred and whether the user was interacting with that person) (Raij et al., 2011; Tsao et al., 2017). This could lead to significant implications for employees in terms of invasion of privacy, causing feelings of uncertainty (Lupton, 2013) and resulting in ambiguity regarding how their personal information is managed and utilized (Spiller et al., 2018); this brings about the question whether these innovations should be practiced in the workplace (Talukder, 2012). Delaney and Agostino (2015) state, "The uncertainty of what new technology means for employees can trigger more resistance to their acceptance of it" (pp.9). Lewy (2015) points out that the current standardization, technology, privacy and security, and models of care are barriers for the implementation and adoption of wearable devices in organizational settings. Thus, uncertainty, privacy concerns, technological challenges, security, standardization, and the current rate of abundancy of wearable devices will fail to produce significant results, limiting the utilization, acceptability, and effectiveness of an intervention program with smartwatches and pedometers, which could hinder the future development and a scale-up of possible interventions (Zhang et al., 2018).

2.6 Usability and user acceptance – Adoption

In this section, we present the definition of usability and user acceptance including how these two terms are interrelated. Further, this section also discusses theoretical models to understand user adoption factors for wearable devices and the need of current study.

2.6.1 Review on usability and user acceptance

Recently, end users have created a broad demand for better usability, wanting a spontaneous way to interact with devices and their associated applications for improved productivity, performance, and safety in any context (Seffah et al., 2006; Trivedi, 2012). As a result, usability as a concept is becoming more recognized throughout the world (Bačíková and Galko, 2018). This demand has led both consumer industries and researchers to understand the term *usability* more comprehensively when compared with the traditional definitions of "ease of use" or "user friendliness" (ISO 9241-110, 2018). For example, Gafni (2009) states, "Usability is one of the most important characteristics when targeting systems to wide audiences that need to operate an intuitive system without direct training and support" (p.755). With this in mind, researchers and organizations have defined usability from different angles. For example, Shackel and Richardson (1992) define the usability of systems and equipment as a "capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and support, to fulfill a specified range of tasks, within the specified range of environmental scenarios"(p.24). Rogers et al. (2011) construe usability as a way to ensure that interactive products are easy to learn, effective to use, and enjoyable from the user's perspective. Specifically, the International Organization for Standardization (ISO) (ISO 9241-110, 2018) has described usability and has given it the following standardized definition: “[The] extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” This means the level of usability achieved by the user while using the product may vary depending on the context of use. In such, quality in use can be measured as the outcome of interactions with the devices, including whether the intended goals of the system are achieved (effectiveness) with the appropriate expenditure of resources (e.g., time, mental effort) in a way the user finds to be acceptable (satisfaction) (Seffah et al., 2006). However, although these three major usability elements (effectiveness, efficiency, and satisfaction) are highly correlated (Joo, 2010), Bengts (2004) argues that these elements may not cover all of the relevant aspects of usability. Hence, Bengts defines usability in terms of affective aspects, utility aspects, and cognitive aspects. Furthermore, Abbas (2010) points out that the outcome of good usability is the increased likelihood of user acceptance and that good usability is often the difference between a product’s success or failure in the marketplace. This is because usability—together with utility—influences the usefulness of a product and affects product acceptance by users (Nielsen, 1993). According to Nielsen (1993), acceptability can be subdivided into social and practical acceptability, with practical acceptability consisting of factors such as usefulness, cost, compatibility, and reliability. Usability and utility are both attributes that affect the usefulness of a product and influence the user acceptability of a product. In addition, Bruno and Al-Qaimari (2004) refer to utility as the right system for the right users and the right task. In addition, to gain user acceptance, devices should provide independent factors, such as clear value, data accuracy, price, brand, physical appearance, security, function, interoperability, trustworthiness, easiness to adopt, and robustness (Kaasinen, 2005; Kim, 2015). With respect to user acceptance of quantified self-tracking wearable devices based on Nielsen's (1993) definition, poor usability has a negative influence on the usefulness of quantified self-tracking devices, affecting their acceptability regarding the ability that individuals can incorporate the devices in their daily lives to increase behavioral change (i.e., physical activities), help them achieve their fitness goals, or maintain the fitness activities or changes in their health-related data. Fogg (2009) points out that poor usability could prevent even the most motivated individuals from using a technology.

In recent years, a variety of theoretical technology acceptance models have been developed and advanced. These models include the social cognitive theory (SCT) (Bandura, 1986), the innovation diffusion theory (IDT) (Brancheau and Wetherbe, 1990), the self-determination theory (Deci and Ryan, 2000), and the technology acceptance model (TAM) (Davis, 1986), which is an adaptation of the theory of reasoned action (TRA) (Fishbein and Ajzen, 1975). Among these theories, TAM is one of the most extensively cited theoretical models for predicting the end-user acceptance of information and communication technology (ICT) before end users have experienced it. TAM predicts that user acceptance of any technology is determined by two factors: perceived usefulness and perceived ease of use (Dillon and Morris, 1996). However, TAM fails to provide meaningful results towards the user acceptance because it has varying degrees of generality, does not explicitly include any social variables, and treats behavioral control differently (Mathieson, 1991). To overcome these limitations, many researchers have tried to improve TAM either by integrating other theories or by adding variables. Taylor and Todd (1995), for example, integrate the theory of planned behavior (TPB) with TAM; (Agarwal and Prasad, 1998; Chau, 1996; Chau and Hu, 2001; Moon and Kim, 2001), modifying TAM by adding different variables to understand individuals' behavioral intentions to use technology in different domains. The most comprehensive effort has been by Venkatesh et al. (2003), who unified the various models of information technology acceptance and integrated the elements of eight prominent models (TRA, TAM, motivational model, TPB, combined TAM-TPB model of PC utilization, IDT, and SCT) into the UTAUT model (Anderson and Schwager, 2003). Venkatesh et al. (2003) reviewed all the elements of eight prominent models and identified seven (i.e., performance expectancy, effort expectancy, social influence, facilitating conditions, self-efficacy, computer anxiety, and attitude toward using technology) out of 32 constructs that had similar meanings and definitions in the context of the theory (Nandwani and Khan, 2016). In further analysis, Venkatesh et al. (2003) theorize that performance expectancy, effort expectancy, social inference, and facilitating conditions are the four key constructs that have a direct influence on behavioral intention to use the technology, whereas the facilitating conditions have a direct impact on usage behavior. In addition, Venkatesh et al. (2003) theorize that self-efficacy, computer anxiety, and attitude toward using technology are the three indirect determinants of intention to use.

2.6.2 Adoption of wearable devices

Based on TAM, Kim and Shin (2015) evaluate the user acceptance of smartwatches at the consumer level. They put forward TAM and conduct an online survey to validate the relationship among attitude, affective quality, relative advantage, mobility, availability, subcultural appeal, cost, intention to use, perceived usefulness, and perceived ease of use. They test the reliability of these factors using a confirmatory factor analysis, while the strength and direction causal paths among the constructs are analyzed via structural equation modeling (SEM) techniques using AMOS 22 statistical software. The study shows that different wearable-device-specific variables may induce unique psychological effects among users, and the presented research model may not sufficiently validate the user acceptance of wearables. Chen and Shih (2014) advance a wearable TAM by incorporating an analytical network process using the UTAUT with two additional clusters to obtain the influential factors of using wearables at the consumer level. They cluster three to five factors and introduce the following main clusters: "performance expectancy ('PE')," "effort expectancy ('EE')," "social influence ('SI')," "facilitating conditions ('FC')," "use intention ('IU')," and "use behavior," which can be utilized while developing a product with wearable technology. Gao et al. (2015), for example, explore the factors influencing a consumer's intention to adopt a wearable device in the healthcare industry and use an integrated acceptance model based on the unified theory of acceptance and use of technology 2 (UTAUT2), protection motivation theory, and privacy calculus theory. With measurements and validation of the structural model, the authors provide a number of findings on the adoption of wearable devices in healthcare by consumers: i) technology, health, and a privacy act are the most significant factors in the decision to adopt and ii) user behavior and intention of use are related to device types and their purpose. For example, the authors state, “fitness wearable device users care more about hedonic motivation, functional congruence, social influence, perceived privacy risk, and perceived vulnerability, but medical wearable device users pay more attention to perceived expectancy, and self-efficacy” (p.1717) (Gao et al., 2015).

Although the adoption rate of wearable technology has been well researched (Gao et al., 2015; Jusob et al., 2016; Kim and Shin, 2015; Rauschnabel and Ro, 2015; Yang et al., 2016) in the younger population, there is currently little research on baby boomers, who are the next fastest growing primary users of quantified self-tracking wearable devices (Puri et al., 2017). For example, Puri et al. (2017) state, “Consumer-grade wearable activity trackers are increasingly ubiquitous in the market, but the attitudes toward, as well as acceptance and voluntary use of, these trackers in older population are poorly understood” (pp.1). Similarly, numerous authors (Ehn et al., 2018; Hounsell et al., 2016; Seifert et al., 2017) indicate a need for further studies on the motivational, usability, reliability, and content supporting effective behavioral change technique aspects regarding the use of tracking devices by older adults. In one study, Maher et al. (2017) find that the key barriers stopping participants from continuing to use wearable devices were device breakage or loss and technical difficulties with the device or its accompanying software. Consistent with the results from Maher et al. (2017), Mercer et al. (2016) also find that apps during use and the lack of clear instructions for installation, rather than understanding and using the technology, were indicators of user frustration. This shows that a study on the adoption of quantified self-tracking wearable devices from the perspective of the usability of the device’s characteristics (i.e., hardware and software), which is one of the most important aspects for assessing the needs and expectations of older adults, is missing. Ehn et al. (2018) state, “For quantified self tracking wearable devices such as activity monitoring to be useful in the long term for senior users, the devices must be easy to use, intuitive, robust, and reliable. Deficiencies in these areas significantly reduce the users' motivation in using the AMs” (pp.11).

To summarize, only a few studies have explored the various theoretical models and used additional constructs to understand the individual user adoption factors for wearable devices; however, the focus has usually been on younger populations. This does not answer adoption rate issues for all age groups. Therefore, the current dissertation offers a comprehensive study to fill the gaps on the i) steps technology designers, application developers, and the research community can take to improve the acceptance of and intention to continue using quantified self-tracking wearable devices among older adults from a device characteristics perspective and ii) how to identify the factors organizations should use to improve the acceptance of and intention to continue using quantified self-tracking wearable devices for different use purposes prior to implementation.

As discussed, there are various categories of wearable devices that have various form factors. Unlike quantified self-tracking devices, not all of these device categories have the ability to measure and collect quantified data and help individuals engage in increased physical activity. In addition, all these different categories of wearable devices are worn on different parts of the body, collect data in various ways, and have data that are viewed through different mechanisms. For example, OHMD devices are not suitable for collecting quantified self-tracking data and are more suitable for delivering content. Moreover, in the current market trends, there are only quantified self-tracking devices such as smartwatches and pedometers that a user can purchase to use for self-tracking purposes and that can be easily worn on the body. In addition, smartwatches and pedometers are the devices that have been identified as the devices that are most likely to be discarded within the first 2 months of use (Lazar et al., 2015) because of the gap between the features desired by consumers and the capabilities of the device (Wu et al., 2016).

Based on the classification, trends in the market, identified research gaps, and scientific domain (de Arriba-Pérez et al., 2016), the current thesis utilizes five consumer-grade COTS quantified self-tracking wearable devices, such as smartwatches, including Apple Watch and Samsung gear, and pedometers, including Fitbit Charge 2, Polar 360, and Misfit, rather than all types of wearables devices. All these devices came in different sizes and could be worn on the wrist and utilized for well-being and information consulting through quantified self-tracking data that can measure the perceived usability during the study period. These COTS devices allowed for the identification of existing issues that users face while accepting the devices; hence, the recommendations provided in the present thesis could be used as guidance to design better usable smartwatches and pedometers.

3 Research Goal and Methodology

The key aim of this chapter is to introduce the research goal and discuss the applied methodologies that underpin the current work. This chapter also elaborates on the reasoning for selecting these research approaches and the data collection procedure.

3.1 The research questions

At the highest level, the main objective of the current research is to conduct an in-depth investigation of the factors associated with the abandonment of quantified self-tracking wearable devices from a usability and behavioral perspective in both individual and organizational settings.

The research questions from the publications that concretize the various aspects of the main research questions, as follows:

RQ1. *For a target audience of older adults, what should technology designers, application developers, and the research community do to improve the acceptance of and intention to continue using quantified self-tracking wearable devices from the perspective of the usability of the device characteristics*?

The RQ from the publication I that links to the RQ1 and allows us to identify the usability barriers that currently exist for wearable devices, as follows:

i. What are the usability barriers preventing individuals from using wearable devices?

Similarly, the RQ from the publications II, III, IV that links to the main research question (RQ1) that allows to determine what usability issues related to the device characteristics of COTS quantified self-tracking wearable devices can become barriers when it comes to older adults accepting and using these devices and how those barriers could be improved, as follows

i. How do the internal and external contexts differ between younger and older people while using the same quantified self-tracking wearable devices and participating in the same experiments? (Publication II)

ii. What usability issues related to the device characteristics of quantified self-tracking wearable devices can obstruct and warrant immediate prioritization to improve the motivation of older adults to adopt these devices, and how have these issues been categorized? (Publication III)

iii. Which types of usability issues related to COTS quantified self-tracking wearable technology persist across different cultures, and what should be considered to provide a richer end-user experience so that wearables can also be adopted by older adult populations? (Publication IV)

RQ2. *How can organizations implement and increase the acceptance of and intention to continue using quantified self-tracking wearable devices for different use purposes?*

In order to answer RQ2, RQ from publication V, VI has been taken in to consideration. The RQ from publication V that is helpful to answer RQ2 by determining the suitable wearable technologies and existing challenges for use in organizational environments, as follows

i. What types of wearable devices are suitable for use, and what challenges currently exist for the use of those devices in the organizational environment?

To conclude, the RQ from Publication VI that investigates the factors affecting the intention to use quantified self-tracking wearables in organizations, as follows

i. What are the factors that affect the intention to use, and how are those factors related to each other?

3.2 Methodology

To address the research objective, we performed a systemic literature review, and a collective case study was utilized within the use context, that is, individual and organizational, to provide insights into particular issues and build a theory. We adopted the CAT proposed by Stanton (1994) and UEM (Ivory and Hearst, 2001) and asked participants to evaluate a device and its associated application. This section summarizes the method applied to address the research objective, which is followed by a justification for the choice of the applied methods.

3.2.1 Systematic literature review

The current study adopts and applies a systematic literature review (SLR) approach to aggregate primary studies in terms of their results and investigate whether these results are consistent or contradictory (Napoleão et al., 2017); this will be judged using the guidelines provided by Kitchenham et al. (2009) and the recommendations of Petersen et al. (2015). Kitchenham and Charters (2007) state that, "[A] systematic literature review is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest" (pp.vi).

The guidelines suggest that a review involves three distinct phases to streamline the SLR approach, as follows:

The overall three-phase review process is presented in Figure 1.

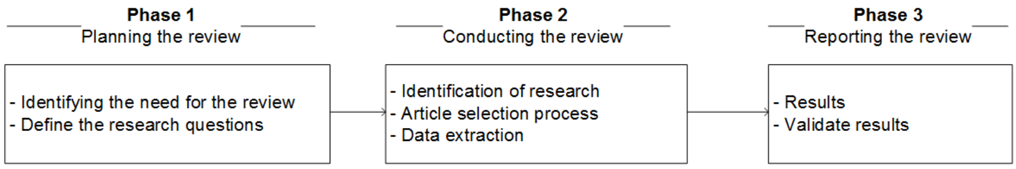

Figure 1: Systematic literature review process.

Planning the review. The guidelines recommend that prior to the SLR, researchers must determine if there is a real need for the review by identifying the review and research question. Following the determination of the need for the review, research questions based on the objectives of the study can be formulated. In the present thesis, following the guidelines from both Publications I and V, we first identified if a review was needed by conducting searches on online databases, such as ACM, IEEE, and Web of Science. For Publication I, we applied the search terms "wearable*," "Usability Issue*," and "systematic literature review" to find if any SLRs exist that summarize usability issues related to wearables and which evaluation methods have been applied in those studies. The search results indicated that there is need for a review that summarizes i) the usability challenges for existing wearable devices and ii) determines which UEMs could be used in evaluation studies. Similarly, for Publication V, we applied the search terms "wearable*," "work environment," and "systematic literature review" to find if any SLRs exist that summarize different categories of wearables and their modes of use, along with the challenges that hinders the implementation of the wearable devices in the work environment. For Publication V, the results indicated there are no studies that have been conducted that summarize i) the types of wearable technologies that can be utilized in the work environment and ii) what challenges currently exist for the use of those devices in the organizational environment.

Conducting the review. Here, a search is performed for articles and primary studies by using search strings in scientific libraries and databases. In this phase, for Publications I and V, we applied the inclusion and exclusion criteria to determine whether each potential study should be included, classified the articles based on keywords from the abstracts of the selected articles, and classified and categorized the articles based on the final set of keywords; this process is crucial to identify relevant primary studies.

Reporting the review. The results of the present review are consolidated from the relevant articles and are presented in the form of graphs and tables with accompanying analysis in Publications I and V.

3.2.2 Case study

A case study is a research method used extensively in a wide variety of fields (Teegavarapu et al., 2008), and the term has been defined by various researchers in various ways but always with the central tenet being the need to explore an event or phenomenon in depth and in its natural context (Crowe et al., 2011). Table 5 presents the definitions of a case study presented by various researchers.

Table 5: Definitions of a case study in the literature

Study	Definition
(Adelman et al., 1976)	"An umbrella term for a family of research methods having in common the decisions to focus on enquiry around an instance." (pp.94)
(Stake, 1995)	"Case study is the study of the particularity and complexity of the single case coming to understand its activity within important circumstances." (p.xi)
(Robson, 2002)	"A strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context aiming multiple sources of evidence." (pp.178)
(Yin, 2003)	"As an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used." (pp.23)
(Dul and Hak, 2008)	"A study in which (a) one case (single case study) or a small number of cases (comparative case study) in their real-life context are selected and (b) scores obtained from these cases are analysed in a qualitative manner." (pp.4)
(Teegavarapu et al., 2008)	"Empirical research method used to investigate a contemporary phenomenon, focusing on the dynamics of the case, within its real-life context." (pp.4)
(Collis and Hussey, 2010)	"A methodology that is used to explore a single phenomenon (he case) in a natural setting using a variety of methods to obtain in-depth knowledge." (pp.68)

In Table 5, the various definitions of a case study show that several authors have different definitions for a case study depending on the discipline the study is conducted in (Simons, 2009). However, a case study can accommodate different research techniques and is normally used when in-depth knowledge on a particular phenomenon is needed (Wedawatta et al., 2011). Gutiérrez et al. (2009) assert, "[A] case study is particularly useful to employ when there is a need to obtain an in-depth appreciation of an issue, event or phenomenon of interest, in its natural real-life context" (p.1). Teegavarapu et al. (2008) present five components that are significant for a case study design and its success: case study questions, case study propositions (similar to a hypothesis), units of analysis, logic linking the data to the case study propositions, and criteria to interpret the case study results. Stake (1995) distinguishes three types of case studies that have been particularly influential in defining the case study approach (Crowe et al., 2011):

i) *The intrinsic.* An intrinsic case is often exploratory in nature, and the researcher is guided by his or her interest in the case itself rather than in extending a theory or generalizing across cases (Mills et al., 2010).

ii) *The instrumental.* The study of a case (e.g., person, specific group, occupation, department, organization, etc.) is conducted to provide insights into a particular issue, redraw generalizations, or build a theory (Mills et al., 2010).

iii) *The collective.* This involves the exploration of multiple instrumental case studies that may or may not be physically collocated with other cases (Mills et al., 2010) and presents the findings from individual cases separately before amalgamating them across cases (Crowe et al., 2011).

In the current thesis, two case study types were applied. A collective case study is utilized because the thesis involves multiple cases within them, here being the use context—individual and organizational—to provide insights into particular issues through Publications II–VI. For example, in Publications II, III, and IV, we looked into older adults, and in Publications V and VI, we looked into organizational settings because the goal of the case study was to understand what impacts the acceptance of and intention to continue using wearable devices, hence allowing us to fulfill the objective of the research. Further, the current study is also a "multisite study" because research has been conducted in Finland and the United States with different participants. The thesis also applied an instrumental case study because it describes how usability challenges vary between specific demographics (e.g., age, culture) (Publications II, III, and IV) and how factors for adoption vary between the stakeholder within the organization (e.g., students, staff, and faculty) (Publications V and VI).

3.2.3 Contextual action theory

Stanton (1994) proposed the "Contextual Action Theory" (CAT) to establish the foundation for conducting research on human actions in terms of coping with technology within a context. Basically, CAT presents an integrated and explicit theoretical framework for assessing the relationship between the demands-resources (Young and Stanton, 1997). According to Matthews (2002), "CAT distinguishes the objective external context and subjective internal context, and supports interventions that address the interaction between these two elements of context" (p. 205). According to the theory, five phases are associated with contextual actions, as follows:

- **First phase:** Presentation of the actual demands and resources to the participants, including the device, the tasks to be performed on the device, environmental constraints (e.g., time), and so on

- **Second phase:** Appraisal of those demands and resources by the participants
- **Third phase:** Comparison of perceived resources with perceived demands
- **Fourth phase:** Possible degradation of pathways
- **Fifth phase:** Appraisal of the effects of these responses on device usage

In the current thesis, the above five phases of the CAT allowed the participants to compare their own perceived resources with perceived demands to determine any imbalance related to the specific properties of quantified self-tracking devices, that is, smartwatches and pedometers, that could affect participation in the study (Stanton, 1994). In addition, the described theory allowed us to gather the emotional responses, which included decreases in user satisfaction and motivation, along with potential behavioral responses, which included an increase in errors and inefficiency. This helped us determine the cause influencing the usability of smartwatches and pedometers regarding their acceptance. As described in the previous section, individuals' perceptions of technology acceptance is highly influenced by the usability of the device.

3.2.4 Usability evaluation method

The UEM consists of various methods that help to evaluate the product design in terms of its device characteristics (hardware and software) and identify the problem in a particular use context. The UEM has been grouped by different authors in different ways. For example, Nielsen (1994) groups UEMs into four basic groups: automatically, empirically, formally, and informally. Similarly, Gray and Salzman (1998) group them into analytic and empirical. However, to expand existing approaches to better support a usability evaluation, Ivory and Hearst (2001) propose a taxonomy where the methods are grouped by the following four dimensions: method class (testing, inspection, inquiry, analytical modeling, and simulation), method type (field study, focus group, diary, etc.), automation type, and effort level.

Ivory and Hearst, (2001) state, of these five method classes, "usability testing, inspection, and inquiry are suitable for both formative evaluation" (i.e., the evaluator identifies specific usability problems that are already known before conducting the evaluation) and summative evaluation (i.e., the evaluator obtains general evaluations of usability) purposes, whereas "analytical modeling and simulation" are appropriate for the performance evaluation of users. Because the thesis consists of both formative and summative elements, we utilized method classes (i.e., inquiry and usability testing).

Inquiry: Ivory and Hearst (2001) define the inquiry method as the extent to which users share their usability experiences with evaluators about the evaluated applications or devices via methods such as focus groups, diaries, or surveys. Usability focus groups first originated as a market research method; however, they have recently been used in human–computer interaction research to identify the usability needs of users, allowing analysts to gather feedback on their desired goal and to validate a high-level strategy for a variety of purposes at all stages of the development process of the product; these data can be acquired through a vote on ideas or capturing and validating user roles, tasks, and workflows (Rosenbaum et al., 2002). However, Rosenbaum et al. (2002) further point out that using this method is highly controversial, and some HCI professionals discourage the dependence on focus group data for design decisions. Therefore, the diary method has been applied in the current thesis because it forced the participants to record all their activities for the covered period, and the data reported in the diary are arguably more reliable than data obtained from questionnaires (Conrath et al., 1983; Rieman, 1993). Surveys have been applied in the current thesis because they allowed participants to provide quick feedback on the perceived usability, attitudes toward the evaluated products, or measured aspect of usability, helping the analysts receive an automated analysis of the results (Dumas, 2003; Kushniruk and Patel, 2004).

Usability testing: Kushniruk and Patel (2004) state, "Usability testing the evaluation of information systems that involves testing of participants (i.e., subjects) who are representative of the target user population, as they perform representative tasks using an information technology in a particular context" (pp.59). Think-aloud has been applied in the current thesis because it allows analysts to better understand the mental model employed by the users, as well as the particular aspects of the interface that cause the most problems (Rogers et al., 2005).

To summarize, in the present thesis, the method classes (i.e., inquiry and usability testing) of the UEM helped us achieve the research objective through Publications II, III, and IV, where we evaluated the usability of the devices and associated applications from a demographic context (age, culture).

3.3 The role of the researcher

The role of the researcher is to conduct research that has complex aspects and to find the consequences of the research (Kiegelmann, 2002). Researchers play many different roles (such as being teachers, observers of the participants, interviewers, readers, storytellers, advocates, interpreters, counselors, evaluators, and consultants) in constructivism, where they bring many different personal aspects (such as their prior experiences, beliefs, purposes, values, and subjective qualities). These personal properties shape how the researcher conceptualizes the study and engages with it. Furthermore, the researcher creates relationships with those who are being studied (Kiegelmann, 2002; Stake, 1995). Stake (1995) states that a "teacher is not just lecturing, not just delivering information more; it is the arrangement of opportunities to learners to follow a natural human inclination to become educated" (p.92). In the present thesis, for Publications II, III, and IV, I played the roles of a teacher, participant's observer, evaluator, and interpreter. I did this because in qualitative research, the researcher is the main instrument for data collection, an agent of new interpretations, and a creator of new knowledge—and there is always a close relation between the researcher and the participants (Kiegelmann, 2002; Stake, 1995). During the meet-up session, I gave advice to the participants on how to use the diary, as well as how wearables could help them be physically active; thus, in the present thesis, I played the role of a teacher. Moreover, the study involved a usability evaluation, where data were collected through a survey, observations collected during a think-aloud session, and information obtained from diaries. In the present thesis, I also played the roles of the participants' observer and an evaluator. I involved myself in the beginning of the evaluation to appreciate the participant's participation, explain the advantages of the device, and complete the tasks during both roles (i.e., the participants' observer and the evaluator). Thus, I was "emic," an insider who is a full participant in the activity (Marilyn, 2011). Moreover, Publication VI was comprised of quantitative data, and data were gathered from a distance. I interpreted the results together with my coauthors; thus, I played the role of being an interpreter. For data collection, I observed several cultural groups (i.e., Finland and the United States) as an objective viewer; thus, I played the role of "etic" (Marilyn, 2011; Morris et al., 1999). My roles as a researcher in this thesis were both "etic" and "emic." Furthermore, I collected the data through naturalistic observations without intervening during the data collection; this can be considered a "noninterventionist" role (Stake, 1995).

3.4 Research process

The research process was divided into four main stages. Each stage in the research process relied on one another to complete the goals of the sub objectives. Figure 2 details the step-by-step overview of the research process.

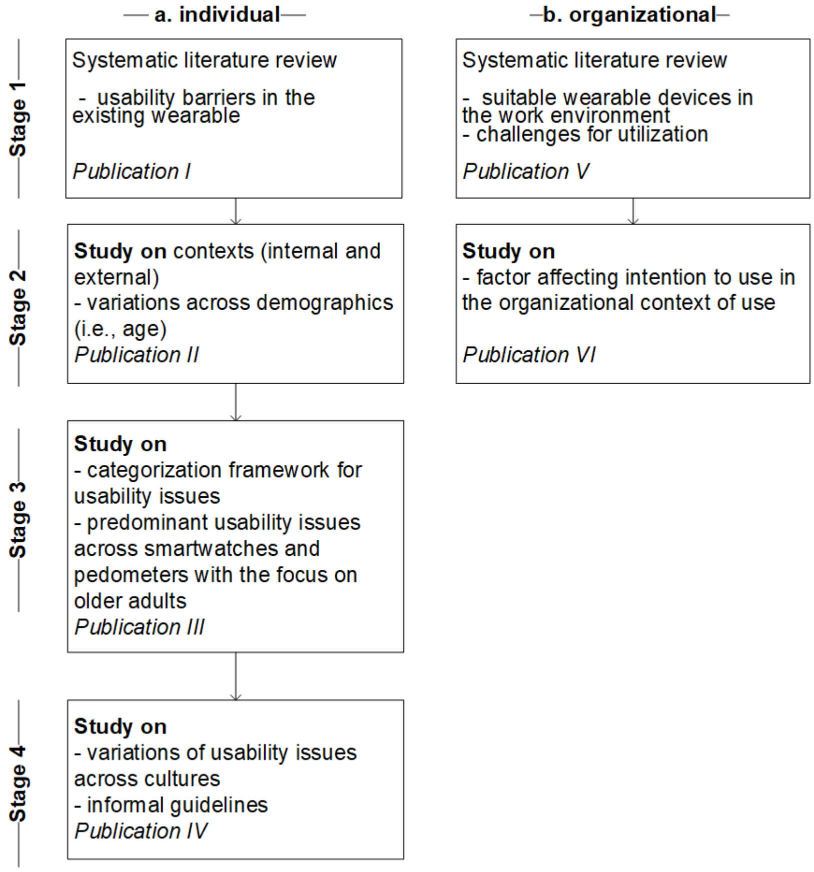

Figure 2: Details of the step-by-step overview of the research process

Stage 1: Trends in research and gaps

Stage 1 was the initial phase of the research process and can be divided into two substages: 1a and 1b. Substages 1a and 1b involved conducting searches on existing electronic databases to identify, appraise, and synthesis primary research papers by using a SLR method to acquire knowledge on the three sub-objectives, hence identifying gaps in the existing literature that could help us in stage 2.

Outcome: Substage 1a resulted in a usability issues categorization framework of wearable devices, and substage 1b resulted in a categorization framework for suitable wearable technology that could be utilized in the organizational context and also resulted in a list of challenges while implementing wearable devices in the work environment.

Research gap: Substage 1a was the need for a study on how usability varies across different age demographics (i.e., younger and older adult) to increase adoption; substage

1b was the need for the identification of a factor that influences the use of wearable devices in the work environment to increase adoption rates.

Stage 2 of the research comprises two substages.

2a. Impact of the demographic context on the external and internal context. 2b. identifying the factors affecting the intention to adopt in an organization context.

In substage 2a, based on the research gap and using the UEM and CAT, looked at how contexts (i.e., internal and external) influence the adoption of COTS quantified self-tracking wearable devices and how this varies across different age demographics (i.e., younger and older adult). The internal context includes the users' states and consisted of the internal parameters of human experiences and activities (Gwizdka, 2000), such as emotional responses (e.g., a decrease in user satisfaction and motivation and manifested behavioral responses, such as an increase in errors, reactions, or inefficient or inappropriate activities) (Stanton, 1994). The external context describes the environmental state and consists of proximity to objects (Gwizdka, 2000), such as the devices and their associated applications.

During stage 2a, research that distinguishes between the external context was also conducted. Substage 2a resulted in discovering what required a closer look in stages 3 and 4: predominant usability issues related to the device's characteristics (i.e., for smartwatches and pedometers) among older adults and informal usability guidelines that should be taken into consideration while designing quantified wearable devices (i.e., smartwatches and pedometers) for older adults.

In stage 2b of the research process, based on the identified research gap, the factors that affect intention to use the quantified self-tracking wearable technologies in an organizational context were discovered by using an attitudinal research method. We looked at this from the point of view of university faculty, staff, and students.

In stage 3, predominant usability issues related to the device's characteristics (i.e., smartwatches and pedometers) among older adults were evaluated. A study of the differences in usability between smartwatches and pedometers was considered because both devices have different device characteristics.

Stage 4 was an important step in our research process because it concluded the research, giving the informal guidelines of usability while designing self-quantified wearable devices (i.e., smartwatches and pedometers) for older adults. A study of culturability was considered relevant because usability can vary across cultures.

3.4.1 Data collection

According to Paradis et al. (2016), “Data collection methods are important, because how the information collected is used and what explanations it can generate are determined by the methodology and analytical approach applied by the researcher” (p.263). In this section, we describe which method was applied and how the data were collected.

Data collection for stage 1: The SLR (Publications I and V)

The data collection for stage 1, that is, the SLR, was conducted using a search string in the electronic databases. Based on the inclusion and exclusion criteria, relevant articles for the objective of the SLR were selected. Each relevant piece of information was carefully registered from the final set of reviewed articles.

Data collection for stage 2b: Intention to use (Publication VI)

The data related to intention to use wearable devices in the work environment were collected through a survey among staff, students, and faculty at a university in Finland. The aim of selecting the university for the survey was because of the availability of respondents; the survey consisted of various stakeholder regulations that could influence adoption.

Data collection for stages 2a, 3, and 4: Usability (Publications II, III, and IV)

Usability: The data related to the usability of quantified self-tracking wearables were collected through usability experiments using focus groups, the think-aloud protocol, diaries, and a survey. Because the outcome of the current thesis aims to provide the guidelines for the device manufacturer and application developers, it is essential to observe and evaluate the user’s context of use and gather results that can be correlated with the participants’ age and country. The set of usability experiments on COTS wearable devices was conducted in Finland and the United States in two phases to understand how age and culture can affect the usability of the devices, and this was conducted with two age groups (<= 60 and > 60 years), as described in Table 6. Alshamari and Mayhew (2008) point out that to perform usability tests, the user should be classified regarding his or her level of systems experience, the total number of users, and the user’s characteristics.

Table 6: Distribution of the participants in phases I and II

Phases	I	II
Region of enrollment	Finland	United States of America
Total number of participants	34	35
Age and gender categorical [units: participants]		
<= 60 years mean ± standard deviation	21	15
	Male=19, Female=2	Male=14, Female=1
	(M = 29.57, SD = 9.10)	(M=25.4, SD=6.23)
➢ 60 years mean ± standard deviation	13	20
	Male=7, Female=6	Male=12, Female=8
	(M=62.23, SD=1.921)	(M=61.92, SD=1.6062)

Of the total participants, younger or middle-aged (<= 60 years) users had relatively substantial technological knowledge and had a positive view of using technology in their daily lives. The second group—the older participants—were without any age-associated memory impairment, only displayed the normal physiological changes related to aging, were living independently, and were keen on using new technology to improve their well-being; this group was recruited through direct contacts and networking. During both phases, the CAT, as explained by Stanton et al. (1994), and the UEM, presented by Ivory and Hearst (2001) were applied as the foundational methodologies for evaluating COTS wearable devices in the present study's set of usability experiments among older adults.

3.4.2 Data analysis

The data analysis focused on both the emotional and behavioral responses of the participants. Because all the different sets of data were collected through focus groups, think-aloud, diaries, and surveys were used throughout different phases of the study to complement the data from the focus groups. During some stages, data from usability testing were analyzed using the instant data analysis technique (Kjeldskov et al., 2004), diaries were analyzed using the data analysis framework presented by Clayton and Thorne (2000), and general spreadsheets, that is, Excel, were used as a tool for data analysis because of their richness in functionality and are used across many industries to capture, store, and analyze data (Nahm and Zhang, 2009)

In the current thesis, stage 1 included the SLR, where in both substages 1a and 1b, articles were collected and critically analyzed using the spreadsheets and criteria based on the formulated research questions.

The gathered data in stages 2a, 3, and 4 came from the same UEM approach, that is, from the focus group and think-aloud, which were analyzed using the instant data analysis technique (Kjeldskov et al., 2004). The qualitative data obtained from the diaries were analyzed using the data analysis framework presented by Clayton and Thorne (2000), “which offers an eclectic approach for qualitative diary data analysis” (p.1514) and using the spreadsheets, which were considered sufficient for this task. The data from the survey responses were downloaded from the Webropol online platform into an MS Excel spreadsheet.

However, for stage 2b, the data gathered from the survey were analyzed using a partial least squares (PLS) analysis technique with nonparametric bootstrapping (Hair et al., 2014).

The qualitative data from the survey in stage 3 were analyzed separately in an Excel spreadsheet using the statistical data analysis language R and the descriptive statistical analysis functions available in R core (R Development Core Team, 2017) and the psych library (Revelle, 2016). The data from stage 4 were analyzed with the R statistical language and its statistics (“stats”) library (R Development Core Team, 2017). Descriptive statistics were generated using the psych R library (Revelle, 2016). The Mann–Whitney U test for difference in means was used to test the differences between the datasets. When analyzing the interval data with the Mann–Whitney U statistical test, a continuity (Salkind, 2007) correction was enabled to compensate for noncontinuous data (Bergmann and Ludbrook, 2000). The Bonferroni correction was used to adjust the p value and compensate for the family-wise error rate in multiple comparisons (Salkind, 2007).

3.5 Summary

In this section, we summarize the research questions and methodology from the publications that was applied to answer main research questions (RQ1) and (RQ2) in the current thesis.

Table 7: Summary of research questions and methodology from publications

Stages	Research questions, purpose and methodology	Publications
1a	What are the usability barriers preventing individuals from using wearable devices? **Purpose:** Usability barriers in existing wearable devices **Method:** Systematic literature review **Data Analysis:** NVivo data analysis tool (version 11) and spreadsheet	Publication I

2a.	How do internal and external contexts differ between younger and old people when using same quantified self-tracking wearable devices while participating in the same experiments? **Purpose:** To enhance the understanding of the existing challenges of wearable devices and how they affect the emotional and behavioral responses among individuals of all age groups. **Method:** UEMs (i.e., focus, think-aloud, diary, and survey) and CAT **Data analysis:** Instant data analysis technique (Kjeldskov et al., 2004), diaries analyzed based on the data analysis framework presented by Clayton and Thorne (2000), and spreadsheets.	Publication II
3.	What usability issues that are related to the device characteristics of smartwatches and pedometers can obstruct the motivation of the older adult to adopt these devices, and how have the issues been categorized? Has there been a sizable impact on the usability needs for smartwatches and pedometers, thus warranting immediate prioritization by technology designers, the research community, and application developers? **Purpose:** To determine perceived usability issues and formulate a usability categorization framework and identify the predominant usability issues that warrant immediate attention. **Method:** UEMs (i.e., focus, think-aloud, diary, and survey) and CAT **Data analysis:** ▪ Instant data analysis technique (Kjeldskov et al., 2004), diaries analyzed based on the data analysis framework presented by Clayton and Thorne (2000), and spreadsheets	Publication III

	▪ Statistical data analysis language R and the descriptive statistical analysis functions available in R core (R Development Core Team, 2017) and the psych library (Revelle, 2016)	
4.	What should be considered by technology designers and the research community to enhance the device characteristics related to quantified self-wearable technologies and to improve older adults' adoption traits? **Method:** UEMs (i.e., think-aloud, diary, and survey) and CAT **Data analysis** ▪ Instant data analysis technique (Kjeldskov et al., 2004), diaries analyzed based on the data analysis framework presented by Clayton and Thorne (2000), and spreadsheets ▪ R statistical language and its statistics ("stats") library (R Development Core Team, 2017) ▪ The Mann–Whitney U test (also known as the Mann–Whitney Wilcoxon Test) to analyze country-specific differences in older adults' identified usability issues (Wohlin et al., 2012) ▪ The Bonferroni correction to adjust the p value to compensate for the family-wise error rate in multiple comparisons (Salkind, 2007)	Publication IV
1b.	What types of wearable devices are suitable for use, and what challenges currently persist regarding the use of wearable devices in organizational settings? **Purpose:** To determine suitable wearable technologies to use and identify the challenges for use in organizational settings **Method:** Systematic literature review **Data Analysis:** NVivo data analysis tool (version 11) and spreadsheet	Publication V

2b.	What specific factors can obstruct the utilization of smartwatches (SW) and pedometers (PM) among university faculty, staff, and students? How are these factors related to each other in influencing the usage of SWs and PMs? **Purpose:** To understand the factors affecting the intention to use wearable devices **Method:** Survey **Data analysis:** ▪ partial least squares (PLS) analysis technique, with non-parametric bootstrapping (Hair et al., 2014)	Publication VI

4 Overview of the Publications

This chapter presents the six individual research contributions of the current thesis. These six contributions explore the barriers preventing quantified self-tracking wearable devices from individual use by looking at device characteristics. Within the organizational setting, factors influencing the intention to use are examined.

4.1 Related Publication I — A Comprehensive Framework of Usability Issues related to the Wearable Devices

4.1.1 Main objective

The main objective is to provide a comprehensive SLR of the usability and user interface issues related to wearable devices, investigating how these issues have been identified, evaluated, and presented.

4.1.2 Research question

RQ1: To date, what categories of usability issues related to wearable devices have been discussed in the past, and which issues relating to wearables still persist and need further investigation?

RQ2: How have UEMs been applied to wearable device evaluation and in which device categories?

4.1.3 Methodology

Publication I adopted an SLR methodology, within which 84 out of 3,271 articles were selected based on the inclusion and exclusion criteria from an independent systematic search of the following scientific databases: ACM Digital Library, Springer, Science Direct, IEEE, BioMed Central, Hindwai, Taylor and Francis, Journal of Medical Internet Research, and the Journal of Computer-Mediated Communication.

4.1.4 Main findings and contributions

The results showed that the number of publications is increasing every year, indicating a growing interest in this field. Device characteristics (screen size, battery life, screen display, elements (text/buttons), interaction techniques, etc.) and deployment categories (motion artifacts, wearing positions) were the most discussed usability-related issues. These issues limit the ways a user can interact with wearable devices. Figure 3 shows the usability issues categorization framework based on the reviewed papers.

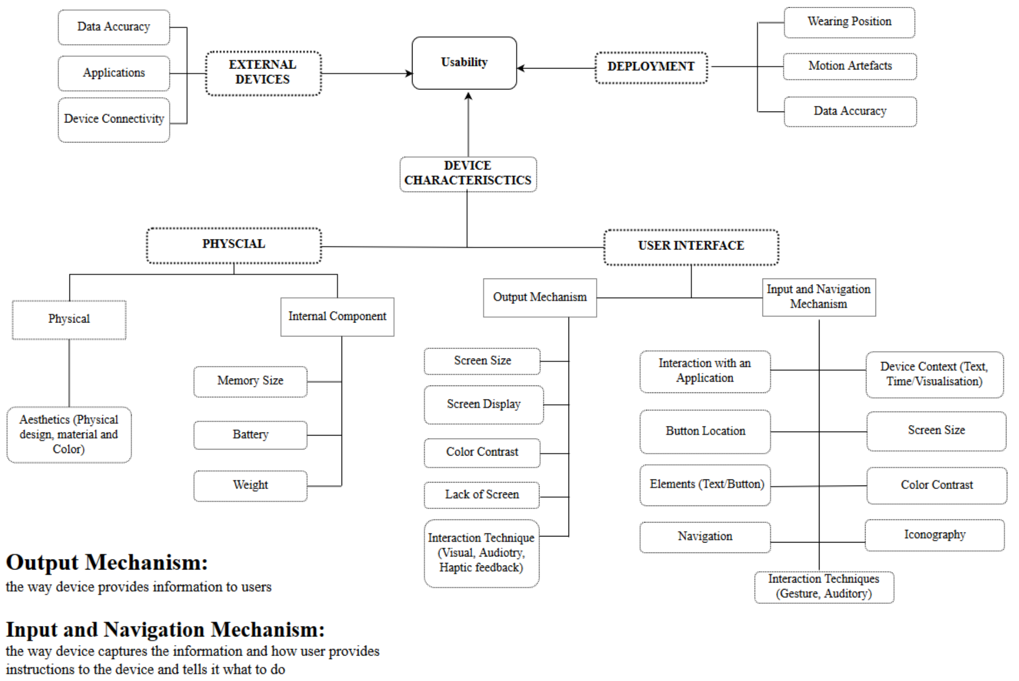

Figure 3: Usability issues categorization framework based on the reviewed papers

In the current thesis, Publication I's contribution aimed at reducing the time needed to acquire an adequate viewpoint of the usability issues of wearable devices via a comprehensive overview through a categorization framework while designing the new types of wearable devices. This allows technology designers, application developers, and the research community to focus on and devote more time toward new design and innovation by eliminating these existing usability issues.

4.2 Related Publication II — Living with smartwatches and pedometers: The intergenerational gap in internal and external contexts

4.2.1 Main objective

The aim of Publication II was to explore and present the commonalities and differences between internal and external contexts when it comes to what may influence older adults' and younger users' intentions to use COTS quantified self-tracking wearable devices, that is, smartwatches and pedometers, as motivational tools for physical activity. The main research question was the following:

4.2.2 Research question

RQ1: Which internal and external contexts can obstruct the use of COTS smartwatches and pedometers among both older adult and younger users while using the wearable as a motivational tool for physical activities?

4.2.3 Methodology

The CAT (Stanton, 1994) and the UEM (Ivory and Hearst, 2001) were used, and "usability testing" and "inquiry" were applied to 21 younger participants and 13 fit, older adult participants.

4.2.4 Main findings and contributions

The results from Publication II showed that there are no differences in the internal contexts between the younger and older participants regarding either the effect or usefulness of the external context. Although there were no differences in the internal context, there were distinctions between the younger and older adult participants regarding the external context, especially for certain aspects of device usability, such as font size, touchscreen interaction, interaction technique, and applications installed, which were the core factors that affected the use of COTS smartwatches and pedometers. This being said, we found that in addition, the external and internal contexts had a cause-and-effect relationship that significantly influenced the use of COTS smartwatches and pedometers.

In the current thesis, Publication II provides a wider contribution toward understanding the link between usability issues between the demographic context (i.e., age) through the external context (i.e., device types and characteristics), which could affect the internal context (i.e., emotional responses) and the acceptance of the intention to continue using quantified self-tracking devices. This allows technology designers, application developers, and the research community to see the importance of the age group when designing the device and its interface. Publication II compared the internal and external contexts that influence older adults' and younger users' intentions to use COTS quantified self-tracking wearable devices. When related to the present dissertation, the results from Publication II gave insights into the differences that exist in terms of the external and internal contexts between the target groups, that is, younger and older participants utilizing the same wearable devices.

4.3 Related Publication III — Categorization framework for usability issues of smartwatches and pedometers for older adults

4.3.1 Main objective

The main objectives of Publication III were to i) determine perceived usability issues and formulate a usability categorization framework based on the identified issues and ii) identify the predominant usability issues of smartwatches and pedometers that warrant immediate attention from technology designers, the research community, and application developers.

4.3.2 Research question

RQ1: What usability issues related to the device characteristics of smartwatches and pedometers can obstruct the motivation of older adults to adopt these devices, and how have these issues been categorized?

RQ2: What usability issues related to the device characteristics have a sizable impact on the usability needs for smartwatches and pedometers, thus warranting immediate prioritization by technology designers, the research community, and application developers?

4.3.3 Methodology

This study used a two-stage research approach, and 33 older adult participants took part in the research; it applied the CAT and UEMs. Existing data from Publication IV were utilized in this study.

4.3.4 Main findings and contributions

The results helped in defining a categorization framework based on perceived usability issues, and after analysis, the framework showed predominant usability issues related to the following device characteristics of smartwatches—user interface (font size and interaction techniques, such as notification, button location) and hardware (screen size)—and of pedometers—user interface (font size and interaction techniques, such as notification, button location, and tap detection) and hardware (screen size). Publication I provided an overall view of the usability issues of the wearable devices; however, it lacked the ability to provide a holistic view of quantified self-tracking devices. In the current thesis, Publication IV contributed toward this gap and identified the predominant usability issues, helping in drafting the recommendations for informal usability guidelines. Further, the categorization framework and predominant usability issues may provide guidance to technology designers, application developers, and research community in identifying key usability issues, hence raising important questions and providing the basis for designing upcoming quantified self-tracking devices. On the whole, the results from Publication III presented a comprehensive set of usability issues analyzed through the lens of a categorization framework and predominant usability issues related to the external context of specific device types and characteristics that are likely to impact device adoption among older adults. Hence Publication III contributes towards understanding the link between usability issues between the demographic context (i.e., age) and its effect on the internal context (i.e., emotional responses) and the acceptance of the intention to continue using quantified self-tracking devices.

4.4 Publication IV — Crafting usable quantified self-tracking wearable technologies for older adults

4.4.1 Main objective

The aims of Publication IV were the following: i) to explore and present the device characteristics that affect the adoption of wearables across different cultures; ii) to study country-specific older adults' importance weights of the identified issues; and iii) to provide informal guidelines for manufacturers, researchers, and application developers.

4.4.2 Research questions

RQ1: What should be considered by technology designers and the research community when it comes to enhancing the device characteristics related to quantified self-tracking wearable devices and improving older adults' adoption traits?

4.4.3 Methodology

Existing data from Publications II and III were utilized in this study. The usability data collected between Finland and US in Publications II and III were analyzed because the data were relevant to understand country-specific older adult's importance weights on the identified issues and the adoption of wearables across different cultures.

4.4.4 Main findings and contributions

The results showed that for older adults, culture might influence the perceptions of some device characteristics, such as device and screen size. We identified 14 usability issues that were reported during the studies (see Figure 1 in Publication IV) between Finland and the United States, of which eight were related to the User Interface (UI) and six to hardware. Publication IV also gave recommended informal guidelines based on the identified usability issues, qualitative feedback from the older adult participants, and existing literature reviews. The recommended guidelines include the following: i) Enhancing the usability for hardware (e.g., configure-to-order (CTO) products, considering the maximum magnitude of effect for minimal means, improving sensor precision, thinking of the culture while designing the devices, etc.) and ii) enhancing the usability of the UI (e.g., considering alternative user interfaces).

Overall, Publication IV contributed toward understanding the importance of culturability when designing quantified self-tracking devices, of which usability issues are especially important among older adults. It can be argued that Publication IV can provide a good starting point for technology designers, application developers, and the research community as they examine these needs from a culture point of view to improve the adoption rate of wearables among older adults. The publication shed light that designing quantified self-tracking wearable devices cannot simply rely on internationalizations and localization of the user interfaces, but rather, one needs to understand the targeted culture through Culturability i.e. relationship been culture and usability (Barber and Badre 1998).

The relation to the whole thesis can be looked at in three ways. First, the device characteristics that affect the adoption of wearables across different cultures was discovered. Second, the country-specific importance weights of older adults on the identified issues was discussed. Third, informal usability guidelines for manufacturers, researchers, and application developers were provided.

4.5 Publication V — Tapping into the wearable device revolution in the work environment: A systematic review

4.5.1 Main objective

The main objective of Publication V was to investigate and expand on the current state-of-the-art wearable technology to assess both its potential in the work environment and the challenges concerning the utilization of wearables in the workplace. The specific sets of questions that were addressed in this review were the following:

4.5.2 Research questions

RQ1: What types of wearable technology for use in the work environment do 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?

4.5.3 Methodology

Publication V adopted a SLR methodology; and in the review, 34 out of 359 articles were selected after an independent systematic search of the following scientific databases: ACM Digital Library, IEEE Xplore, ScienceDirect, and Web of Science.

4.5.4 Main findings and contribution

The findings from the SLR show that currently, there are 23 categories of wearable devices. Further analysis of the categorization of the devices delivered a holistic perspective of how the identified devices can be utilized in the work environment for different purposes: monitoring, augmenting, assisting, delivering, and tracking, all of which facilitate the adoption of wearable devices in the workplace. Figure 4 illustrates the categorization of wearable devices regarding their different use purposes in the work environment. The results showed that wearable technology has the potential to increase work efficiency among employees, improve workers' physical well-being, and reduce work-related injuries. Despite the potential, the review revealed that the technological, social, policy, and economic challenges related to the use of wearable devices remain.

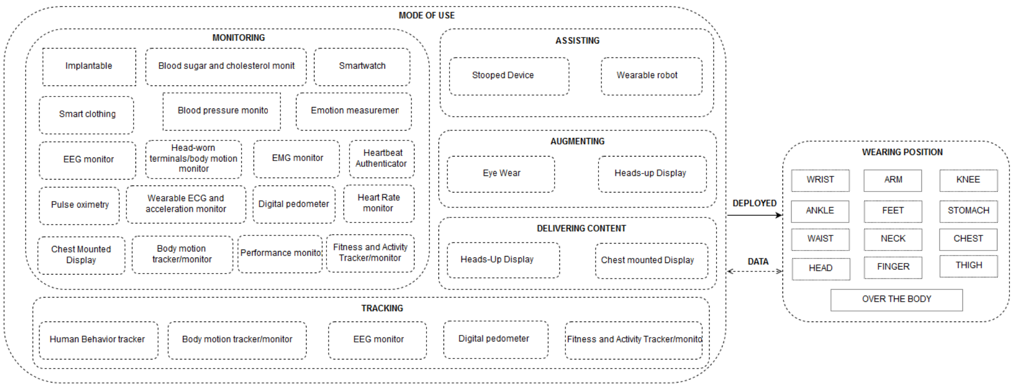

Figure 4: Categorization framework of wearable technology types

The findings of Publication V provided a valuable framework for managers and consultants planning to implement wearable devices in organizational settings, helping them in identifying the correct use purpose and correct type of wearable device categories. This would allow managers and consultants to identify the risks in the early stage of the implementation process to reduce any issues that may arise after implementation in terms of adoption. Furthermore, the identified challenges in Publication V would allow stakeholders to review the existing policy regarding privacy (i.e., collection of quantified self-tracking data) and the safety of the devices in organizational settings.

The results from Publication V revealed that the technological, social, policy, and economic challenges related to the use of wearable devices are present in organizational settings and may affect the adoption of wearable devices in this environment. This encouraged us to begin the research on the factors affecting the intention to use quantified wearable devices, that is, smartwatches and pedometers, in an organizational setting.

4.6 Related Publication VI — Intended use of smartwatches and pedometers in a university environment: An empirical analysis

4.6.1 Main objective

Publication V identified the social, technological, economic, organizational, strategic, and policy adoption challenges in a university setting. It is necessary for an organization to determine the challenges that can threaten the adoption of wearable devices. The main objective of Publication VI was to examine the factors that influence the intention to use wearables in an organizational settings, here being a university environment; this was conducted as a case study through the UTAUT as the baseline model (Venkatesh et al., 2003) but with additional variables, including the wearable acceptance model (WAM) among employees and students.

4.6.2 Research question

RQ1: What specific factors can obstruct the utilization of SWs and PMs among university faculty, staff, and students?

RQ2: How are these factors related to each other in influencing the use of SWs and PMs?

4.6.3 Methodology

In Publication VI, we adopted the UTAUT as baseline model presented by Venkatesh et al. (2003), and the factors that can influence the intention to use wearables were tested using an online survey of 129 university employees and students. PLS path modeling was applied in the analysis to test the nine hypotheses to validate the WAM, which was derived from the UTAUT model and additional variables.

4.6.4 Main findings and contribution

First, it was found that wearability and attitude tend to have a direct effect on intention to use, whereas performance and effort expectancy had a direct influence on attitude and hence no direct influence on usage intention. In addition, privacy concerns and social influence positively influenced the intention to use both directly and indirectly through attitude. The design and physical characteristics were to shown have a significant negative influence on intention to use. Figure 5 shows the simplified version of WAM, which could be used by the research community as a baseline model—where additional variables could be added—for use in organizational settings.

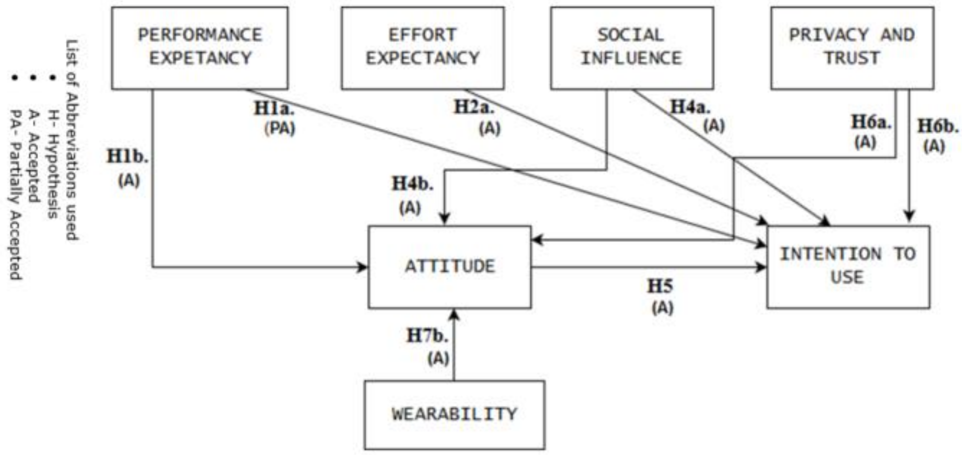

Figure 5: Wearable adoption model

In the current thesis, Publication VI provided new knowledge for managers, consultants, vendors, and the research community, helping give a better understanding of the factors affecting intention to use among individuals and what type of design could be used in the early stage of the utilization of quantified self-tracking wearable devices through WAM. Further, WAM could be expanded by organizations into different categories of wearables for different domains, which would help identify additional factors. On the whole, the results from Publication VI gave a holistic view of factors such as wearability, privacy concerns, social influence, and individual attitude, showing how they are important for the intention to use.

4.7 Summary of the publications

Overall, the results of the current thesis shed light on how adoption can be improved in the use context, specifically for individual (older adults) and organizational (employee) purposes. Table 8 summarizes the key content of the individual publications. Publications II, III, and IV showed that for quantified self-tracking wearable devices, efforts should be made to improve usability, which could improve the usefulness of the product. For example, the results in Publication II identified both the issues related to the external (i.e., the usability issues related to the device characteristics of the quantified self-tracking wearables) and internal context (i.e., user emotions, learning new behavior, and transformation in motivation). Furthermore, the results also demonstrated that there is a strong link between external context (device characteristics) and internal context, along with how the external context, such as device characteristics, impact the internal context of individuals, showing how this impact can strongly influence any age group. This means that usability issues affect the internal context and can obstruct the acceptance of COTS smartwatches and pedometers by changing an individual's perceptions of the device. Looking closer, Publication II showed that a user's demographic characteristics affect the usability of the device and the internal context, Publication III looked into the perceived usability issues and predominant usability issues of two quantified self-tracking wearable devices—smartwatches and pedometers—among older adults. Investigating the differences between the usability issues between these two devices, we found differences in the participants' interaction techniques; this may be because of the screen sensitivity of the pedometers and the pressure applied by the older participants during the study. Similarly, the study also identified one of three kinds of device usage problems that usually occur among older adults: short term, occasional, and long term. The short-term usability issues (i.e., the first few days of the studies when they first interacted with the device), along with the occasional issues, had a minimal effect on acceptance. Although the participants had usability issues throughout the studies, there were no drop-outs. This may show that when the users became accustomed to the short-term or occasional usability issues, the users would generally cope with the devices. In such cases, the device may have i) acted as a facilitator to change behavior for the elderly participants because of motivational aspects and objective control (Rasche et al., 2015) and ii) provided immediate accessibility (Rodríguez et al., 2017). For example, the participants' feedback indicated during the study that they were motivated because of "daily steps," "fun to meet challenges," "made me aware of sleep patterns," and "aware to move and not to be sedentary for long period of time." Given the fact that devices are not only sold beyond one cultural boundary and that previous research has pointed out that usability varies between cultures (Khaslavsky, 1998), in Publication IV, we examined if the culture may influence usability issues, that is, culturability. For example, in Publication IV, we identified that between two Western cultures, the participants' cultural backgrounds, particularly the users' perceptions of effectiveness, efficiency, and satisfaction (Wallace and Yu, 2009), differed regarding the device and screen size. Connected to the subquestions of RQ1, Publication IV recommended guidelines that may lay the groundwork for future quantified self-tracking wearables design while improving the usability of these devices; these guidelines include the following: Enhancing the usability for hardware (e.g., configure-to-order (CTO) products, considering the maximum magnitude of effect for minimal means, improving sensor precision, thinking of the culture while designing the devices, etc.) and ii) enhancing the usability of the UI (e.g., considering alternative user interfaces).

In accordance with the organizational settings, Publication V showed that although there are benefits of having wearable devices, including i) monitoring the psychological and physiological factors of employees; ii) enhancing operational efficiency, iii) promoting work environment safety and security, iv) performing industrial design, and v) improving workers' health, the technological (i.e., usability, technology readiness, and security), social (i.e., privacy and adoption), policy-related, regulatory, and economic issues remain. Furthermore, Publication V revealed that for organizations to utilize wearable devices, they first need to identify the devices that are suitable for the use purpose, which includes the context of the work and potential technological challenges. For example, wearable devices such as Head Mounted Devices (HMD) are not suitable for quantified self-tracking purposes and are instead better designed for delivering content. Further, the survey results from Publication V showed that while utilizing quantified self-tracking wearable devices within the organization, the adoption rate among employees can be improved by decreasing wearability issues and improving the attitudes of users, protecting privacy, and the awareness of the devices its benefits among users and surrounding people. Based on the results from Publication VI, wearability can only be seen as one of the numerous influential factors for the acceptance of quantified self-tracking wearable devices. In addition, social influence can affect both the attitude and intention to use. This means that within an organization, if the people close to the employees, for example, friends or influential people, recommend the devices, the employees will be more likely to use the device. Also, we found that attitude plays a very important role because it has the strongest effect on intention to use; if the user learns that the device is usable and will motivate him or her to do more physical activities or elicits a positive mindset about the physical activities through user engagement features—such as data, gamification, and content—then the user will be more likely to form a positive attitude toward the use of quantified self-tracking devices and, ultimately, have a greater intention to use those devices. Le Roux and Maree (2016) also assert that attitudes are learned through experiences with a product or from information received or acquired from mass media or individuals. Therefore, to increase the adoption rate of wearables in a work environment, especially smartwatches and pedometers, we recommend that organizations should find suitable devices for use in the work environment and that have specific use purposes; in addition managers should consider how the device fits, each user's body shape, the device's size and dimensions, and the employees' preferences, interests, and wishes (Motti and Caine, 2014).Doing this could reduce the wearability concerns found in Publication VI. In addition, employees should be actively involved throughout the implementation process of the devices so that they can form a positive attitude toward intention to use. Karsh (2004) supports this by stating, "Having employees participate during implementation of technology improves commitment, trust, and control while reducing resistance to change and anxiety" and results in "increases in information and knowledge which reduce uncertainty" (p.390). Morris et al. (2005) state, "Early perceptions can have a lasting impression on individual's intentions and behavior" (pp.81). Similarly, technology designers should consider usage environment and wearability factors when designing smartwatches and pedometers, which could help lead to adoption among individuals and lead to more positive opinions from referents so that users actively build a positive attitude toward the intention to use. Similarly, privacy concerns, another factor within the WAM model, can be improved by giving a sense of i) disassociability (i.e., actively protecting or "blinding" an individual's self-tracking data from exposure); ii) predictability (i.e., informing individuals about how their information is being handled); and iii) accessibility and manageability (i.e., actively giving access and greater control to manage the collected health information data) (Brooks et al., 2017) to employees. Zhang et al. (2014) state, "Affording users control over information release would not only allow users to modify their privacy settings and gain a sense of autonomy, but also help them predict what information might be at risk, thereby reducing the concern level resulting from uncertainty" (p.167).

Table 8: Summary of key contents of the individual publications

	PUBLICATION I	PUBLICATION II	PUBLICATION III	PUBLICATION IV	PUBLICATION V	PUBLICATION VI
Title	A systematic literature review of the usability of wearable devices	Living with smartwatches and pedometers: The intergenerational gap in internal and external contexts	Categorization framework for usability issues of smartwatches and pedometers for older adults	Crafting usable quantified self-tracking wearable technologies for older adult	Tapping into the wearable device revolution in the work environment: A systematic review	Intended use of smartwatches and pedometers in the university environment: An empirical analysis
Objectives	To provide a comprehensive systematic literature review of the usability issues related to wearable devices.	To identify the existing challenges of wearable devices and how they affect the emotional and behavioral responses among individuals of all age groups.	To determine usability issues and formulate a usability categorization framework and identify the predominant usability issues that warrant immediate attention.	To explore the country-specific older adults' importance weights of the identified issues and provide informal guidelines.	To investigate and expand the current knowledge of wearable technology to assess both their potential in the work environment and the challenges.	To investigate the factors that influence the intention to use wearables in organizational settings
Data	84 out of 3271articles	13 older adult, 21 younger participants,	33 older adult participants,	33 older adult participants, FIN and USA	34 out of 359 articles	An online survey of 129 university employees and students
Method	SLR	CAT, UEM	CAT, UEM	CAT, UEM	SLR	UTAUT and additional variables
Main Findings	The results indicate a growing interest in this field. Device characteristics (screen size, screen display, battery life, elements, interaction techniques, etc.) and deployment categories (motion artifacts, wearing positions) were the most discussed usability-related issues.	The findings show that there are no differences in the internal contexts between the younger and older participants, but differences exist because of the external context caused by device usability.	The findings suggest that usability issues related to the user interface (font size and interaction techniques, button location) and hardware (screen size) of smartwatches and user interface (font size and interaction techniques, button location, and tap detection) and hardware (screen size) of	The findings suggest culture influence the perception of some device characteristics, such as device and screen size when it comes to older adults. Further study provided informal guidelines on how to improve devices.	The findings from the SLR show that currently, there are 23 categories of wearable devices that can be used in the work environment for different use purposes. In addition, there are tremendous benefits associated with wearables if implemented correctly.	The findings indicate that wearability and attitude have a direct effect on intention to use, whereas performance and effort expectancy had only a direct influence on attitude and intention. In addition, privacy concerns and social influence had a positive influence on the intention to use both directly and indirectly through attitude. The design and device characteristics have a significant negative influence on intention to use.
Main Contribution	The study gives a comprehensive overview of the existing usability issues of wearable devices through a categorization framework, which allows technology designer, application developers, and the research community to focus and devote more time toward new design and innovation by eliminating the existing usability issues.	The study contributes toward understanding the link between the usability issues between the demographic context (i.e., age), the external context (i.e., device t characteristics), and the internal context (i.e., emotional responses) toward the adoption of devices.	The study provides a comprehensive set of usability issues through the lens of a categorization framework and predominant usability issues related to the external context of specific device types and characteristics that are likely to impact device adoption among the older adults.	The study provides the importance of culturability while designing device characteristics of the quantified self-tracking devices, of which the usability issue is predominantly important among older adults. Further studies can provide informal guidelines for technology designer, application developers, and the research community.	The study develops the categorization framework, which could be beneficial for managers and consultants to understand which devices could be used for which use purposes and identify the risks in the early stage of the implementation process to reduce the risk.	The study provides insights into the factors affecting intention to use quantified self-tracking wearable devices through the WAM among individuals to managers, consultants, vendors, and the research community, which helps them to focus toward design a solution in the early stage of the utilization.

5 Discussion

In light of the concerns about the rate at which quantified self-tracking wearable devices are being adopted by older adults and the current challenges that may impact the adoption of wearables in the organizational context, the current study had two major research questions. Section 5.1 discusses the contributions of RQ1 (*For a target audience of older adults, what should technology designers, application developers, and the research community do to improve the acceptance of and intention to continue using quantified self-tracking wearable devices from the perspective of the usability of the device characteristics?*). Section 5.2 will discuss the contributions and implications of RQ2 (*How can organizations implement and increase the acceptance of and intention to continue using quantified self-tracking wearable devices for different use purposes?).*

5.1 Understanding demographic and external and internal contexts to improve usability, user acceptance, and intention to continue using quantified self-tracking technologies

Increasing the acceptance rate of intention to continue using quantified self-tracking technologies for older adults means lowering the barriers related to the device characteristics and reliability and validity regarding the accuracy of recording steps (O'Brien et al., 2015; Puri et al., 2017). Although studies have focused on universal design guidelines and principles for wearable technology (Gandy et al., 2003; Tomberg et al., 2015; Tomberg and Kelle, 2018; Wentzel et al., 2016), how wearable devices should be designed to accommodate as many different users' needs as possible is still lacking; however, an approach to design guidelines on the external context (i.e., predominant usability issues of specific quantified self-tracking wearable device categories) and the demographic context (age, culture) has not been the focus of researchers.

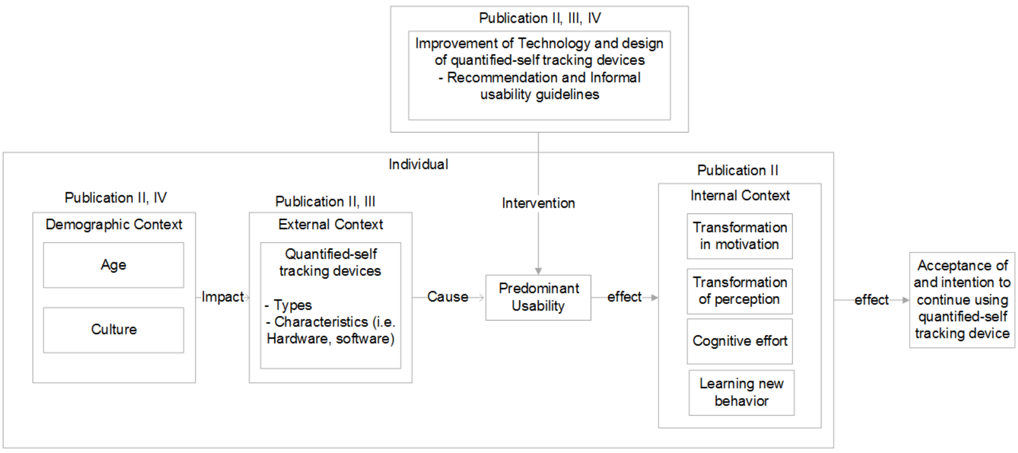

Figure 6: Summarizing the key contributions from Publications II, III, and IV

To help address these gaps, the current research contributes new knowledge, laying the groundwork for technological and design issues by providing several recommendations (see Publications II, III, and IV), such as considering CTO products, considering the maximum magnitude of effect for minimal means, improving sensor precision, thinking of the culture while designing the devices, and thinking of alternative user interfaces. The findings from Publications II, III, and IV (see Figure 6) indicate the predominant usability issues can be linked to the demographic context (i.e., age and culture) through the external context (i.e., device types and characteristics), which could affect the internal context (i.e., emotional responses) and the acceptance of the intention to continue using quantified self-tracking wearable devices (i.e., smartwatches and pedometers). The presented informal guidelines (see Publications II, III, and IV) could be used by technology designers, application developers, and the research community to improve the design of upcoming smartwatches and pedometers, helping to launch the product for older consumer segments (Lin et al., 2016). This could have a long-term and direct impact on society. For example, when the design manufacturer and the application developers design wearable devices and their associated applications that better suit older adults' abilities and motivate them to do more physical activities, this could help prevent and treat diseases and reduce the risk of developing other chronic diseases, premature mortality, functional limitations, and disabilities (Nelson et al., 2007). Furthermore, this contribution will also have an indirect impact on other areas, including i) ongoing economic concerns (i.e., decreasing healthcare costs for governments, which could lead to more spending in other sectors such as education, agriculture) and ii) long-term use of the devices by the users, leading to a reduction in technological waste.

Although the adoption rate of wearables devices among younger individuals and the abandonment rate has been the same, the literature lags behind on how to improve the acceptance and intention of using wearables among all individuals, not just younger people. Based on the findings from the literature review, we present a framework (see Figure 6) that extends the relatively scarce literature, allowing the research community to improve the understanding of the impact of the demographic context, external context, and internal context, which may offer support for researchers as they conduct further studies to better understand the predominant usability issues that could improve the acceptance of and intention to continue using wearable devices.

Furthermore, the findings from Publication IV also indicated that culture can influence the perceptions of some device characteristics among individuals using the same devices. Therefore, instead of a culture-blind product development approach to increase the adoption rate, technology designers, developers, and the research community should instead use culture as a catalyst when designing an innovative product that shapes users' everyday culture and responds to that culture (Moalosi et al., 2010).

The preliminary results from Publications III and IV identified a range of perceived usability issues that were indicated by older adults across cultures as they used different types of quantified self-tracking wearable devices. Each indicated issue was either short term, occasional, or long term. Therefore, not all the preliminary perceived usability issues were in the scope of human–computer interactions (HCI) and hence not usability problems (Jose, 2016). As Conrad and Alvarez (2016) state, “One source alone may not always indicate a trend,” and having to go through all the usability issues without knowing the predominant issues may be time-consuming. The applied two-stage approach in Publications III and IV identified the perceived usability issues and prioritized them as predominant issues, shedding light on how the research community could precisely identify predominant usability issues from the indicated usability issues.

5.1.1 Understanding usability issues across quantified self-tracking wearable device categories (i.e., smartwatches and pedometers)

Although the categorization framework provided in Publication I is an important source when it comes to having a cohesive understanding of the usability-related issues of wearable devices from the user’s perspective, usability issues with respect to older adults and device-specific issues are still missing. Each of these usability factors that are related to the device characteristics may vary depending on the type of application, device, and technology (Wirtz et al., 2009). Because understanding which usability issue is important for the type of device and technology, Publication V identified the range of device usability barriers that occurred from an external context when testing two self-quantified tracking wearable device category types, that is, smartwatches and pedometers, among older adults. Further analysis in Publication III revealed the categorization framework of usability barriers, providing a systematic structure of the usability barriers of two quantified wearable device category types for older adults. The categorization framework can help technology designers, application developers, and the research community obtain a holistic overview of the similarities and differences of the usability barriers, which would lend itself to being a viable methodology for (Hambling et al., 2011) improving the usability qualities of the smartwatches and pedometers for older adults.

Past work (Shih and Liu, 2007) has suggested that user experiences may encompass emotional response factors, which might affect the users as they interact with the products. Although the phenomenon of emotional responses is well known, how these responses vary across different age groups and if they affect device acceptance are unknown. Based on our findings in Publication II, there are no differences in internal contexts (i.e., transformation in motivation, perceptions, cognitive effort, and learning behavior) between the younger and older adults in both the effect and usefulness of the external context. However, external contexts appear to show a distinction between the younger and older adult participants, especially in certain aspects of device usability, such as font size, touchscreen interaction, interaction technique, and applications installed, which were the core factors that affected the use of COTS smartwatches and pedometers. Also, the external and internal contexts had a cause-and-effect relationship that significantly influenced the use of COTS smartwatches and pedometers.

5.1.2 Guidelines on the identifying existing usability issues across wearable devices

The categorization framework (see Publications III) contributes to a straightforward guideline for the designers of wearable technologies, especially regarding its usability and in understanding what kinds of usability contexts currently exist. Prior research (Dzhagaryan et al., 2015; Holzinger et al., 2010; O'Brien et al., 2015; Puri et al., 2017; Rasche et al., 2015) has indicated that usability issues appear while interacting with the wearable devices, but these studies tend to emphasize a couple of usability issues that need interventions from technology designers, application developers, and the research community. In contrast, Publication I makes it easier to have a future roadmap and cohesive understanding of the usability-related issues of overall wearable devices from the user's perspective.

5.2 Lessons of the utilization of wearable technology for organizational use

There are many types of COTS and proof-of-concept wearable devices that could be used for different purposes in an organization (see Publication V). Kritzler et al. (2015) state that "different work environments could lead to different implementations of the system" (p.216). For example, in hazardous environments, it is necessary for workers to wear the right personal protective equipment (PPE) when using sensors for specific tasks. Lavallière et al. (2016) state that if a user at the workplace is either an older or impaired individual, wearable devices should be designed to be inclusive for this type of user. A question then arises: How can organizations select the correct types and categories of devices based on the needs, requirements, and utilization purposes to increase adoption rates so that wearable technology be a real asset for improving productivity, increasing efficiency, and improving safety? To answer this, in Publication V, we created the categorization framework of wearable device types, which could be used for specific use purposes that would help wearable devices become validated in the context of their use. The presented framework offers valuable guidelines for managers and consultants to identify the appropriate wearable types in the early stages of implementation to offset any challenges (see Publication V) and lower the risk of early abandonment of the devices. If the risk is higher, utilizing specific wearable devices may be terminated to reduce costs, and alternative devices or solutions can then be sought.

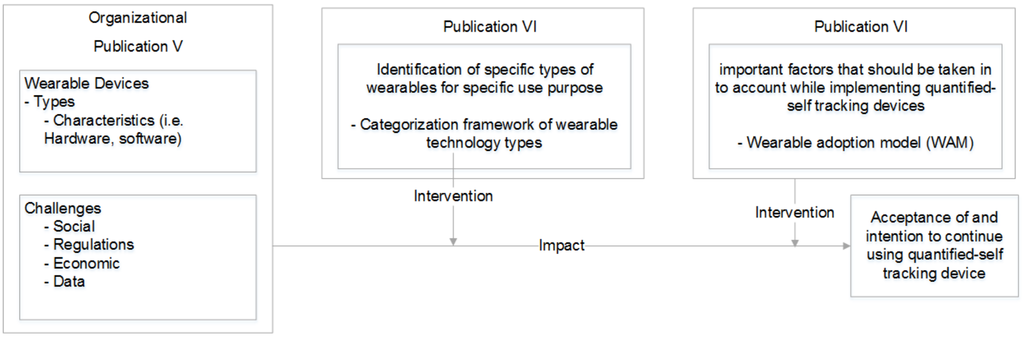

Figure 7: Summarizing the key contributions from Publications V and VI

Having an organizational utilization process is not sufficient for increasing the acceptance and adoption of wearable devices because of the attitudes and intentions of the end users (Ghobakhloo et al., 2012). Although many have tried to realize the importance of wearables for organizational use and to overcome organizational challenges (see Publication V), there is very little knowledge of which factors affect the intention to use when implementing quantified self-tracking technology for use in an organizational environment. Therefore, the WAM presented in Publication VI contributes to managers, vendors, and the research community, helping them better understand the factors that influence intention to use among individuals and helping them design a solution in the early stage of the utilization of quantified self-tracking device types. In addition, organizations that intend to utilize different categories of wearables for different domains could use the WAM as the baseline model to identify additional factors.

5.3 Limitations of the research

According to Cherulnik (2001), “Validity is the degree to which the results of a research study provide trustworthy information about the truth or falsity of the hypothesis” (p.466). In this section, we discuss the threats to the validity of the research, particularly regarding the content, construct, maturation effects, instrumentation, conclusion, descriptive, interpretive, theoretical generalizability, and reactivity (Lewis-Beck, 2004; Lund Research Ltd, 2012; Maxwell, 1992; McCambridge et al., 2014; Zamanzadeh et al., 2015).

Content validity: Content validity—also known as definition validity or logical validity—addresses the degree to which the items of an instrument sufficiently represent the content domain; content validity can be defined as the ability of the selected items to reflect the variables of the construct in the measure (Zamanzadeh et al., 2015). Researchers have stated that the content validity of an instrument can be determined using a panel of experts. As a result, the instruments designed for Publications II, III, and IV were reviewed by three experts who had knowledge of the subject matter. Similarly, for Publication VI, the measurement instruments were reviewed by two reviewers. This ensured that the items in the instruments matched the research objectives and increased the trustworthiness of the instruments.

Construct validity: In the current thesis, for Publications II, III, and IV, the final lists of measurements for the diaries were derived from the literature review. Search strings were utilized after refining the results from the digital databases (IEEE Xplore, the ACM Digital Library, Science Direct, and Web of Science). For publication, baseline constructs were derived from the UTAUT theoretical models (Venkatesh et al., 2003). Additional constructs were derived from the literature review, which is usually used in empirical studies to understand individuals' technology acceptance.

Maturation effect: The maturation effect refers to any short- or long-term biological or psychological changes (such as a good mood changing to a bad mood); this can occur because of various factors (such as tiredness, boredom, hunger, or inattention) within a participant during the experimental settings. The occurrence of this is likely to threaten the internal validity of the findings (Lewis-Beck, 2004; Lund Research Ltd., 2012). To reduce this effect, data were collected beyond the meet-up sessions—through a diary. The diary entries were short, only took a few minutes to complete, and could be completed in the participants' natural settings. In the diaries, the participants recorded their events, thoughts, feelings, and behaviors using their own words; the data in the diaries were arguably more reliable (Ohly et al., 2010; Rieman, 1993). In addition, the duration of the meet-up session was kept reasonably low (a maximum of 2 hours); and the participants were not overburdened with tasks, helping reduce the threat to internal validity.

Instrumentation: Instrumentation refers to the internal validity being affected by instrumental bias or instrumental decay; this can occur because of the measuring instrument (e.g., a measuring device, survey, or interviews/participant observation) used in a study changing over time (Lund Research Ltd., 2012). In the present thesis, there were no changes in the devices; however, in 2018, there were new models of the devices available. Similarly, the same evaluator performed the experiment during the studies, and the same instructions and tasks were applied across all the participants.

Descriptive validity: Descriptive validity refers to the factual accuracy of the collected data (i.e., data must accurately reflect what has been reported by the participants), and all other forms of validity are built upon this (Maxwell, 1992; Thomson, 2011). Because the data were collected in the current thesis for Publications II, III, and IV by using diary methods, there may have been data entry errors because of the burden of data entry and the handling or misinterpretation of the data (Bolger et al., 2003). To reduce this type of validity threat, data were double-checked during data entry and validated by an additional author. Similarly, for Publications I and V, data were extracted and entered into Excel; data were double-checked during the data entry and later validated together with another coauthor to create the categorization framework.

Interpretive validity: Interpretive validity (also known as conformability or justifiability) refers to how well the researcher interprets the reported meaning of events, objects, and/or the behavior of the participants (rather than using his or her own perspective) (Maxwell, 1992; Thomson, 2011). In the current thesis, this threat to validity was reduced for Publications II, III, and IV; this was done by using two data analysis techniques. First, qualitative feedback was reported using “quotation marks”; second, for Publications I and V, we utilized the SLR method, where the interpreted data were quoted to validate the meaning of the results. In addition, the present thesis was written by seven coauthors, and the final draft was read by a coauthor who had no prior knowledge of the publications (i.e., Publications I–VI). This was done to reduce overanalysis and to validate the data. Furthermore, the research bias was reduced through the use of anonymous peer review.

Theoretical validity: According to Maxwell (1992), “Theoretical validity goes beyond concrete description and interpretation and explicitly addresses the theoretical constructions that the researcher brings to, or develops during, the study” (p.50). In the current thesis, theories were built on qualitative and quantitative data and based on the CAT. The UEM was applied to older participants from two countries for Publications II, III, and IV. As a baseline model for Publication VI, the UTAUT model was used for survey respondents from organizational settings; this was done in collaboration with other coauthors and researchers from the research community, which enhanced the theoretical validity of the current thesis.

Conclusion validity: The present study encountered more challenges when recruiting older adults for the case studies in Finland than in the United States; as a result, the study had a relatively small and nonrandom sample number. This may have been because of mistrust and transportation obstacles, sensory and cognitive limitations, and excessive restrictions on eligibility (e.g., computer requirements, which included having a smartphone and a certain operating system; a lack of knowledge about the evaluated topic or device; and language or cultural differences) (McHenry et al., 2015). However, according to (Macefield, 2009), a group size of 3–20 participants is typically valid, with 5–10 participants being a sensible baseline range. Therefore, the results of this thesis are not threatened by internal validity—though the results may not be generalizable. Therefore, the findings should be taken as suggestions rather than conclusive evidence.

Generalizability: The generalizability, external validity, or transferability refers to the extent to which the research findings that were based on a sample of individuals or objects can be generalized to the same population that the sample was taken from or to other similar populations in terms of contexts, individuals, times, and settings (Lavrakas, 2008; Thomson, 2011). As Wagner et al. (2014) state, “All research studies have some limitations, and this study is no exception” (p.279). The first external threat to generalizability deals with ethical and governance difficulties. For example, we evaluated and followed different research methods while coming to a theory on how to increase the adoption of wearable devices. We identified how the context, such as age and culture, can have an impact on the external context, which can hence affect the internal context. These results lead to specific outcomes for improving the adoption of wearable devices among older adults. We recognize that in doing this, we missed studies involving frail older adults with impairments who were > 60 years of age and were either independently living (e.g., private housing), in assisted living, or in nursing homes (Pew and Hemel van, 2004) and who hence require assistance while using the devices. Although we wanted to explore and provide recommendations for the research community, application developers, and technology designers, if the current research would have included a vulnerable population, that is, frail older adults (Barron et al., 2004), it would have caused ethical and governance issues, leading to resource constraints during the informed consent process. However, the framework (Figure 6) can be taken as a baseline work to evaluate in future studies with a focus on frail older adults.

The second threat to the study's generalizability was related to the devices (for Publications II, III, and IV). We started the research in late 2016 with recently introduced COTS devices; however, in 2018, a new range of device models were available. Because of cost constraints, we could not purchase the devices, which resulted in us testing the same older devices, so the results cannot be generalized to other devices. However the framework provided in Publications III and IV could be taken as a baseline framework to conduct further research on the latest built-in features, such as GPS, call, and text, which might affect the internal context.

The third threat to generalizability was the focus on the quantified self-tracking devices—smartwatches and pedometers. The usability issues of quantified self-tracking devices and recommendations made here cannot be generalized to other forms of wearable devices. This is because each wearable device has different device characteristics and needs and may not resemblance the characteristics of quantified self-tracking devices. However, the framework presented in Figure 6 and 7 could be used as a baseline study to understand what contexts should be taken into consideration while designing other forms of wearable devices.

The fourth threat to generalizability was the datasets for the survey on organizational use (for Publication VI). This study was conducted for 10 days, during which a total of 129 individuals responded to the survey, and 42.64% (n=55) were university faculty and staff; 39.53% (n=51) were students; and 17.83% (n=23) were both. Although all obtained responses were valid because all the answers were mandatory and only university staff, faculty, and students were allowed to complete the survey, the sample size was very small, and the results cannot be generalized. Although the survey results can be generalized to some extent, the WAM itself needs further testing with larger datasets.

The fifth threat to generalizability is reactivity, which is also known as the Hawthorne effect; this concerns research participation, the consequent awareness of being studied, and possible impact this has on behavior (McCambridge et al., 2014). To reduce this effect, prior to the experiment and during the meet-up session, a friendly environment was created between participants though discussions not related to the experiments all while maintaining professionalism. During the experiment, the participants were observed from the behind instead of from the front (face-to-face) during the meet-up sessions to reduce the impact on their behavior and influence their views toward the findings. In addition, data were collected beyond the meet-up session through dairies in the participants' natural settings, where the participants recorded events, thoughts, feelings, and behaviors in their own words.

5.4 Future research directions

Although the results from the current study present a number of contributions and steps toward improving the acceptance of and continuing use of quantified self-tracking wearables among older adults and for organizational use, there are also some unexpected findings that can fuel future research (Wagner et al., 2014). First, the results from the present study provide a framework (Figure 6), which uses a demographic context (i.e., age and culture). Further research may incorporate additional demographic characteristics, such as gender and additional countries for the culture context, to understand how these may affect the predominant usability issues and if they may increase the ability for technology designers and application developers to provide more targeted, relevant, and desirable user experiences (Vollman et al., 2010). Second, in Publications II, III, and IV, one of the concerns was about data reliability and validity. Because wearable devices produce large amounts of data which is largely recognized as a new form of capital in the digital era (Pikkarainen et al., 2018), the meaningfulness of the data can have a major effect on a user's behavior, which could confuse and discourage the individual user (Hänsel et al., 2015). Reeder and David (2016) assert, "Data must be represented as meaningful information for health-related decision making by a range of stakeholders including patients, family members, health care providers, public health professionals, and policy makers" (p.276). Therefore, future research should focus on how to improve the data usability, reliability, and validity of quantified data, including if there is a correlation regarding the adoption of quantified self-tracking wearable devices. Third, because the current study was limited to the improvement of technology, the framework provided in Figure 6 could be further expanded to understand the impact of pricing and advertising strategies and how this may affect the device types and characteristics that affect the adoption rate of wearable devices among older adults. Lee's (2014) model could be used as a base model to understand the core relationships between pricing, advertising strategies, and the emotional responses with respect to adoption.

In addition, each country has its own regulations. For example, in the European Union (EU), construction products and personal protective equipment are regulated by EU laws (the Regulation (EU) No 305/2011 for Construction Products (CPR) and Directive 89/686/EEC for PPE, respectively) (Eufinger, 2014) that impose a Conformité Européene, or European Conformity (CE), marking to improve safety in workplaces. The impact of these regulations is not clear when it comes to the utilization of the devices at the organizational level. The categorization framework presented in Publication II could be further expanded on to include which devices fulfill government requirements.

Similarly, the General Data Protection Regulation (GDPR) imposed by the EU (Regulation (EU) 2016/679) (European Union, 2016) came into effect on May 2018; this regulation strengthened the data protection for individuals within the EU and states the requirements regarding how any organization can collect and process personal data at the consumer level, along with how an employer can process the personal data of employees. For example, prior to the GDPR, organizations could collect employees' personal data from any wearable device to improve company performance and productivity through monitoring and tracking, all without any consent needed; in addition companies could store and analyze data outside the EU. However, the current GDPR prohibits the transfer of personal data outside the EU unless there is a foreign jurisdiction judged to have adequate data protection measures in place. In addition, the GDPR also gives rights to employees i) to revoke consent of data processing at any time and ii) to view and obtain they type of data that are being collected and processed from them. Furthermore, meeting the requirement of data minimization by implementing “Data Protection by Design and Default” (Article 25) (European Union, 2016) also provides additional security among employees regarding the data collected from wearable devices. In summary, with the introduction of the GDPR, employers are expected to meet fairly strict standards when it comes to receiving, holding, and distributing (processing) the data collected (Morrison et al., 2017) from wearable devices, which may reduce privacy concerns, one of the factors affecting the intention to use and attitude among the individuals for organizational use (see Publication VI). Although there are other influencing factors that need to be addressed for improving the user acceptance of wearables for organizational use, the GDPR can be seen as a first step toward influencing and improving the trust between employees and employers when it comes to the implementation of wearable devices within EU regions. Further empirical studies could be conducted on how much the GDPR has influenced trust among employees toward their employers regarding collecting and analyzing the personal data from wearable devices. Because the GDPR only can be applied within the EU region, this opens a new research area to see how the adoption rate of wearables varies between the same organization that complies with the GDPR in the EU region and also collects data from employees in a non-EU region.

In addition, Article 35 of the GDPR (European Union, 2016) states that a privacy impact assessment should be undertaken prior to implementing new technology or services that process the data of individuals; this should be done to identify if there is a high privacy risk at an earlier stage. Therefore, the framework in Figure 7 could be further extended to include the guidelines provided by the EU (European Commission, 2017) on a data protection impact assessment and used for planning and implementing at all levels—including identifying the essential wearable types, determining potential challenges, deploying devices, creating strategies for service adaptation and device adoption, collecting results, and measuring and refining data.

6 Conclusion

Wearable computing offers new opportunities that can revolutionize almost every aspect of our lives (Tomberg et al., 2015). However, the adoption rate of these computing devices is still weak. The present study provides new knowledge on how to improve the adoption of quantified self-tracking wearable devices in both use contexts: individual from the device characteristics perspective and from the organizational perspective, which includes factors such as technological, social, and ethical. Validated from the various stages of research, two frameworks were presented to give an overview of which factors impact, cause, and affect the adoption of quantified self-tracking wearable devices, such as smartwatches and pedometers.

For the adoption of quantified self-tracking wearable devices for individuals, that is, among older adults, the demographic context, such as age and culture, had a significant effect on the external context, such as the device characteristics; the external and internal contexts affected the adoption rate among older adults. Informal usability guidelines are recommended for technological designers and developers (Publication IV) as an intervention for how to improve the effectiveness and efficiency associated with the use of quantified self-tracking wearable devices in the future, as well as increase user satisfaction with them; here, the objective is to reduce the rate at which wearables are abandoned. Thus, the current study contributes to filling in this gap on usability (Ehn et al., 2018; Hounsell et al., 2016; Mercer et al., 2016; Puri et al., 2017; Seifert et al., 2017) by supporting the aspects of effective behavior change techniques regarding the use of tracking devices by older adults.

Additionally, for the adoption of quantified self-tracking wearable devices by organizations, the current study explored specific types of devices that could be used for particular purposes in the organizational environment, ranging from commercially available to proof-of-concept wearable devices, and we also created a categorization framework (Publication V). To improve the adoption rate, this framework may offer valuable guidelines and be taken as the first step that would let managers and consultants identify the appropriate wearable types for the utilization of wearable devices in the early implementation stages, lowering the risk of early abandonment of devices. To offset the influencing factors related to technological, privacy, social, and ethical challenges, the WAM was empirically validated and presented in Publication II, which could be taken as a baseline model by managers, vendors, and the research community, helping them apply or study wearables in the organizational environment.

In conclusion, if the findings of the current thesis are accepted by researchers and practitioners, they can impact the adoption of the wearable devices for both personal and organizational use. The potential increase in adoption could result in a win–win situation on a number of levels. For example, on the individual level, more people will become involved in physical activities, resulting in immediate and long-term health benefits. Similarly, at the organizational level, employers could fulfill corporate social responsibilities, reduce health care costs, retain healthy employees, and increase productivity; employees could increase their family spending power and well-being; and at the government level, these devices could help in having fewer health care expenditures and healthier communities. Moving forward, practitioners and researchers should collaborate and open a constructive dialog on how to approach and accommodate these current and upcoming technological advances in a way that ensures wearable technology (Piwek et al., 2016) can become a valuable asset at the individual, organizational, and government levels.

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Living with smartwatches and pedometers: the intergenerational gap in internal and external contexts

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Abstract. The purpose of this article is to explore and present the range of commonalities and differences between internal and external contexts that influence elderly and younger users' intentions to use commercial off-the-shelf (COTS) smartwatches and pedometers as motivational tools for physical activity. Therefore, this article follows the contextual action theory and the usability evaluation approach, in which "testing" and "inquiry" were applied to 21 younger participants and 13 fit, elderly participants who were in either the pre-contemplation, contemplation, action, or maintenance behavior-change stage. The results revealed no differences in internal context between the target groups due to both the effect and the useful-ness of the external context. However, there were distinctions between the younger and elderly participants regarding external context, especially in certain aspects of device usability, such as font size, touchscreen interaction, interaction technique, and applications installed, which were the core factors that affected the use of COTS smartwatches and pedometers by the study groups. In addition, the external and internal contexts had a cause-effect relationship, which significantly influenced the use of COTS smartwatches and pedometers.

Keywords: Wearable Devices; wearable applications; smartwatches; pedometers; elderly; intergenerational gap; Commercial-off-the-shelf (COTS), usability

1 Introduction

Much effort has been paid recently to exploring how technologies can promote older adults' well-being and independent living [13]. One area of technology and its user engagement features—such as data, gamification, and content [2]—that has recently become popular among young populations for well-being, and which can be effective to motivate the elderly to be more physically active, is commercial off-the-shelf (COTS) wearable devices. Wearable devices are smart electronic devices available in various forms, worn near or on the body, to sense and analyze physiological and psychological data, such as feelings, movements, heart rate, and blood pressure [12]. This can be done via an application that is either installed on the device or on external devices (e.g. smartphones connected to the cloud) [12]. Wearable devices like activity trackers that measure motion and steps enable users to monitor their behavior and could support a healthier lifestyle

[19]. They feature different degrees of usability and a varying range of user experiences [12]; the International Organization for Standardization [9] defines "usability" as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context. Currently, this definition doesn't apply to the elderly, as they have a more difficult relationship with COTS devices than their younger counterparts [3], primarily because hardware and software have not been designed to suit their physical or mental abilities [14], which can discourage the elderly's adoption of devices such as smartwatches and pedometers as tools to perform physical activities.

Despite growth in the use of COTS smartwatches and pedometers, few studies have drawn technological comparisons between the elderly and their younger counterparts [5, 21, 30]. However, no studies have considered how elderly and younger users' perceptions of, and usability challenges associated with, COTS smartwatches and pedometers varies and affects their adoption due to contexts. Context encompasses an internal and external context [7, 20]. The internal context describes users' state and consists of internal parameters of human experience and activity [7] such as emotional responses (e.g. a decrease in user satisfaction and motivation [20]) and manifested behavioral responses such as an increase in errors, in reactions, or in inefficient or inappropriate activities [20]. The external context describes the environmental state and consists of proximity to objects [7], such as devices and their associated applications. To fill the research gap, the present study explores the divide in contexts (internal and external) that appears between target user groups (fit elderly users and younger users) while using the same COTS smartwatches and pedometers and participating in the same usability experiments. Thus, the research question (RQ) is: "Which internal and external contexts can obstruct the use of COTS smartwatches and pedometers among both elderly and younger users while using them as motivational tools for physical activities?" To answer this RQ, we will follow the contextual action theory (CAT) presented by Stanton et al. [20] and a usability evaluation method [10] to explain human action in terms of coping with technology within a context. The outcomes of this study identify challenges associated with wearables that need to be addressed by stakeholders, including device manufacturers, researchers, and caregivers, to enhance user experience, by understanding factors relating to internal and external context.

2 Related Work

Gregor et al. [6] classified the elderly into two categories: fit, who do not appear—nor would consider themselves—disabled, but whose functionality, needs, and wants are different to those they had when they were younger; and frail, considered to have one or more "disabilities," often severe, and who will have a general reduction in many functionalities and require general assistance from caregivers or relatives. Wojtek et al. [4] concluded that regular exercise by the fit elderly can have significant psychological and cognitive benefits for their health, which is consistent with the 2008 Physical Activity Guidelines for Americans [25]. Nelson et al. [15] and Tudor-Locke et al. [24] pointed out that regular physical activity can help both the fit and frail elderly in preventing and treating disease and reducing the risk of developing other chronic diseases, premature mortality, functional limitations, and disabilities.

The elderly population is the least physically active of any age group [25], and little is known about how they can be motivated to engage in physical activities to enhance their well-being and independent living. Siek et al. [21] found no major differences in performance between older and younger users when physically interacting using mobile computing devices and completing tasks that are not complex and don't require maximum cognitive effort. However, they found differences in terms of preferences, such as for font sizes. Fukuda et al. [5] compared younger and elderly users' web use and found differences related to navigational behavior due to the decline of elderly users' visual and fine motor functions. Meanwhile, Zhou et al. [30] concluded that ageing has significant negative effects on performance and accuracy.

3 Study

Methodological approach To enhance our understanding of commonalities and differences among elderly and younger participants using the same device in the same experiments, CAT and a usability evaluation method [10] form the foundation of this methodology. According to CAT, human behavior can be segmented into actions by assuming, attributing, or reporting a goal for the behavior [29]. Stanton et al. [20] pointed out that CAT explains human actions in terms of coping with technology within a context, with five phases associated with contextual actions: i) actual demands and resources are presented to the user, which comprise the design of the device, the tasks to be performed on the device, environmental constraints (e.g. time) and so on; ii) appraisal of those demands and resources by the actor; iii) a comparison of the perceived demands and resources; iv) possible degradation of pathways; and v) the effects of these responses on the interaction with the devices.

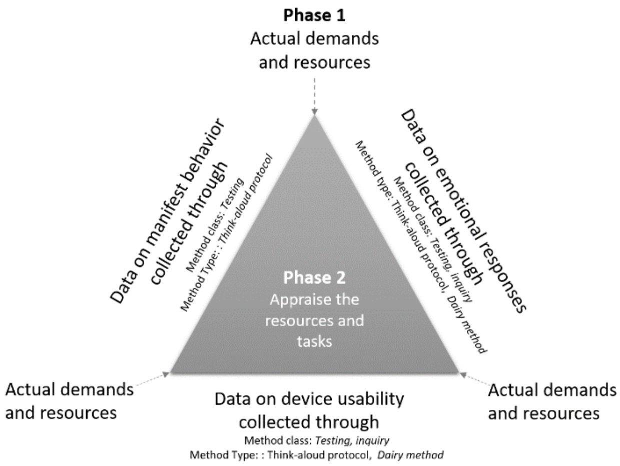

Fig. 1. Methodological Approach, image adapted from [28]

The type of internal and external data we gather from action is also dependent on the data-gathering procedures [29]. Therefore, we applied a usability evaluation method composed of a series of well-defined activities to collect data related to the interaction between the end user and device characteristics to determine how the specific properties of a particular device contribute to achieving specific goals, as shown in Fig. 1. We applied two (testing and inquiry) of five method classes (testing, inspection, inquiry, analytical modeling, and simulation) proposed by Ivory et al. [10]. Under “testing,” a “think-aloud session” was conducted, where an evaluator observed participants’ actions (i.e. interacting with the device and performing the task) to determine various usability challenges and witness users’ emotional responses (e.g. a decrease in user satisfaction and motivation [20]) and manifested behavioral responses (e.g. an increase in errors, in reactions, or in inefficient or inappropriate activities [20]). Under “inquiry,” participants reflected on their emotional and behavioral responses, and the effect those responses had on their use of the devices and associated applications, using a method type “diary”. **Participants.** The experiments were carried out in Finland with two age groups (younger than 60 and older than 60) and three different target user groups (students, university staff, fit elderly adults older than 60). Of the sample of 34 participants, 21 were younger or middle-aged, had relatively substantial technological knowledge, and had a positive view of using technology in their daily lives. The second group of 13 were fit elderly participants who were living independently and keen to use new technology to improve their well-being; this group was recruited through direct contact and networking. Members of both groups were at different health-behavior-change stages, as described by the Transtheoretical model (TTM) [18]: pre-contemplation (younger (n=8), elderly (n=4)); contemplation (younger (n=7), elderly (n=3)); action (younger (n=1), elderly (n=2)); and maintenance (younger (n=5), elderly (n=4)). The Lappeenranta University of Technology’s ethical committee approved the study. All participants were presented with an ethical review statement and informed consent (participants’ right to confidentiality, risks, data storage, the use of anonymized data, voluntary participation, no health-related data collected), and a signed consent form was obtained in return. **Procedures and tasks.** In phase 1 (see Fig. 1), we presented the actual demands and resources to the participants, which consisted of:

- Device presentation: Functioning wearable COTS smartwatches (Apple Watch, Samsung Watch) and pedometers (Misfit Shine 2, Fitbit Charge 2, and Polar A360) were presented to help us to explore the significance of various types of data for future design, as noted by Kanis [11]. These devices were selected based on market availability. No requirements were provided for device selection.
- Timeline: Participants were asked to participate in two one-hour controlled environment sessions (i.e. first meet-up session and final meet-up session), with four weeks of everyday device use between the sessions in a semi-controlled environment.

Experimental tasks: During the first and final meet-up sessions, we assigned experimental tasks (see Appendix A[1]) to be performed to test usability and its effect on participant’s emotions and behavior. Usability is one of the most important aspects for the success of any technological product [17], and it has positive correlations with three motivation measures: attention, relevance, and satisfaction [8]; participants’ interaction with the device can determine how its specific properties can affect their emotional and behavioral responses. During both sessions, participants were asked to follow a “think-aloud” protocol while performing the presented tasks. In the semi-controlled environment, participants were asked to i) use devices in real conditions and ii) complete an open-ended questionnaire in their diaries regarding the devices and associated applications, including any issues they faced or change in the levels of motivation to conduct physical activities, or any other issue they experienced. The aim was to make participants comfortable using the device and to gather data on their emotional and behavioral responses.

[1] https://doi.org/10.5281/zenodo.832159

In phase 2 (see Fig. 1), consent to collect and use data was presented prior to asking both sets of participants to appraise the resources and tasks set in phase 1. This allowed participants to understand their own perceived demands and resources in using the COTS smartwatches and pedometers. Their appraisal reflected the possible degradation of pathways (i.e. emotional responses and behavioral responses). The effects of these responses on the interactions with the devices were gathered from the participants through diary entries. From this data, we identified commonalities and differences in terms of external and internal contexts.

4 Results

In this section, we synthesize the findings and emphasize commonalities and differences, particularly regarding internal and external contexts (see[2] for Matrix of Study).

C1 Internal Context

C1.1 learning new behavior. Both target groups had to learn new behaviors, such as remembering to charge the device, which affected their daily use of the device. One younger participant stated, "Remembering to charge the device was an issue. I couldn't wear the device because I forgot to put [it] on to charge." Similarly, an elderly participant said, "I didn't put the watch on in the morning, since I took a shower. After that, I forgot to put it on completely." Some general confusion occurred during the evaluation among elderly users when they had to switch between using the external devices and the smartwatches and pedometers. One elderly participant with a Fitbit Charge 2 reported, "Why can't I see my sleep data on the device, while I can see it on my smartphone?" Similarly, another elderly participant noted, "I really can't remember which data I can see on my pedometer and on my mobile phone." However, the younger participants made no such comments.

C 1.2 Meaning of technology and its usefulness. During the first activity, it was surprising to see i) color of the device and design and ii) "sleep," "number of steps," and "calories burnt" data being more important than other pedometer/smartwatch functionalities among elderly participants. For example, one elderly participant stated, "I am so excited to see how much I walk a day." Another said, "I just need the band that measures my sleep." However, younger participants placed importance on advanced functionalities, such as receiving calls and texts and the ability to use various applications. One young participant stated, "I would like to have the smartwatch because I want to receive calls." Similarly, during the think-aloud session, in the midst of a lively discussion about privacy invasion by smartwatches and pedometers, there was a positive reaction from both elderly and younger participants regarding how health and physical activity-related data is collected, stored, and analyzed by pedometers and smartwatches. These findings illustrate that the elderly ascribe different meanings to technology than their young counterparts who grew up in a more technological environment [16]. We also found that participants from both groups formed favorable attitudes toward the technology if the devices were useful and relatively easy to utilize.

C 1.3 Transformation in motivation. Some young and elderly participants reported a decrease in motivation after a week of device usage, particularly non-physically active participants who were not willing to engage through data, content, and gamification. In addition, some participants

[2] https://doi.org/10.5281/zenodo.832167

lost motivation due to usability challenges. Indeed, most of the participants in the pre-contemplation or contemplation stage felt that the content did not motivate them, as highlighted in the following: “I see the same information every day; it didn’t motivate me to be more physically active.” However, participants in the action or maintenance stage [18] engaged though data, content, and gamification; one stated, “The number of goals that have to be achieved motivated me to take more steps.”

C 1.4 Transformation of perception towards device characteristics. It was astonishing that, in both groups, the participants’ requirements regarding the devices’ color and design changed within a week of using them. For example, one elderly participant stated, “I don’t like to wear it anymore, because it’s white in color and doesn’t match my outfit.” Conversely, one participant noted, “This color is perfect for me.” One younger participant stated, “I have to be very careful when I wear this device, because it’s too big,” while another younger participant stated, “I can’t go to sleep wearing this smartwatch; it’s irritating.” However, the same participants stated, when selecting the devices, that they looked nice. This change during transformation from the experimentation to habit stage reflects this statement from a previous study [23]: “Doing *something once was an experiment, doing it every day for a week was a habit, and doing it every day for a month was a lifestyle. When attempting to take some new action on a regular basis, one is confronted with many different aspects of the change—how it makes one feel over time” (p.131).*

C 1.5 Cognitive effort. Our findings revealed that previous knowledge of technological devices (e.g. computers or smartphones) does not decrease the cognitive effort required by the elderly in adapting to new devices. For example, there was an increase in cognitive needs while interacting with smartwatches and pedometers for the first time, and while conducting tasks such as account registration and connecting the pedometers and smartwatches to external devices. Further, increased cognitive effort led to frustration among participants. The participants stated, “I got this device but I don’t know where to start.” Similarly, two other participants said, “It says I have to first register my device, how do I do it?” and “I don’t have an email address, how can I use this?” Another elderly participant commented, “There are so many details to be filled.” Following the elderly users’ frustration, moderators carried out activities such as application installation on external devices, account registration, and connecting the device to Bluetooth.

Another striking observation of cognitive effort requirements occurred while restoring the device. When elderly participants were asked to restore the device during the think-aloud session (i.e. while returning the loaned device), they were unable to do so because of difficulties with navigation or the need for smartphones or computers. One elderly participant remarked, “I cannot find it on my Fitbit; it’s too confusing, do I really have to do this?” This result matched observations from a previous study [26], stating that “the ongoing advance of technology suggests that younger people’s experience with computers will not be a crucial advantage when they grow older.” Young participants also required greater cognitive effort while restoring device. One responded, “It looks like I need my phone to reset my device, which I forgot to bring.” Similarly, another participant commented, “I cannot remove this device from my account using [my] phone; it seems I have to download [an] application on my computer and do it manually.” Participants explained that they lacked practice in restoring devices, and did not have proper instructions for how to do so from the device manufacturer. It seems cognitive effort may occur among younger participants when complex tasks, coupled with a lack of information, are introduced to their busy life schedules.

C2 External context

C 2.1 Engaging factors. We found that the number of steps taken and data on exercise, heartbeats, calories burned, and sleep statistics were engaging factors for both young and elderly participants. Communication tools such as Skype, Slack, and Telegram were also engaging factors for younger participants.

C 2.2 Device Usability. The COTS smartwatches and pedometers used during the evaluation could be worn on wrists, necks, or ankles; thus, these devices were in close proximity to the bodies [22] of all participants. However, they reported that the device interactions did not satisfy their body shape, size, ability, and dimensions, nor their preferences, interests, and wishes [22]. *The subsequent section describes some commonly reported commonalities and differences in usability factors.*

Font size. Elderly participants complained that the text size on COTS devices with touchscreens was too small to read, stating for example, "I cannot read the text with my reading glasses, can I make this font larger?."

Interaction with touch screen. During the think-aloud sessions, some elderly participants had difficulties using the touchscreen on pedometers, smartwatches, and external devices due to dexterity problems. In addition, scrolling and navigating within the applications proved difficult for elderly participants. For example, a participant using a pedometer asked, "I pressed the screen on the device but it doesn't respond; is this device broken?" Another participant who used the smartwatch said that the "touchscreen reacts so fast when I press on it."

Interaction techniques. During the evaluation, elderly and younger participants regarded the push notifications and reminders differently. A younger participant reported, "I like the device because I could receive all notifications about calls and text data on my watch; I don't have to use my phone all the time." This comment reflected a statement from a previous study [14]: "Reminders are the most effective when delivered at the right location, at the right time and the right devices." However, an elderly participant stated, "Having all the notifications on my watch with vibration feels so irritating and like getting an electric shock." While the young group of participants found receiving notifications and reminders through COTS devices useful, their counterparts felt the opposite, which is in line with a previous study's finding [14] that "age might however influence the interaction techniques."

Reliability and accuracy. The data's reliability was a concern for both groups of participants. For example, one of the elderly participants reported, "It didn't record one of my afternoon naps. How can I rely on the sleep analysis data?" Similarly, a younger participant stated, "I had the device with me when I went to the fitness center, but there was no change in fitness activities." According to another younger participant, "Sometimes I feel the measuring data isn't accurate. For example, I was sitting and working, but the app shows I am resting."

Device connectivity. Connecting the wearables and the external device, and synchronizing the data using Bluetooth technology, were the most commonly reported usability challenges by both groups of participants. For example, one younger participant stated, "Connecting the phone with the watch, I had to turn on and off the Bluetooth all the time." An elderly participant reported, "I got an error on my application. My Charge 2 isn't syncing because my phone's Bluetooth is off, but the Bluetooth on my phone is on."

Battery: Both older and younger participants raised concerns about the battery. As one of the younger participants reported, "Using the watch is easy, but keeping track of the battery is a problem." Another participant stated, "The battery runs out quickly." Participants with an integrated battery (e.g. Misfit COTS pedometers) had usability advantages over the other smartwatches and pedometers, as there were no comments regarding battery issues. Elderly users reported that it was difficult to parallel the use of the application installed on the external devices and COTS pedometers without any display. One participant commented, "When I was walking and wanted to see how long I had walked, it was difficult to take out the phone and view data."

5 Discussion and conclusion

Here, we will discuss the results of the evaluation of both elderly and younger participants, present implications for practice, and reveal our research findings. In addition, we will offer suggestions for future work. This study involved a small number of participants in a limited geographic location, meaning the generalizability of the results may not be possible; thus, all stakeholders, including device manufacturers and application developers, should take the findings as suggestions rather than conclusive evidence.

The first finding showed that both the internal and external contexts had a cause-effect relationship with both target groups, with more commonalities than differences in terms of the internal context, especially regarding usability factors of the external context and the users' own perceptions of the devices. Therefore, it would be beneficial to integrate both contexts during the design of wearable devices and their associated applications. The data gathered from emotional responses and manifested behavior showed that the internal context can strongly influence any age group if the effect on the external context appears or vice-versa; it can obstruct the acceptance of COTS smartwatches and pedometers by changing an individual's motivation. Further, the higher the degree of external context (i.e. usability factors), the better the internal context.

The most common external context usability elements that affected the use of wearable devices included font size, interaction with the touchscreen, interaction techniques, and applications installed; these strongly influenced age-related deficits and are in line with previous studies [1]. Device connectivity, battery life, reliability, and accuracy were the most commonly cited common important internal factors, which also aligns with previous studies [27]. Further, these results may change, depending on the context in which individuals use COTS devices. Future studies should measure how quickly both the internal and external contexts that can obstruct device usage appear in large numbers within both target groups over a specified period, and both elderly and younger individuals could retain the COTS device after appearance of cause-effect relationships.

Interestingly, despite having all user engagement features, such as data, gamification, and content, on either wearable devices or external devices with associated applications, these extrinsic motivational factors did not have a long-term effect on physically inactive participants who were in either the pre-contemplation or contemplation stage. Hence, for a person to be physically active, intrinsic motivation must evolve on its own, while extrinsic motivation will only enhance intrinsic motivation. Further studies can implement self-determination theory to discover which influential factors might awaken the intrinsic motivation of individuals in the pre-contemplation or contemplation stages of behavior change.

First impressions of the devices were temporary for both groups, which likely faded based on the individuals' context of use and hierarchy of needs, whether cognitive or psychological. This finding led us to understand that a changed impression might affect the motivation to use the wearable device long term. Therefore, future work could develop guidelines that include the hierarchy of needs of both younger and elderly individuals based on the context of use of COTS wearable devices, which could help device manufacturers and application developers create sustainable COTS devices and associated applications

To understand the commonalities and differences between younger and elderly participants using the same COTS devices, we developed experimental tasks. The results found commonalities in terms of internal context in both participant groups, apparently due to both the effect and usefulness of the external context. Therefore, certain measures should be taken regarding the external context, such as including age-appropriate smartwatch and pedometer device characteristics to reduce the cause-effect relationship of the internal and external contexts. Users will then feel comfortable and develop a high degree of satisfaction, motivation, and enjoyment regarding these devices' usefulness. The new design could decrease manifested negative behaviors and emotional responses by increasing the acceptance of COTS smartwatches and pedometers. For the elderly, appropriate font sizes and better interaction with the touchscreen and associated applications, as based on their hierarchy of needs, could improve their manifested behaviors and emotional responses and increase their satisfaction, leading to them adopting the devices for longer. Our future work will investigate: i) how the internal and external contexts differ when secondary users, such as caregivers or relatives, use COTS smartwatches and pedometers on behalf of frail elderly users; ii) the strong bond between the two contexts through an empirical study; and iii) differences caused by geographical area, gender, and/or culture when repeating the same study with a larger sample of participants.

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Publication III

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Categorization framework for usability issues of smartwatches and pedometers for the older adults

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Categorization Framework for Usability Issues of Smartwatches and Pedometers for the Older Adults

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Abstract. In recent years various usability issues related to device characteristics of quantified-self wearables such as smartwatches and pedometers have been identified which appear likely to impact device adoption among the older adults. However, an overall framework has not yet been developed to provide a comprehensive set of usability issues related to smartwatches and pedometers. This study used a two-stage research approach with 33 older participants, applying contextual action theory and usability evaluation methods both to determine perceived usability issues and to formulate a usability categorization framework based on identified issues. Additionally, we prioritized the predominant usability issues of smartwatches and pedometers that warrant immediate attention from technology designers, the research community, and application developers. Results revealed predominant usability issues related to the following device characteristics of smartwatches: user interface (font size, interaction techniques such as notification, button location) and hardware (screen size); and of pedometers: user interface (font size, interaction techniques such as notification, button location, and tap detection) and hardware (screen size).

Keywords: Wearables · Usability · Older adults · Framework
User interface · Elderly · Quantified self-technologies · Smartwatches
Pedometers

1 Introduction

Commercially off-the-shelf (COTS) quantified-self wearable devices such as smartwatches, pedometers, and associated applications are seen as a potential medium to: (i) support health self-management among older populations [16]; and (ii) improve physical activities through "Quantified Self" [50]. Despite the potential, compared with their younger counterparts, many older adults have challenges in adopting such

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wearable device categories [7]. Previous researchers and practitioners have identified that such challenges are due to: (i) usability issues related to complex interfaces and extensive functionalities [18] that have not been designed to suit them [31]; and (ii) age-related changes in cognitive and physical capabilities [39]. Tedesco et al. [51] state, “wearable technologies are mainly designed to attract a young, sporty and technical affine group of adults.” This is a setback facing the older adults when seeking to take advantage of wearables.

To offset such challenges, research has been emerging on identification, evaluation, and analysis of usability issues faced by the older population while using smartwatches and pedometers [9, 22, 43]. Researchers have identified usability issues including button size, screen size, interaction with the screen, iconography, battery, reliability, and accuracy [39, 40, 43]. However, these previous lack an overall framework to provide a comprehensive set of identified usability issues related to specific wearable device categories. This can keep researchers, industry manufacturers, and wearable application developers from understanding most important usability issues that need to be rectified in order to improve adoption of smartwatches and pedometers by the older adults.

While previous studies (see Table 1) have provided insight into various aspects of the usability issues related to wearable devices that the older adults face, they do not directly answer our research questions.

RQ1: What usability issues, related to device characteristics of smartwatches and pedometers, can obstruct the motivation of the older adults to adopt these devices, and how have the issues been categorized? **Rationale**: Identify the range of usability issues of each device category that affect adoption. This enables creation of an overall framework to provide a comprehensive set of usability issues for each device category.

RQ2: What usability issues, related to device characteristics, have a sizable impact on usability needs for smartwatches and pedometers and thus warrant immediate prioritization by technology designers, the research community, and application developers? **Rationale**: Prioritize the predominant usability issues that need immediate potential solutions to improve adoption of smartwatches and pedometers among older adults.

The aim of this study is therefore to: (i) explore the usability issues of specific wearable device categories, i.e. smartwatches and pedometers, by reviewing the literature and applying Contextual Action Theory (CAT) [49], and the Usability Evaluation Method [23] to this study’s set of usability experiments among older adults users; and (ii) empirically validate quantitative data gathered from older participants in order to prioritize the predominant usability issues of each device category requiring immediate potential solution. The presented framework and empirically validated result may be valuable for researchers, industry manufacturers, and wearable application developers to improve smartwatches and pedometers for the older adults.

2 Related Work

In order to answer the above research questions, this section details previously identified usability issues faced by older populations while using COTS wearable devices. Table 1 summarizes recent literature on usability issues associated with wearable devices and their associated applications.

Table 1. Usability issues identified by previous researchers.

Citations	Usability issues	Technologies
[40]	Screen size, icons, tapping detection	Web-camera, an accelerometer, and a small Pico projector
[3]	Screen size, font size, and small buttons.	Smart bracelet
[16]	Data accuracy, wearability	Activity trackers
[57]	Interaction with application, resolution of screen	Head mounted devices
[39]	Typography, Data accuracy	Activity trackers
[47]	Font size, icon & button, screen size	dWatch
[48]	Color contrast	smartwatch
[36]	Alert sound from device	Prototype wearable device with sound and haptic feedback
[43]	Location of the button, battery life, design, shape, colour, wearing position, an application using external devices.	Activity trackers
[22]	Typography, button	Wrist device
[41]	Display, battery, comfort, aesthetics	Activity trackers

3 Research Design Process

To answer the research questions, we propose a two-stage research process (see Fig. 1) to measure the issue variables and compare their influence on motivation to adopt smartwatches and pedometers. This study was conducted in two stages, namely Identifying and Prioritizing (see Fig. 1). During the identifying stage, we performed a usability evaluation of devices with older participants to determine perceived usability issues and to formulate a usability categorization framework based on identified issues, whereas in the prioritizing stage, we collected and organized the predominant usability issues into a categorization framework.

3.1 Identifying Stage

The main purpose of this stage was to identify the number of times that usability issues during usability evaluation of devices with older participant throughout the study. First, a general presentation and requirements for participation were provided to participants,

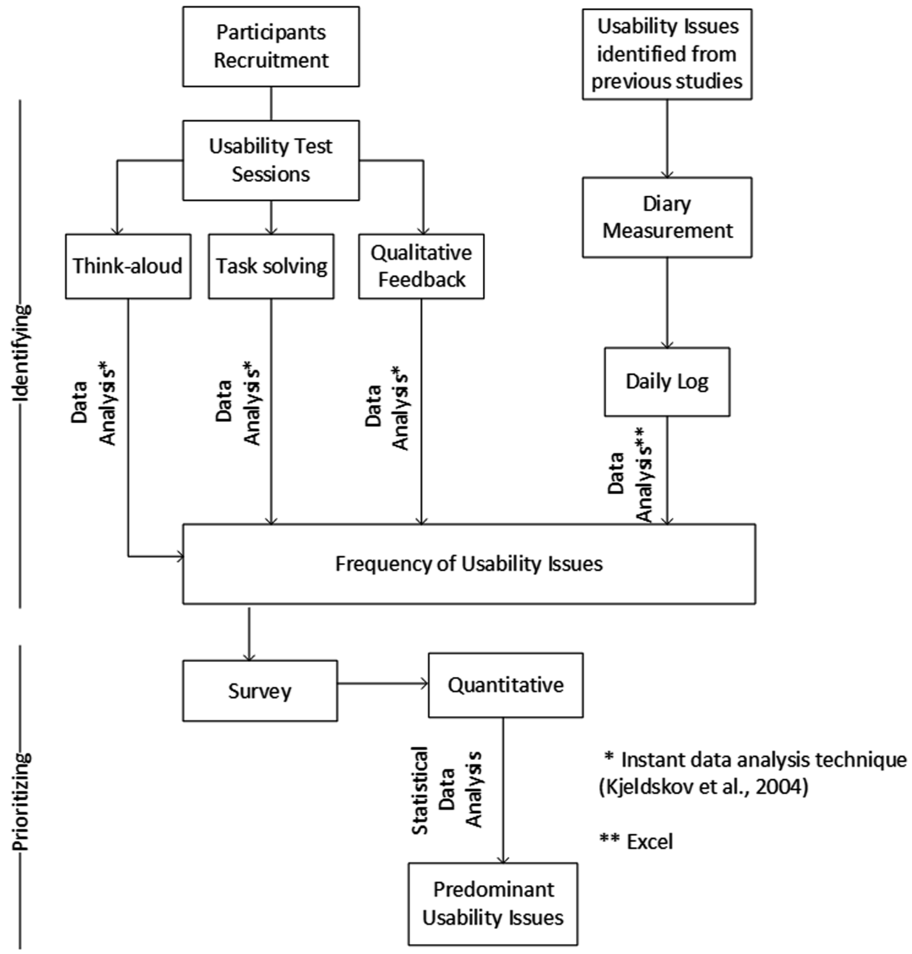

Fig. 1. Flow diagram of research process

followed by a recruitment form, which collected preliminary participants' information such as age, technological knowledge, current use of external devices like smartphones, and consent. Alshamari and Mayhew [2] suggest performing usability tests so that participants can be classified based on their level of systems experience, other individual characteristics. Black [5] point out, "Ideally participants should fall in the middle of the qualification spectrum to ensure that the tests do not result in excessive false positives or false negatives" (p. 7). Based on this suggestion, data obtained from the recruitment form was analyzed and used to select participants for the evaluation study. All participants in the study were presented with an ethical review statement and aspects of informed consent (i.e. participants' right to confidentiality, risks, data storage, the use of anonymized data, the voluntary nature of participation, that no health-related data would be collected), and in turn signed consent forms were obtained. The ethical committees of the Lappeenranta University of Technology and California State University, Long Beach, approved the study.

Thirty-three older participants from Finland and the U.S., with a mean age of 62.46 years (SD = 2.295), were voluntarily recruited to participate in the usability test sessions. This sample size is sufficient based on the recommendation [33] that a group size of 3–20 participants is typically valid, with 5–10 participants demonstrating a sensible baseline range. Participants from both countries were living independently and were interested in using new technology to improve their well-being [27]. The contextual action theory (CAT) explained by Stanton [49] and Usability Evaluation Method (UEM) presented by Ivory and Hearst [23] were applied as foundational methodologies in evaluating COTS wearable devices in this study's set of usability experiments among older users. Stanton et al. [49] states that CAT explains human actions in terms of coping with technology within a particular context and that five phases are associated with contextual actions.

First phase: *Presentation of actual demands and actual resources to participants, consisting of the device, the tasks to be performed on the device, environmental constraints (e.g. time), and so on.* Firstly, participants were presented with functioning wearable COTS devices, i.e. smartwatches and pedometers, to help explore the significance of various types of data for future design, as pointed out by Kanis [26]. No requirements were provided for device selection. Secondly, participants were presented with several experimental tasks (See Appendix A[1] for presented experimental tasks) along with a timeframe, namely two one-hour, controlled environment sessions (i.e. the first and final meetings). As stated by [11], "the idea of momentary memory implies that we don't store our experiences in perfect experimental and temporal fidelity, rather memories are formed from snapshots of the representative moments in an experience" (p. 90). Therefore, participants were asked to use each category of device under real conditions every day for the two weeks between the meet-up sessions (i.e. in a semi-controlled-environment) and to capture the usage in a daily log using the diary method. No specific pre-defined activities such as put on/take off, charge, walk, eat, rest, sleep, or exercise [24] were specified. Participants were requested to return to another one-hour, controlled environment session to return the device and test usability. Finally, participants were told that upon completing the semi-controlled usability evaluation, they would be asked to respond to a survey.

Second phase: *Appraisal of those demands and resources by participants.* As stated by [25], the primary appraisal of an interaction event can result in a negative emotional response such as anxiety or frustration. To reduce such negative emotional response from participants, participants were asked to appraise the demands and resources presented during the first phase, so that their stated perception might help to redirect negative emotional response away from the experiment itself [21].

Third Phase: *Comparison of perceived resources with perceived demands.* In this phase, participants were asked to compare their own perceived resources with

[1] https://doi.org/10.5281/zenodo.832159.

perceived demands to determine any imbalance related to the specific properties of smartwatches and pedometers, which could affect participation in the study [49].

Fourth Phase: *Possible degradation of pathways.* Participant appraisal and comparison may reflect the potential for degradation of pathways, i.e. emotional responses and behavioral responses. Such emotional responses may include decreases in user satisfaction and motivation, while potential behavioral responses include an increase in errors and inefficiency.

Fifth Phase: *Appraisal of the effects of these responses on device usage.* The effects of these responses on participant interaction with the devices were gathered through the daily log, which included several kinds of measurements.

Measurements of identifying usability issues
The search strings "*usability issue*", "smartwatch*", "pedometer*", and "wearable*"* were conducted utilizing the digital databases IEEE Xplore, the ACM Digital Library, Science Direct, and Web of Science. After refining the results from the digital databases, the final lists of usability issues were derived from [3, 16, 37, 39, 40, 43, 48].

Participants were asked to keep a diary of their experiences. The diary included several kinds of data, such as: (i) whether devices were worn (*if not, why*); (ii) which activities were undertaken (*e.g. walking, hiking, running, cycling, etc.*); (iii) whether device use motivated physical activity (*and why/why not*); (iv) which applications were used (*if not used, why*); (v) usability issues (*e.g. screen size, icons, interaction techniques, tap detection, font size, button location, data accuracy, screen resolution, device weight, device shape, device size, lack of screen, battery life, and the option to add any missing usability issues*); and (vi) additional comments.

For the purpose of analysis, the usability issues for both device categories (smartwatches and pedometers) have been categorized into two components: hardware and user interface. Specifically, the hardware concerns involve issues related to external look and feel and to internal components such as sensors, processor, memory, power supply, and transceiver [1, 32]. User interface involves issues with various parts through which users interact with the device [1]. Furthermore, the user interface component has been sub-categorized into input and navigation mechanism, based on the work of [1].

The first set of data gathered from the first and final meet up sessions was analyzed using the instant data analysis technique proposed by [29]. The qualitative data obtained from diaries were analysed based on the data analysis framework presented by [10], "which offers an eclectic approach for qualitative diary data analysis" (p. 1514).

The final data set of identifying stage derived from (i) the first and final meet-up sessions and (ii) four weeks of daily logs by the older participants data. The analysis was done using a Microsoft Excel spreadsheet, wherein reported usability issues were assigned (1) to understand the number of times they were reported by participants during the entire evaluation period. This analysis enabled understanding of the breadth and occurrence of reported usability issues in order to find out the most frequent usability issues that could be used as the basis for quantitative analysis.

3.2 Prioritizing Stage

The main purpose of this stage was to collect quantitative data from the participants using an immediate prioritization scale. This study's immediate prioritization scale utilized most usability issues reported by older participants during (i) the usability test sessions (first and final meet-ups) and (ii) four weeks of participants' daily logs. In a survey, participants were asked to rate on a 7 Likert scale (0 = strongly agree to 7 = strongly disagree) how much the identified usability issues correspond with the motivation to adopt. Qualitative data from the survey was analyzed separately in an Excel spreadsheet, using the statistical data analysis language R and the descriptive statistical analysis functions available in R core [42] and the psych library [45].

Data analysis was performed with multiple linear regression [12] in order to test hypotheses to see which variables most influenced the motivation to use the devices. Multiple linear regression modeling was performed using the R core statistics library [42], following the methodological guidelines set out by Weisberg [55, 56] and Laerd Research [30]. Additional multiple linear regression diagnostics were performed using the following R libraries: mctest (multicollinearity diagnostics) [52], MASS (standardized residuals) [53], car (Durbin-Watson Test, outlier testing, Spread-Level and QQ plots) [17], and lmtest (Breusch-Pagan test) [59].

3.3 Results

After analyzing sets of data from the identifying stage (i.e. the first and final meet-up sessions and four weeks of daily logs by the older participants data), we identified 13 usability issues common to pedometers and smartwatches and categorized them into a framework of hardware or user interface related issues (see Fig. 2), with the lack of screen being the only additional issue unique to pedometers. Interaction techniques were a multi-faceted category under user interface. Participants reported that interaction techniques can cause usability issues despite their intended functions of providing feedback to the user that can be perceived without continuous visual attention [19] and engaging users through quantitative or qualitative understanding of underlying data [6] through notification. For example, in this study participants reported usability issues caused by interaction technique sub-categories of both feedback (tactile and kinesthetic) and notification. In addition, on both smartwatches and pedometers, older participants reported issues with data accuracy and connectivity as sub-categories under hardware sensor issues, which was in line with previous research [38, 43].

To understand the important usability issues, we further analyzed the data based on number of times usability issues were reported by the participants during the entire evaluation period. Figures 3, 4, 5 and 6 show the mean and standard deviations of the scores (frequency) of the usability issues related to hardware and user interface and its sub components for both smartwatches and pedometers. This outcome indicates that, screen size, interaction techniques (i.e. feedback and notifications), font size, tap detection, and button location were the most influencing.

Therefore, we focus on screen size, typography (i.e. font size), tap detection, and interaction techniques (i.e. feedback and notifications) and button location to validate and enhance our understanding of the most frequent issues with device characteristics.

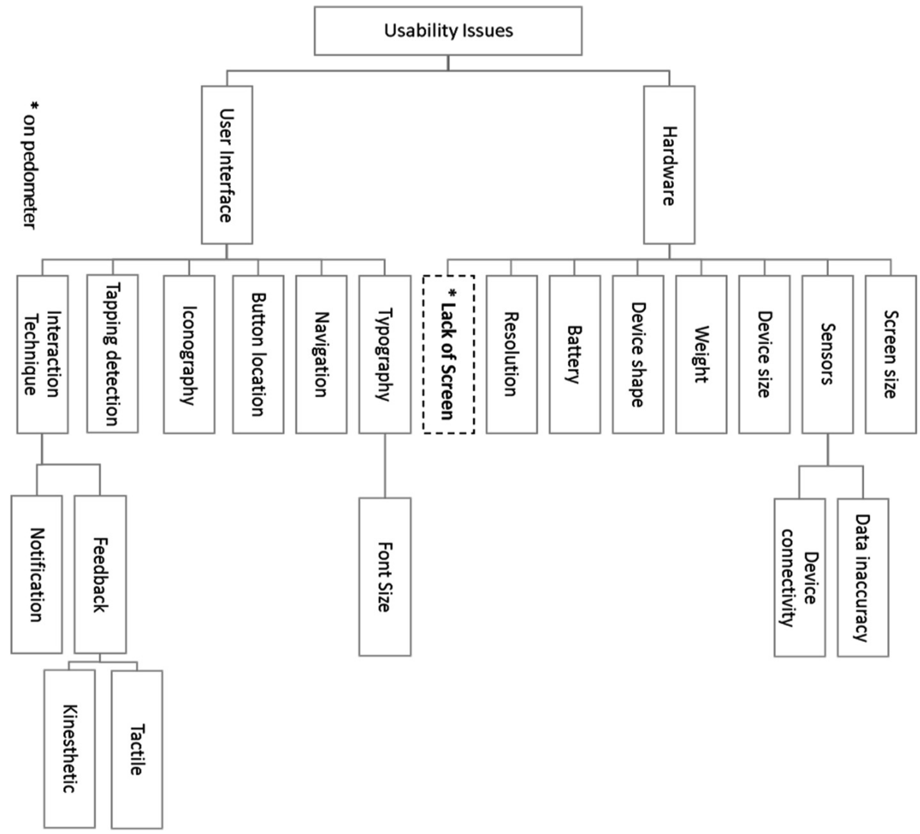

Fig. 2. Categorization framework of usability issues of pedometers and smartwatches identified from the identifying stage of this study.

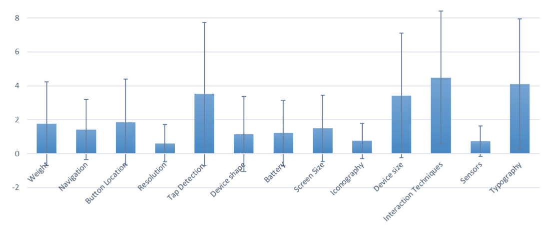

Fig. 3. Descriptive analyses of usability issues related to hardware and user interface for smartwatches

It is in this way that we pursue our proposed process (see Fig. 1) to measure the issue variables and compare their influence on motivation to adopt smartwatches and pedometers. The following section presents the variables used in the statistical research model and hypotheses formulated based on the variables.

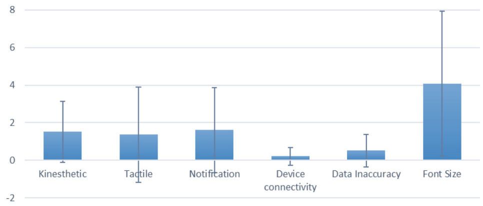

Fig. 4. Descriptive analyses of usability issues related to sub components of hardware and user interface for smartwatches

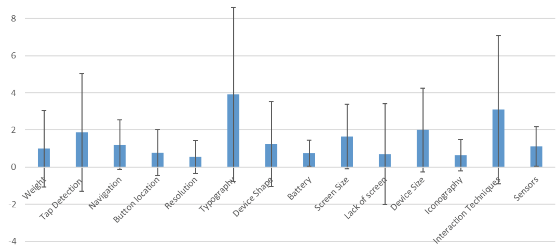

Fig. 5. Descriptive analyses of usability issues related to hardware and user interface for pedometers

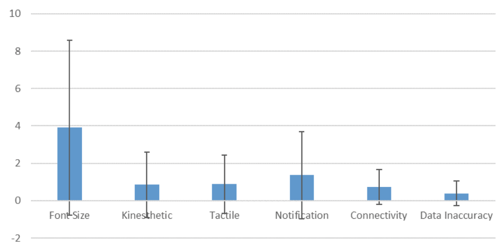

Fig. 6. Descriptive analyses of usability issues related to hardware and user interface and its sub components for smartwatches

3.4 Validity of the Measurement

The hypotheses were tested by creating multiple linear regression models from the issue variables that were most frequently cited as affecting usability. Separate models were created for smartwatches and pedometers. First, a multiple regression was run to predict motivation to adopt smartwatches from screen size, font size, wrist feedback, finger feedback, touch controls, interrupting distractions, and button location perspectives. A second multiple regression was run with those same variables in order to predict motivation to adopt pedometers. In both models there was linearity, as assessed by a plot of studentized residuals against the predicted values. There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.86 in the first model and 2.48 in the second model. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values and the studentized Breusch-Pagan test. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1 and VIF testing. There were no studentized deleted residuals greater than ±3 standard deviations, outlying leverage values, or values for Cook's distance above 1. In the second model two outliers were removed as guided by the regression model diagnostics. The assumption of normality was met in both models, as assessed by a Q-Q Plot.

The first multiple regression model statistically significantly predicted motivation to adopt smartwatches, $F(7, 23) = 3.733$, $p < .01$, adj. $R2 = .39$. Some variables added statistically significantly to the prediction, confirming part of the hypotheses. Regression coefficients and standard errors can be found in Table 2.

The second multiple regression model statistically significantly predicted motivation to adopt pedometers, $F(7, 23) = 3.74$, $p < .01$, adj. $R2 = .39$. Some variables added statistically significantly to the prediction, confirming part of the hypotheses. Regression coefficients and standard errors can be found in Table 3.

Table 2. Multiple Linear regression result for smartwatches

Coefficients:	Estimate	Std. Error	Significance
(Intercept)	8.9416	2.1399	***
Screen size	−0.6115	0.2145	**
Typography (Font Size)	−0.4249	0.1582	*
Button location	−0.5160	0.2229	*
Tap detection	0.1213	0.1518	
Interaction techniques			
Notifications	0.4052	0.1564	*
Kinesthetic	0.1791	0.2432	
Tactile	−0.2958	0.1640	

Table 3. Multiple Linear regression result for pedometers

Coefficients:	Estimate	Std. Error	Significance
(Intercept)	8.7454	2.3928	**
Screen size	−0.5961	0.2145	**
Typography (Font Size)	−0.5139	0.1808	**
Button location	−0.4464	0.2433	
Tap Detection	−0.4272	0.1518	*
Interaction techniques			
Notifications	0.7475	0.2122	**
Kinesthetic	0.2464	0.2620	
Tactile	−0.0801	0.1640	

4 Discussion

The focus of this section is to discuss the results obtained during the identifying and prioritizing stages of this study, based on interpretation and exploration of the retrieved data. The categorization framework explains there are not major differences between the identified usability issues related to smartwatches and pedometers. As both wearable device categories consist of similar features, the only identified difference was due to the pedometer's lack of screen. The main advantage of the categorization framework is that it summarizes and structures usability issues of smartwatches and pedometers identified in previous research and during the identifying stage of this study. If one finds additional usability issues of smartwatches and pedometers in the future, the tree within the framework could be expanded.

During the identifying stage, older participants reflected *three kinds of device usage problems* on both smartwatches and pedometers: short-term, occasional, and long-term issues. Short-term issues, for example those caused by hardware, such as weight, device shape, resolution, device connectivity, sensors (data inaccuracy), and battery, as well as those associated with user interface, such as button location, and iconography, lasted relatively briefly (i.e. the first few days of the study, when participants had their first interactions with the devices) and had minimal effect on device usability. For example, battery could be classified as a short-term issue, because within a few days, participants adjusted to charging the device regularly. Findings regarding short-term usage issues reinforce the statement from [43] that with "increasing time participants were more and more confident in the battery life and thereby decreased the number of charging cycles as well as charged the tracker later and thereby with a lower battery status" (p. 1414). Other identified usability issues, for example those caused by hardware, such as screen size and device size, and by user interface, such as tap detection, font size, interaction techniques, and navigation, appeared either occasionally or throughout the study.

Although participants experienced certain usability issues throughout the study, there was *zero drop-out*. As stated by [25], "Facing an obstacles during the use of technology doesn't necessarily lead to frustration because in the face of goal-incongruent events, the user may still cope with the arising emotions" (p. 73). In practice, the smartwatches and pedometers may have: (i) provided immediate accessibility [46]; and/or (ii) acted as facilitators of behavior change for the older adults due to motivational aspects and objective control [43]. For example, participant feedback indicated that devices facilitated motivation by providing "daily steps," that it was "fun to meet challenges," and that devices "made me aware of sleep patterns" and "aware to move and not to be sedentary for a long period of time." In addition, this study also found though qualitative feedback that users had a positive intention to use devices that are expected to work well, have good design, wearability, and do not raise privacy concerns.

Hypothesis testing revealed that *small screen size* is the main device characteristic related to both smartwatches and pedometers that *needs immediate prioritization* to improve adoption among the older adults. Supporting previous research, this study further reveals that screen size plays a significant role in adoption of wearable devices, in that small screen size restricts user behavior [20] in their ability to move beyond the fixed functionality of a tradition watch and to support a variety of apps [58] through input and output capabilities [20, 44, 58]. As perception of utility has been found to be of great importance for the older adults [46], options to address screen size include creating smartwatches and pedometers with: (i) non-graphical technology designs with led arrays [44] (ii) a larger screen by curving the screen around the wrist [58]; and (iii) the novel gaze interaction technique that enables hands-free input on smartwatches [15], all of which provide better user experience and can lead to a positive opinion from referents, so that older users actively build a positive attitude towards adoption of devices.

In addition, hypothesis results demonstrated that *font size was statistically significantly important* for the older adults in both categories of wearable devices. However, font size had higher significance for pedometers than for smartwatches. Pedometers currently have very limited amounts of screen space, and their visual displays can easily become cluttered with information and widgets [6]. Furthermore, the human eye reads an individual line of text in discrete chunks by making a series of fixations (i.e. brief moments, around 250 ms, when the eye is stopped on a word or word group, and the brain processes the visual information) and saccades (i.e. fast eye movement, usually forward in the text around 8-12 characters, to position the eye on the next section of text) [8]. One study [14] asserts that "individual characteristics such as age, impairments may affect movement of the eyes." Thus significantly longer fixations for smaller fonts [4] on the pedometers may have adversely differentiated the result between two device categories.

Both smartwatches and pedometers provide individuals with various types of *tailored and quantified self-data* supporting daily physical activities, wherever they are and at any time, [28] through notification in the form of audio, visual, and haptic signals [34]. However, results from hypothesis indicate that the older adults are more sensitive towards the disruptions caused by all push notifications. Current smartwatch and pedometer user interfaces may demand users' attention at inopportune moments, [34] e.g. without knowing which context the user is in and featuring repetitiveness in the notification content [35]. Other prioritized, predominant usability issues were button location on smartwatches and tap detection on pedometers. The result related to button location was in line with a previous study [20] indicating that pointing error rate is significantly affected by button size and location on the UI as the index finger taps on a device. However, the tap detection were significantly higher for pedometers, it may be because of (i) variance in touch screen technologies used between two device categories. For example, smartwatch devices evaluated in this study used display with the force touch technology and the pedometers with the monochrome Liquid Crystal Display (LCD) touch screen which has different ways of detecting if user is touching the screen. As tap detection has been found to be of great importance for the older adults with regards to pedometers, options to address improving the touch screen with new sensing technology [54] which could detect how much pressure is been exerted by the older users and display the output based on measurements; (ii) characteristics of older participants. For example, Culen [13] state, "age-related changes constitute challenges of touch and grip" (p. 464).

The above discussion highlights prioritized needs for immediate attention and further investigation by technology designers, the research community, and application developers regarding the predominant issues older adults face when using smartwatches and pedometers. We see two lines of immediate future work: First, the *effect of timing and frequency* using intelligent, sensor driven and/or pre-determined, static notification [35] could be analyzed to gain insight into how the older adults prefer to receive push notifications of "quantified self" data from their smartwatches and pedometers. The findings may help in the design of effective user interfaces to reduce usability issues caused by push notifications and thereby increase device adoption. Second, through a longitudinal study using eye-gazing techniques, future research should look into *which typographical variables* such as font size and font type [4] are most effective for older users of smartwatches and pedometers.

5 Conclusion

This study presented a categorization framework for usability issues of smartwatches and pedometers. Additionally, this paper used multiple linear regression modeling to prioritize the issues predominantly reported during the first 'identifying' stage of the study. "Prioritizing" stage of the study found for (i) pedometers issues of *screen size, Typography (i.e. font size), interaction technique (i.e. notification), and tap detection;* and (ii) smartwatches issues of *screen size, Typography (i.e. font size), interaction technique (i.e. notification); button location* warrant immediate attention by technology designers, the research community, and application developers to increase device adoption among the older adults. The main limitation of this study is the relatively small and non-random sample, meaning the results cannot be generalized. This study can, however, be used as a basis for further studies to: (i) investigate how prioritized predominant usability issues differ when secondary users, such as caregivers or relatives, use smartwatches and pedometers on behalf of frail older users; (ii) discover how a categorization framework of usability issues related to smartwatches and pedometers varies across different cultures; (iii) provide information that can serve as a basis for improving adoption by enhancing device characteristics; and (iv) identify the prioritized predominant usability issues among higher age and frail older users.

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Publication IV

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Crafting Usable Quantified Self-wearable Technologies for Older Adult

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Abstract. Commercially off-the-shelf (COTS) quantified self-wearable technologies (QSWT) have enabled younger individuals to adopt a measurable living style [49] through the collection of "quantifiable data". However, the adoption of wearables remains lowest among the older adult, and the question of what is holding adoption back remains. The purpose of this study is to: (i) explore and present the device characteristics of smartwatches and pedometers that affect the adoption of wearables across different cultures; (ii) study country-specific older adult's importance weights on identified issues; and (iii) provide informal usability guidelines for manufacturers, researchers, and application developers. The results revealed that the usability issues such as screen size, tapping detection, device size, interaction techniques, navigation, and typography were some of the reasons for the low adoption of wearables among the older adult. Further, device and screen size were significantly more essential for the Finnish compared to US older adult participants, demonstrating that culture might influence the perception of some device characteristics.

Keywords: Wearables · Usability · Culturability · Older adult Framework · User interface · Elderly · Quantified self-technologies Smartwatches · Pedometers

1 Introduction

Quantified self-wearable technologies (QSWTs), such as commercial off-the-shelf (COTS) products including smartwatches and pedometers, and their associated applications have enabled individuals to adopt a measurable living style [49] through the collection of "quantifiable data," such as sleep patterns, calorie intake, and steps taken. However, smartwatches and pedometers have the lowest adoption of wearables among the older adult[1] to enhance quantifiable data practices [38] due to: (i) various design dimensions, complex interfaces, and extensive functionalities [14] or (ii) perceptions of

[1] http://www.emarketer.com/Chart/US-Wearable-User-Penetration-by-Age-2017-of-population-each-group/202360.

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being unable to learn new things because of insufficient cognitive capability, vision, or motor function [11]. Almost none of the QSWTs available on the market in their current form are suited for the older adult [39]. For example, Angelini et al. [3] reported that most interfaces proposed to date for smartwatches offer limited accessibility to older adult: the screens are small, the information is often shown with small characters, and small buttons are used to navigate the interface [3].

Even though the low adoption of wearables has become increasingly visible, there is still a lack of (i) research on older adult experiences with the adoption of wearing smartwatches [6]; (ii) knowledge about what features the older adult desire when using COTS smartwatches and pedometers, which is critical for wearable device and service design [19]; and (iii) knowledge of usability issue variances related to cultural dimensions, leading to non-adoption among the older adult. Angelini et al. [3] show that one reason could be that designing for the older adult implies several additional challenges concerning products with a generic target; in addition, in our society, "older adult" are classified generally as a single separate group. Furthermore, country-specific older adult importance weights given to the specific cause of non-adoption from the perspectives of device characteristics may vary because of cultural origins and different traditions, custom, ethics, and values [9, 44]. This is a setback for the older adult in using and taking advantage of COTS QSWTs. Therefore, the research question (RQ) is posed to obtain a more comprehensive overview of the gap:

RQ: What should be considered by technology designers and the research community to enhance the device characteristics related to QSWTs and to improve older adult adoption traits? Rationale: This provides information that can serve as a basis for improving adoption by enhancing device characteristics.

To answer the research question, we identify which types of usability issues related to COTS QSWTs persist across different cultures. The study begins with previously identified reasons associated with the adoption and withdrawal of wearables by the older adult, and it continues with identifying the current usability issues of various stages evaluated using contextual action theory (CAT), as presented by Stanton [43], and a usability evaluation method from Ivory and Hearst [18]. Second, we apply the Mann–Whitney U test [48] (also known as the Mann–Whitney Wilcoxon Test) to analyze country-specific differences in older adults' identified usability issues. Third, we provide informal usability guidelines for technology designers, researchers, and application developers to broaden the scope of their designs and interfaces for upcoming devices and applications to provide a richer end-user experience so that wearables can also be adopted by the older adult.

2 Related Work

Related work on crafting usable quantified wearables falls within two areas: a focus on reasons associated with the adoption and withdrawal of wearables by the older adult and a focus on "Culturability" to understand the importance of the relationship been culture and usability [5].

Wearable Technology Adoption and Withdrawal Among the older adult. Rasche et al. [35] conducted a usability evaluation with an activity tracker of the older adult (60 + years) to understand whether activity trackers are emphasized to stigmatize the older adult, their intention to use the devices, and their positive and negative experiences. Results from their study show that the older adult were motivated and felt comfortable adopting activity trackers as a motivational support tool in their lives because of the motivational aspects and objective control. However, usability remained challenging concerning the device's wearing position on the body. Similarly, Fausset et al. [13] evaluated activity-monitoring devices among the older adult over two weeks to understand the cause of adoption and withdrawals. Interestingly, for the older adult, the initial interest was "positive;" however, some participants continued for only a short time due to "lack of usefulness of wearable devices," "data inaccuracy," and "wearability." Their results indicate that (i) despite being initially receptive to using the technology, participants do not always accept and use the technologies unconditionally [13]; and (ii) there is an "interplay of usability issues, such as inaccuracy of data, wearability, and adoption which kept them from not using activity tracker for long-term." Another study that conducted usability experiments using fitness trackers among older adult was described by Schlomann et al. [39]. In this study, "consequences of use" and "device functionality" were the two main concerns for older adults to adopt wearable devices.

Culturability. Wallace et al. [45] distributed a survey to 144 subjects from four countries to understand whether usability attributes vary among them and whether these variances were related to cultural dimensions. According to their results, usability attributes across countries vary in terms of efficiency and satisfaction, whereas no differences were noticed concerning effectiveness. The influence of culture on usability and design, even within western nations, is also emphasized by Khaslavsky [23], who asserted that users between two western countries might display different culturally motivated problems when interacting with the same application localized only through translation. To offset such differences, the authors presented a series of guidelines for integrating culture into design. The guidelines are as follows: (i) Consider more in-depth conceptual problems with your design when localizing; (ii) Culture-specific localization is necessary for every country, not only Asia; and (iii) Use the package of variables, such as speed of message, context, personal space, time, power distance, collectivism, diffuse vs specific, and particularism vs universalism, to drive your search for more information from users.

3 Methodology and Procedure

3.1 Experimental Setup

Data for this study were derived from the four-week-long usability experiments on COTS wearable devices, which were carried out in Finland and the US among individuals aged 60 years or over. The first evaluation was carried out in Finland (2017) with 13 elderly participants (age M = 62.23, SD = 1.921), and the second study was carried out in the US (2018) with 20 elderly participants (age M = 61.92, SD = 1.6062), which is considered sufficient based on Macefield's [26] recommendation that i.e. a group size of 3–20 participants is typically valid, with 5–10 participants being a sensible baseline range. Participants from both countries were living independently and were keen to use new technology to improve their well-being. Both countries followed the same methodology for usability experiments, and participants were recruited through direct contact, advertisement, and networking. The two countries were selected because of the overall similarity of the cultures, except in aspects most relevant to this study, such as in how welfare and healthcare are arranged, including in elderly care. The Finnish system is mostly based on public funding and healthcare system is centrally funded, whereas US system is mostly based on private funding and private medical insurances.

As a first step, a general presentation about the particular research was provided to each participant, followed by a recruitment form that collected preliminary information from participants, such as technological knowledge, current use of external devices including smartphones, age, and consent to participate. All participants in the study were presented with an ethical review statement and informed consent, and in return, a signed consent form was obtained. The entire questionnaire was reviewed by two reviewers before submission for ethical committee approval. The Lappeenranta University of Technology and California State University, Long Beach, institutional review board approved the study.

Procedure. Contextual Action Theory (CAT), as explained by Stanton [43], and the usability evaluation method [18] were used as the foundational methodologies to enhance our understanding of the cause of the non-adoption of COTS QSWTs among fit older individuals across different culture.

Stanton [43] point out that contextual action theory explains human actions in terms of coping with technology within a context, and five phases are associated with contextual actions: (i) the user is presented with the actual demands and resources of the device design, the tasks to be performed on the device, environmental constraints (e.g. time), and so on; (ii) those demands and resources are appraised by the actor; (iii) perceived demand and resources are compared; (iv) the possible degradation of pathways might occur; and (v) these responses' effects on device interactions. During the first phase of CAT, we present the actual demands and resources to the participants, consisting of the following: (i) **Devices:** Functioning wearable COTS devices, i.e. smartwatches and pedometers, to help us to explore the significance of various types of data for future design, as identified by Kanis [21]. No requirements were provided for device selection. (ii) **Timeline:** Participants were asked to participate in two one-hour controlled environments (i.e. first meet-up session and final meet-up session), with two weeks of each category of device (i.e. every day) use between the sessions in a semi-controlled environment. (iii) **Experimental tasks**: During the first and final meet-up session, we assigned experimental tasks[2] to be performed to test usability. For the semi-controlled environment, participants were asked to use the devices in real conditions and to complete the daily log in the provided diary. No specific pre-defined activities, such as sleep, walk, and exercise, were presented to the participants. This

[2] https://doi.org/10.5281/zenodo.832159.

semi-controlled environment aimed to make participants comfortable with using the device and to gather influential data from their dairies. The diary method has been applied because it forces participants to record all activities for the period covered, and data reported in the diary are arguably more reliable [37].

Measurements. The diary included several kinds of data, such as (i) whether the devices were worn (*if not, why?*); (ii) activities undertaken (*i.e. walking, hiking, running, cycling, etc.*); (iii) motivation in doing physical activities because of device use (*i.e. if yes, reason for motivation; if not, why?*); (iv) used applications (*which ones; if not used, why?*); (v) usability issues (i.e. screen size; icons; interaction techniques; interaction with screen; font size; button location; data accuracy; screen resolution; device weight, shape, and size; lack of screen; and battery life, with options to add any missing usability issues); and (vi) additional comments that asked participants for "other comments that should be specified." A list of usability issues from the diaries was derived based on issues previously identified issues [3, 13, 16, 32, 33, 41]. For analysis, the usability issues of COTS QSWTs have been clustered into two categories: hardware and user interface (UI). Especially, hardware concerns issues related to the external look and feel and internal components, such as sensors, processor, memory, power supply, and transceiver [2, 25]. Meanwhile, the UI concerns issues with the various ways in which users interact with the device [2].

4 Results

In the interest of the study, we focus our discussion on two results: identifying usability issues from usability evaluations to focus on what types of usability issues participants reported and comparing significant relations across cultures reveals that the importance weights given to specific usability issues concerning device characteristics significantly vary across cultures among the older adult.

Identifying Usability Issues from a Usability Evaluation. We identified 14 usability issues that were reported during the studies (see Fig. 1) between Finland and the US, of which eight were related to UI and six to hardware.

Participants also reported usability issues with interaction techniques, such as that feedback on smartwatches was irritating: "*Having all the notifications on my watch with vibration feels so irritating and like getting an electric shock*," or "*I pressed the screen on the device but it doesn't respond; is this device broken?*" Similarly, other participants reported that it was too annoying to receive notifications: "*I received the notification while I was sleeping at night, it was annoying*." Another participant who used the smartwatch said the "*touchscreen reacts so fast when I press on it*."

Connectivity issues appeared when participants tried to connect with external devices using Bluetooth: "*Trouble pairing with computer. After much research on computer, figured out I needed dongle. Once dongle connected, able to connect to laptop, never to table top*". Regarding iconography on pedometers, "*I don't remember all the icon. Preference should be given what we used the most*." Inaccuracy regarding sleep and walk data was also reported by the older adult, which was in line with the previous study of [13]. Further, it was mentioned that the font size was too small to read: "*I cannot read the text with my reading glasses, can I make this font larger?*"

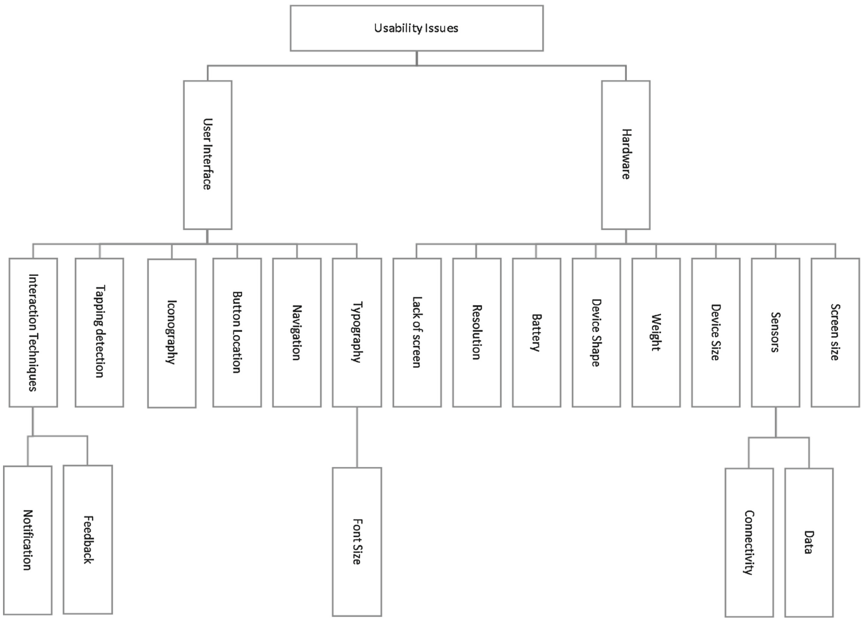

Fig. 1. Reported usability issues for smartwatches and pedometers

After the final data coding, the data were analyzed further based on the number of times the participants reported each usability issue. UI and hardware sub-categories, such as interaction techniques; tapping detection; iconography; button location; navigation; lack of screen; typography; screen resolution; battery; device shape, device size, weight, and size; sensors; and screen size, were considered. Statistics show (Figs. 2 and 3) the mean and standard deviations of the scores for the usability issues for both Finland and US.

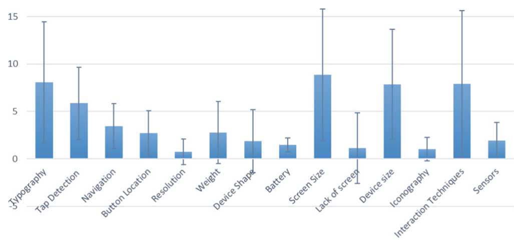

Fig. 2. Mean and standard deviation of usability issues for Finland

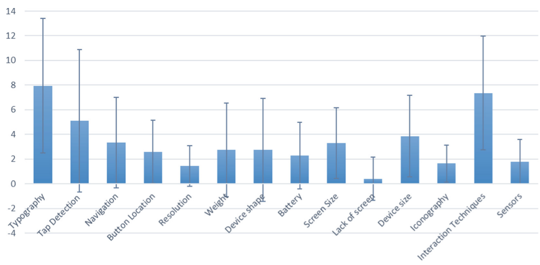

Fig. 3. Mean and standard deviation of usability issues for US

This outcome can point to the fact that for QSWTs, screen size, device size, interaction techniques, tapping detection, typography, and navigation were the most influential in both countries.

Comparing Significant Relations Across Cultures. A survey scale was constructed based on the identified most dominant usability to understand further whether the importance weights exist in the culture. Participants were asked to rate how much the identified usability issues correspond to the questionnaire on a 7-point Likert scale (0 = strongly agree to 7 = strongly disagree). The hypothesis was based on screen size, device size, interaction techniques, tapping detection, typography, and navigation. To gain insight, we surveyed with same participants from the usability studies. Data from the survey responses were downloaded from the Webropol online platform into an MS Excel spreadsheet, and they were analyzed with the R statistical language and its statistics ("stats") library [34]. Descriptive statistics were generated by the psych R library [36]. The Mann–Whitney U test for difference in means was used to test the differences between datasets. When analyzing the interval data with the Mann–Whitney U statistical test, a continuity correction was enabled to compensate for non-continuous data [7]. The Bonferroni correction was used to adjust the p-value to compensate for the family-wise error rate in multiple comparisons [1].

The Mann–Whitney U test results are summarized in Table 1. A total of six variables were tested and the difference of means between the two groups was significant between (i) the device size and (ii) the screen size. Other tested variables related to typography, navigation and interaction were not significant. For example, the Mann–Whitney U test indicated that issues related to device sizes has a significant difference ($U = 228$, $p < 0.001$) for Finnish (Mdn = 4), compared to US older participants (Mdn = 6).

The significant relationship result obtained from the two survey datasets (Finland and US) shows that some of the usability issues concerning wearable device characteristics are significantly essential and vary across cultures among older adult participants from Finland more than those from the US, which is in line with Khaslavsky's [23] statement. Khaslavsky [23] stated that two western countries may display different culturally motivated problems. For example, Mallenius et al. [27] found that Finnish individuals are interested in ease of use and value services provided by the devices that can make their everyday lives and tasks easier and safer.

Table 1. Results from Mann–Whitney U tests.

Variable	U-value	Mdn (US)	Mdn (Finnish)	p	Corrected p (Bonferroni method)/significance
Device size	228	6	4	0.0001727	0.001036233/Yes
Screen size	284.5	5	4	0.003384	0.020305537/Yes
Typography	539	2	3	0.5336	1.000000000/No
Interaction technique	587.5	4	4.5	0.1909	1.000000000/No
Tapping detection	654.5	5	6	0.02295	0.137708336/No
Navigation	364	4	3	0.07015	0.420873408/No

Therefore, one reason the results varied is because Finnish older individuals prefer more perceived comfort and convenience attributes [20] that could also include value services. For example, Finnish participants perceived comfort from wearability, convenience attributes from size and weight, and the value services from wearable devices as tools to facilitate behaviour changes to increase and maintain physical activity levels more than their US counterparts. Another reason could be the participants' cultural backgrounds; particularly, users' perceptions of effectiveness, efficiency, and satisfaction [46] may differ with regard to device and screen size.

In contrast, usability issues with wearables characteristics (i.e. UI), such as font size and feedback, showed no significant differences between both countries. One possible reason is that the importance weight tied to typography and feedback among older participants could usually be countervailed by (i) individual characteristics, such as age and health [10] or (ii) the local font characters, such as Chinese font characters, which are composed of strokes affecting readability [17]. However, when it came to the tapping detection threshold and navigation, the results were close to significant, and the closeness in the results can be attributed to either the differences in older adult or cultural characteristics. Therefore, this warrants further investigation with larger datasets.

5 Discussion

In his inspiring work, Carmien and Manzanares [8] state, "Identifying the cause of the non-adoption is the first step towards ameliorating this situation; having identified the problem the next step would be to design around the obstacles that were designed into the systems" (p. 28). This research has dealt with identifying the cause of adopting COTS QSWTs among the older adult (60+). Our results raise concerns from many angles of device characteristics, and they were in line with previously identified usability issues [3, 13]. To offset such concerns, the authors have recommended informal guidelines based on identified usability issues, qualitative feedback from the older adult, and existing literature reviews to help technology designers, developers, and researchers to design upcoming QSWTs targeted to the older adult. The most important set of informal guidelines is followed for both hardware and UI.

5.1 Enhancing Usability for Hardware

Consider Configure-to-Order (CTO) Products. During usability studies, the older adult indicated that the device and screen sizes presented the most dominant usability issues. This may be because screen size decreased the efficiency and processing of conveyed information [24] by limiting input modalities, navigation behavior, and readability, while the device shape limited wearability because of individual characteristics, such as variation in wrist shape and size due to the age, gender, or body structure. To reduce the impact on usability caused by device and screen size, technology designers should ensure both are sized appropriately for the older adult. We propose it is highly important for technology designers to consider applying CTO products with wide device and screen size measurement and shape variations, such as large/round, small/round, large/square, and small/square [24], depending on preferences.

Consider Maximum Magnitude of Effect for Minimal Means. Likewise, a visual pattern is pleasing to the eye when relatively simple design features reveal a wealth of information [15], so the hardware design of smartwatches and pedometers should be pleasing to the body through wearability and comfort that improve the aesthetic experience of older adult users. When it comes to the older adult, we found that wearable devices were used mainly for sleep analysis and counting heartbeats and steps, and those data were used to facilitate behaviour change. Therefore, technology designers should give careful consideration while designing the device characteristics (hardware and User Interface) that have a maximum magnitude of effect for minimal means. For example, removing unwanted hardware, such as the near field communication (NFC) and radiofrequency (RF) chips handling calls and texts, might reduce the shape, size, and weight of smartwatches and pedometers to be light and comfortable and to not affect older adults' daily behaviour.

Consider Improving Sensor Precision. Quantitative feedback showed that the older adult had difficulties trusting the reliability of notified sleep analysis data, such as wake after sleep onset (WASO), sleep efficiency (SE), and total sleep time (TST) with current smartwatches and pedometers. This may be because (i) current wearable devices measure the binary presence of sleep or waking states by measuring wrist movements [28] using wrist-worn accelerometer sensors [50] or because (ii) consumer health wearables are based on simple descriptive statistics [31]. Therefore, technology designers and researchers should consider alternative techniques to could improve notifications of sleep analysis data. This could be done by, for example: (i) identifying sleep stages: awake, light sleep, deep sleep, and rapid eye movement (REM) through RF [51]; (ii) measuring skin temperature, light, and activity across days to detect internal circadian rhythms [42, 47]; (iii) capturing entire body movements, rather than focusing on one specific body part; and (iv) detecting the complete set of motion-related parameters [30].

Consider Culture While Designing the Devices. From the Mann–Whitney U tests, we found that culture may have an influence when it comes to some user characteristics. For example, Finnish users place more importance on device and screen size than their US counterparts. Therefore, we recommend technology designers look into cross-culture design requirements and get feedback from local older adult using local usability evaluators before designing devices. Shi [40] states, "When cultural differences exist between the evaluator and test user, some usability problems might be masked, instead of being uncovered." This may help to understand local users' attitudes and intentions to use, as well as to build an effective relationship with them and their devices.

5.2 Enhancing Usability for UI

Consider Alternative UIs. The older adult indicated that the UI characteristics of devices, such as typography, button location, and interaction techniques, affected their daily usage. This may be because individual characteristics, such as age, disabilities, and environmental context, might have influenced the UI. A previous study [39] and qualitative feedback from the older adult also indicated, "There are so many things, which I do not need." As [12] pointed out, simple interface manipulation can contribute to positive preference outcomes, and one basic approach to improving the UI's usability is for technology designers and application developers to consider an alternative user interface (AUI) approach. We believe such a consideration could support User personalization, which the older adult desire. For example, adding age and any impairments during first time device or application start up could allow devices to personalize the typographical variables automatically, such as font size, font color, and background color, which could reduce the demands placed on accommodation (the eye's ability to change its optical power for a better focus) and vergence (eye movement for focusing on near and far objects) [4]. As Morrison et al. [29] state, "Notifications appear to be most acceptable when users are provided with control over if, when, and how they are received, and when notifications are delivered at convenient times that do not disrupt daily routine." Therefore, personalized information, daily behaviour data, and the environmental context of the UI should alert on device screen with any of the following interaction techniques: text, audio, graphic, tactile, and haptic [49]. The consideration of an alternative UI has implications for the "how information" for older adult at first; therefore, specific instructions should be presented during device or application startup.

6 Conclusion

Previous studies [13, 35, 39] have identified issues such as data inaccuracy, functionality of devices, consequences of use, wearability because of device characteristics as reasons associated with the withdrawal from the use of wearables by older adult. In this study, we first identified usability issues related to smartwatches and pedometers among the older adult between two countries. Second, we looked at whether culture weighs on usability issues. Finally, based on those issues, we provided informal usability guidelines that aim to help technology designers and application developers craft usable future COTS QSWTs for the older adult. This study involved a small number of participants in both geographic locations, meaning the results may not be generalizable; thus, all stakeholders, including device manufacturers and application developers, should take the findings as suggestions rather than conclusive evidence [22].

This study suggests several potential areas of improvement of QSWT for technology designers, researchers, and application developers. First, technological designers must be sensitive to individual and device characteristics and cultures that might impact device adoption by the older adult. Second, both technology designers and researchers must be sensitive to improving sensors and algorithms to avoid the potential consequences of inaccurate data that are currently occurring through wearable devices. Third, technology designers, researchers, and application developers must consider an AUI on both embedded operating systems and applications, so the older adult feel comfortable and develop a high degree of satisfaction, motivation, and enjoyment regarding these devices' usefulness [22].

While more research is needed to offset the usability issues caused by the smartwatches and pedometers among the older adult, future research could investigate the impact of: (i) low and high context cultures; (ii) local font characters, such as Chinese font characteristics, which are composed of strokes and which affect the readability [17] and usability of wearable devices; (iii) evaluate the significance of an AUI through a task-based experiment; (iv) analyze empirically the weights of different interaction techniques between smartwatches and pedometers; and (v) study how long it takes the older adult to learn device functionalities. The research can also be extended to analyze empirically older adults' perceptions of adopting the CTO approach.

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Publication V

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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.

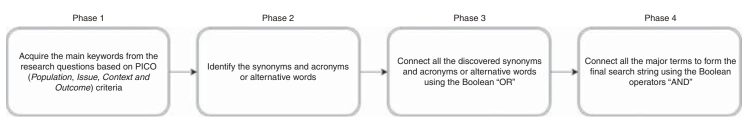

Figure 1. Search string formulation process

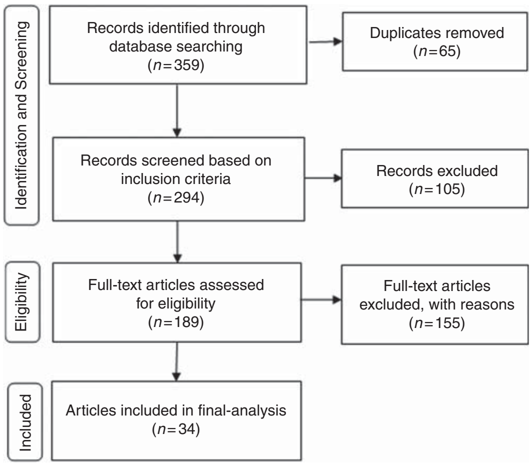

Figure 2.
Flow diagram of the search procedure

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)	Availability: 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?

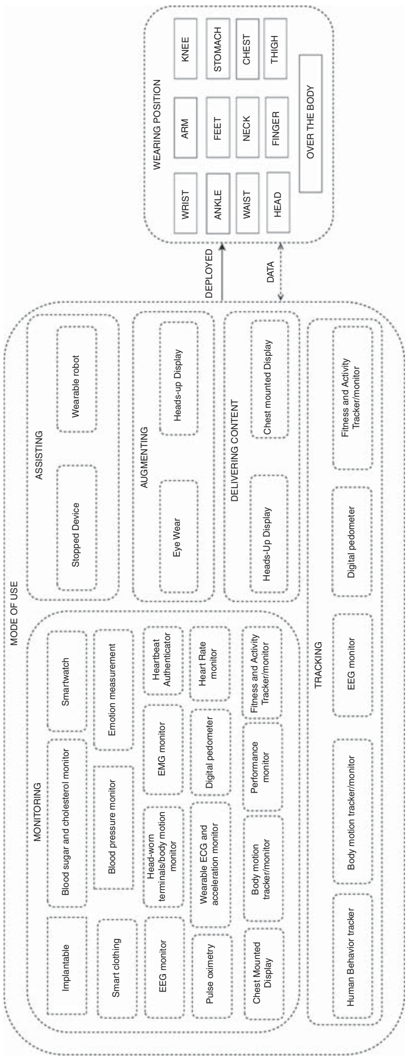

Figure 4.
The categorisation framework of wearable technology types

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.

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

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Publication VI

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Intended use of Smartwatches and Pedometers in the University Environment: An Empirical Analysis

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Abstract
In this work, we empirically examine factors that influence the intention to use wearables e.g. smartwatch or pedometer, in the university environment through a Wearable Acceptance Model (WAM). WAM incorporates UTAUT model and additional variables like wearable characteristics (e.g. wearability, design and physical characteristics), attitude and privacy. WAM was used with an online survey of 129 university faculty, staff and students. Further, partial least square (PLS) path modeling was applied in analysis of 14 hypotheses to validate WAM results. In accordance to WAM, wearability and attitude tend to have a direct effect on intention to use, whereas performance and effort expectancy had only a direct influence on attitude and no direct influence on usage intention. Similarly, privacy concern, social influence had a positive influence on the intention to use both directly and indirectly through attitude. However, design and physical characteristics had no effect on intention to use. This study makes a unique empirical contribution to wearable research by extending knowledge on university users' behavior regarding wearables for well-being.

Author Keywords
Wearables; Smartwatch; pedometer; Structural equation modelling (SEM).

ACM Classification Keywords
K.6.m. Management of Computer and Information Systems.

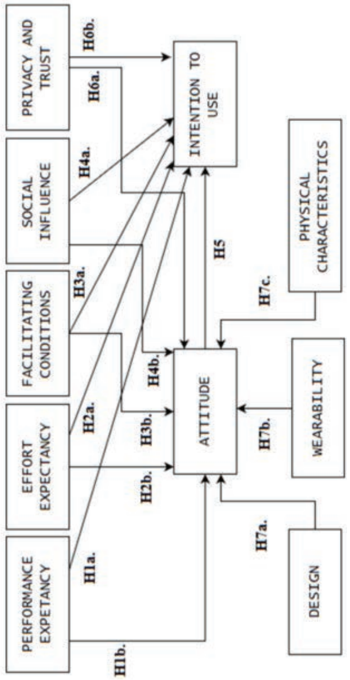

Figure 1. WAM model (view[1] for larger image)

Introduction

At present, a number of commercial off-the-shelf ('COTS') wearables such as smartwatches (SWs), pedometers (PMs), or specially designed wearables have gained popularity for both personal and organizational use for well-being through behavioral change (i.e., physical activities) by simplifying data collection, management, and visualization [10].

The utilization and acceptance of SWs and PMs within the university setting are likely to differ from other work environments, due to: i) the uniqueness of the academic settings (i.e. policies, regulations by government); ii) wearability factors; iii) personality factors of faculty, staff, and students (i.e., motivation, behavior, ability); iv) ability of SWs and PMs to accumulate vast amounts of biometric and health-related habits and data [3]; and v) demographic differences between faculty, staff, and students. This raises many questions, including: How are these groups' attitudes and intentions to use (IU) affected by: i) pushed or imposed self-tracking [7]; ii) monitoring outside work/study hours; iii) need for new behaviors (e.g., remembering to charge and wear the device); and iv) ownership of data by other vendors for analysis [4]. The answers are complex, therefore making it appropriate to investigate such behavioral intentions and contributory factors within the university environment.

The present research intends to empirically investigate and explain the factors that influences intention to use through the following questions: "**RQ1:** What specific factors can obstruct utilization of SWs and PMs among university faculty, staff and students?", **"RQ2:** How are these factors related to each other in influencing the usage of SWs and PMs?"

Research model and hypothesis

To validate and enhance our understanding of the university faculty, staff and student's intention to use (IU), we consider UTAUT model which claims that four main constructs—"Performance expectancy," "Effort expectancy," "Social Influence," and "Facilitating conditions"—are related to behavioral intention and user behavior model developed by Venkatesh et al. [12] to be the foundation and wearability, design (aesthetics), physical characteristics, attitude, privacy and trust as additional variables, such. In so doing, we have a strong proposed model Wearable Acceptance Model (WAM) (see Figure 1).

The following section presents the variables used in the research model and hypotheses formulated based on the variables: **i)** Performance expectancy (PE) is the extent to which the user believes the technology will help them achieve their daily goals [12]. **H1a.** PE will have a positive effect on the intention to use SWs and PMs. **H1b.** PE will have a positive effect on the attitude of the university faculty, staff and student and their IU technology; **ii)** Effort expectancy (EE) is "defined as the degree of ease associated with use of technology" (p.450) [12]. **H2a.** Higher levels of EE among university faculty, staff and student will lead to greater uptake of SWs and PMs. **H2b.** EE will have a positive effect on university faculty, staff and student's IU; **iii.)** A facilitating condition (FC) is "defined as the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the" (p.453) [12] technology, or the perception of external control. **H3a.** FCs will have a significant influence IU SWs and PMs. **H3b.** FCs will have a positive effect on the attitude of IU of university staff and student; **iv)** Social influence (SI) refers to the "process by which individuals adapt their opinion, revise their beliefs, or change their behavior as a result of social interactions with other people" (p.1) [9] with respect to use of new technology. **H4a.** SI will have a positive influence on IU SWs and PMs. **H4b.** SI will have a positive effect on the attitude of university faculty, staff and student and promote IU; **v)** Attitude (ATT) in terms of technology use "is defined as an individual's overall affective reaction to using a system" (p.455) [12]. **H5.** Positive attitudes

H	Path /Results	β	T-Statistics	P Values
H1a	PE→IU **PA**	0.132	1.490	n
H1b	PE→ATT **A**	0.459	6.748	****
H2a	EE→ATT **A**	0.138	1.702	*
H2b	EE→IU **R**	0.073	0.779	n
H3a	FC→IU **R**	-0.166	1.615	n
H3b	FC→ATT **R**	0.108	1.269	n
H4a	SI→IU **A**	0.206	2.082	**
H4b	SI→ATT **A**	0.215	2.335	**
H5	ATT→IU **A**	0.308	2.492	**
H6a	PCI→ATT **A**	0.170	2.234	**
H6b	PCI→IU **A**	0.178	2.011	**
H7a	WD-D →IU **R**	0.112	1.561	n
H7b	WC-W→IU **A**	0.198	2.342	**
H7c	WC-P→IU **R**	-0.053	0.852	n

n) not significant, *) Statistically significant at p<0.1, **) Statistically significant at p<0.05, ***) Statistically significant at p<0.01, ****) Statistically significant at p<0.001; **H:** Hypothesis ***PA:*** *Partially accepted*, ***A:*** Accepted, ***R:*** *Rejected*

Figure 2. Direct effects in the structural model to test hypothesis of the study

of users' toward SWs and PMs create IU behavior; **vi)** Privacy concern and iteration (PCI): Privacy concern (PC) while using technology depends on trust level between the users and the organizations providing the technology or services. In the context of this study, both SWs and PMs collect data of users' health related and physical activities data (i.e., heart rate and steps walked daily). **H6a.** PCI will have significant influence on the attitude of university faculty, staff and student. **H6b.** PCI have a significant influence on IU SWs and PMs; **vii)** Wearable characteristics: Wearables are in close proximity to body and must suit users' body shape, size, as well as their preferences, interests, and wishes [8]. Previous study has addressed: i) aesthetics (design) [1], and ii) physical characteristics such as: screen size, device size, battery life [2,11], which play a rather important role in the duration of user– SWs and PMs interaction. **H7a.** Aesthetics (design); **H7b.** Wearability; **H7c.** Physical characteristics (PC): will have an influence on intention to use SWs and PMs.

Data Analysis and Results

An online survey was conducted to collect data, of the 129 respondents, 42.64% (n=55) were university faculty and staff; 39.53% (n=51) were students; or 17.83% (n=23) were both.

To address the slight non-normality of data and the somewhat small sample size, we employed partial least squares (PLS) analysis technique, with non-parametric bootstrapping [5]. The outer model, also known as measurement model was validated with regards to i) reliability: measurement; ii) validity: facto structure, and discriminant. Construct reliability (CR) and the Average Variance Extracted (AVE) were used to assess the measurement reliability. CR coefficient of more than .50 indicates strong and acceptable model [6] otherwise good. We analyzed the main effects in the model, defined through hypothesis 1 to 7 (see Figure 2). Bootstrap sample size (n=129), was taken in to consideration and the main effects in the model was analyzed, through defined hypothesis H1 to H7. Further, the resampling of data was repeated 5000 times, which is adequate for the estimation of the model parameters. The r-squared for latent variables in the path model varied from ATT = 0.691 to IU = 0.670.

The model shows that both PE and the EE have a significant positive direct influence on ATT (H1b and H2a), but no direct influence on IU (H1a and H2b). However, post-hoc analysis showed that PE has a significant positive indirect effect on IU. These results did not find any significant effects of FC on user behavior (H3a and H3b). SI had a significant positive influence on both ATT and IU (H4a and H4b), which supports the significance of this variable as a prior-to-use factor. Indeed, the user's attitude to IU has a highly significant positive influence on use of SWs and PMs (H5). PCI has a significant positive direct influence on both ATT and IU (H6a and H6b). In the tested model, the wearable's characteristics had a significant influence on the IU only with regard to WC-W (H7b), whereas other design features, physical characteristics, and appealing design had no statistically significant effects (H7a and H7c).

Conclusion and Future work

In this work, we studied the factors that influence to use SWs and PMs among university faculty, staff and student. We tested several hypotheses based on UTAUT and additional variables with PLS path modelling. This study confirmed some of the results from previous research on wearable device adoption evaluation with UTAUT [12], regarding effort expectancy, social influence, and performance expectancy. As shown in Figure 3, Users' perceptions (i.e., attitude) had the strongest effect on IU, meaning that the user has to believe the device i) will address their needs; ii) is fun. Results also show that users' are more likely to use the device if people close to them recommend it. Performance expectancy (the user's expectation of the device's efficacy) had a significant indirect effect on intent to use. The most interesting factors not affecting IU are aesthetics and

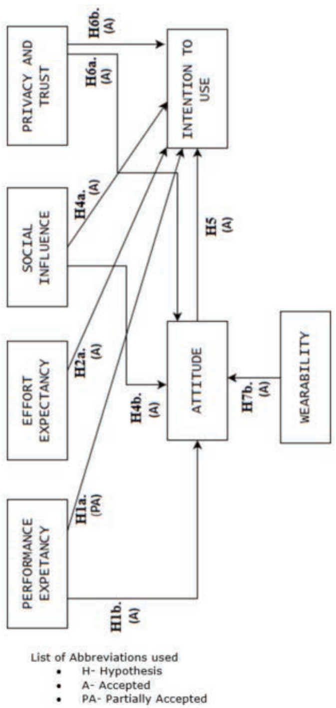

Figure 3. Simplified "WAM" model based on analysis

facilitating conditions and learning new behaviour. In this study, the users did not consider physical characteristics (design, screen size, or battery life) as important which is surprising. Having to learn new behaviours, such as remembering to charge the device, did not affect intent to use. For the physical characteristics, only being worn well during fitness activities had a significant effect on intent to use.

Further, the study can be used as a basis to understand how other influential variables such as motivation, anxiety, accuracy, gender and age, differences in the demographic between faculty, staff and students facilitate intention to use SWs and PW's in the university environments among university staff and student to improve health through behavioral change.

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