Received: 9 August 2019 | Revised: 26 August 2019 | Accepted: 29 August 2019

DOI: 10.1002/hbe2.173

SPECIAL ISSUE ARTICLE

WILEY

A review on intelligent wearables: Uses and risks

Yukang Xue

Department of Educational and Counseling Psychology, University at Albany, Albany, New York

Correspondence
Yukang Xue, Department of Educational and Counseling Psychology, University at Albany, Albany, NY.
Email: yxue2@albany.edu

Peer Review
The peer review history for this article is available at https://publons.com/publon/10.1002/hbe2.173.

Abstract

Intelligent wearable technology is becoming very popular in application fields such as clinical medicine and healthcare, health management, workplaces, education, and scientific research. Using the four-element model of technological behavior, the first part of this review briefly introduces issues related to the uses of intelligent wearables, including the technologies (i.e., what kind of intelligent wearables are used?), the users (i.e., who use intelligent wearables?), the activities involving the technologies (i.e., in what activities or fields intelligent wearables are used?), and the effects of technology usages (i.e., what benefits intelligent wearables bring?). The second part of this review focuses on the risks of using intelligent wearables. This part summarized five common risks (i.e., privacy risks, safety risks, performance risks, social and psychological risks, and other risks) in the use of intelligent wearables. The review ends with a discussion of future research.

KEYWORDS

application, consumer behavior, human behavior, intelligent wearables, internet of things, privacy, risk factor, smart wearables, wearable device, wearable internet of things

1 | INTRODUCTION

Since intelligent wearables can collect real-time information on human activities and behaviors, they are becoming very popular in application fields such as clinical medicine and healthcare, health management, workplaces, education, and scientific research. Unlike traditional wearable objects, such as wristwatches and clothes, intelligent wearables can both collect information and work as a carrier of the internet of things (IoT), through which domain-specific intelligence is created by interconnecting physical objects to each other and computing data (Gubbi, Buyya, Marusic, & Palaniswami, 2013).

The first part of this review introduces the uses of intelligent wearables in the existing literature using the four-element model of technological behavior (Yan, 2017). This model was initially used to delineate mobile phone behaviors based on four basic elements: users, technologies, activities, and effects. It is also very useful for delineating how humans interact with other technologies including intelligent wearables. Thus, this article discusses intelligent wearable usages based on the same four elements: the technologies (i.e., what kind of intelligent wearables are used?), the users (i.e., who use intelligent wearables?), the activities involving the technologies (i.e., in what activities or fields intelligent wearables are used?), and the effects of technology usages (i.e., what benefits intelligent wearables bring?).

Since the benefits of intelligent wearables have received more attention while the risks were overlooked, the second part provides a scoping review on the risks of using intelligent wearables to introduce what risks were concerned in the previous research. In this part, the article starts with an introduction of the literature search methods to be used and then it provides detailed information about the studies. The review ends with a discussion of future research directions.

2 | USES OF INTELLIGENT WEARABLES

2.1 | Intelligent wearable technologies and users

2.1.1 | The concept of intelligent wearables

Wearable devices such as watches have long appeared in human history. However, intelligent wearable devices have only developed rapidly in recent years and have gained popularity among the general

public. An intelligent wearable should at least possess two features: wearability and smart. Wearability means the technologies or devices could be worn on human bodies either by being incorporated into garments or by being designed as wearable accessories. Smart means the wearable devices are able to provide intelligent services, such as collecting information from the surrounding environment, performing the necessary data processing, and outputting the processed information, as well as working as one part of a larger smart system (Fernández-Caramés & Fraga-Lamas, 2018).

Since one important feature of smart devices is the ability to connect with other objects automatically, this review tends to equate the concept of intelligent wearables with wearable IoT (Hiremath, Yang, & Mankodiya, 2014). Take wearable dietary monitoring devices as an example. Many of those devices can be smart enough to detect chewing and swallowing events, some can even be used for food type classification (Vu, Lin, Alshurafa, & Xu, 2017). However, if only used for data collection and preliminary analysis, those devices are more likely to be considered as functional devices with wearability. Similar devices also include non-networked virtual reality helmets or glasses, basic pedometers, and eye trackers that are often used in behavioral science laboratories. Although those devices may be considered more intelligent than ubiquitous wearable devices such as wristwatches and wearable cameras, they normally do not have the ability to automatically interact with other objects and thus could be considered as non-intelligent wearables. However, it should still be noted that the evolution from nonintelligent wearables to intelligent wearables is a continuous process and the boundaries between nonintelligent wearables and intelligent wearables are often blurred. In fact, non-intelligent wearable devices and intelligent wearable devices share many common features and the ability to connect with other objects is not the only feature that matters.

2.1.2 | The forms of intelligent wearables and users

Depending on the specific applications, wearable devices could be used on different parts of human bodies and thus present different forms. For example, smartwatches and fitness bracelets are wrist devices that could be used for GPS tracking, sleep quality detection, and heart rate measurement; intelligent glasses, such as Google glass, could be used for information display (Lunney, Cunningham, & Eastin, 2016; Saleem et al., 2017). Smart clothing and smart jewelry (e.g., smart rings, smart necklaces) are also common intelligent wearables.

The wearable devices could also be classified according to their application fields. One of the most important and common application fields is health-related settings. In those cases, intelligent wearables are used for clinical applications, health care, and daily health management. By providing real-time monitoring and recording, as well as timely and personalized feedback, intelligent wearables work for patients with defined illness and comorbidity (Piwek, Ellis, Andrews, & Joinson, 2016). People who need real-time monitoring, such as the elderly and those in rehabilitation, are also the main users for smart wearable devices (Baig, Gholamhosseini, & Connolly, 2013; Viteckova, Kutilek, & Jirina, 2013). As for health management, intelligent wearables, such as smartwatches and smart bracelets, are more likely to be adopted by people who wish to keep a healthy lifestyle. Usually, they use those wearable devices to quantify and acquire feedback on their progress.

Another popularity application field is workplaces. In a systematic review, Khakurel, Melkas, and Porras (2018) concluded that the application of intelligent wearables in workplaces includes monitoring, augmenting, assisting, delivering, and tracking. Employees in general workplaces can use wearable devices to help them work more efficiently. For those working in hazardous environments, wearables can help them monitor dangers in the environment and provide necessary help. Professional athletes and coaches can also apply wearable devices to help them analyze the physical condition and performance of athletes, thus acquiring a quantitative basis for training designs and improvements (Baca, Dabnichki, Heller, & Kornfeind, 2009).

In addition to the above application fields, intelligent wearables are also used for education and scientific research. For example, a program conducted by Vallurupalli, Paydak, Agarwal, Agrawal, and Assad-Kottner (2013) applied Google glass for exploring different scenarios in cardiovascular practice where fellows can improve their education.

2.2 | Human activities involving intelligent wearables and effects of using intelligent wearables

Depending on the application settings, the use of intelligent wearables can have both therapeutic (e.g., disease diagnosis, disease treatment, and rehabilitation) and nontherapeutic/enhancement functions (e.g., exoskeletons and hazard detection). The following part introduces how intelligent wearable technologies are applied to various settings, including clinical applications and healthcare, health management, workplace, and other application fields.

2.2.1 | Clinical applications and healthcare

Both high medical costs and global aging are critical social issues. Intelligent wearable applications in clinical situations include disease diagnosis, treatment and rehabilitation, and monitoring. Many physiological parameters and biochemical variables could be monitored or measured by wearable devices, including cardiac activity, blood pressure, blood oxygen saturation, respiration, and so forth (Teng, Zhang, Poon, & Bonato, 2008). The acquisition of these parameters, especially the understanding of long-term changes, will be very conducive to the diagnosis of the disease. Moreover, intelligent wearables can also be applied to rehabilitation (Patel, Park, Bonato, Chan, & Rodgers, 2012). For example, smart limb robots (i.e., rehabilitation exoskeletons) can help people recover from neurological injuries. Those devices have many advantages, including high accuracy of patient movement observations and improved rehabilitation training efficiency (Viteckova et al., 2013). Sensorized T-shirts can monitor postures during rehabilitation exercise which helps the elderly or impaired people restore proper physiological states (Sardini, Serpelloni, & Pasqui, 2014).

Since most of the patients and the elderly are not familiar with the new wearable technologies, both the functionality and the usability need to be considered when designing. Moreover, risk factors, such as privacy and safety, should also be considered.

At present, the application of intelligent wearables in clinical settings is still very limited. It should be noted that the functions and potential applications of those devices are based more on academic research than on real clinical settings. Therefore, the uses of intelligent wearables in clinical fields are still at a very early stage.

2.2.2 | Health management

In the past, it was only when people had obvious physical symptoms that they began to pay attention to their health problems. However, the situation is changing in modern society and people's concern about their health commonly becomes an important part of their daily lives. People who pursue a healthy lifestyle use the wearables to monitor their health management progress and the manufacturers also use a lot of social strategies to encourage people to participate more in those activities (Piwek et al., 2016).

Since obesity can lead to many serious diseases, it is becoming a global health issue. People are trying to use wearables to track and provide interventions on weight management (Holzmann & Holzapfel, 2019; Lewis, Lyons, Jarvis, & Baillargeon, 2015). Increased physical activity and diet control are two main ways that wearables can help people combat obesity. A systematic review conducted by Lewis et al. made a preliminary conclusion that electronic activity monitor system technology which both objectively measures physical activity and provides informative feedback could increase physical activity and decrease weight (Lewis et al., 2015). Diet control is another way of weight management. Previous studies compared and confirmed the effectiveness of wearable devices in monitoring people's dietary behaviors (Heydarian, Adam, Burrows, Collins, & Rollo, 2019; Schiboni & Amft, 2018; Vu et al., 2017).

Besides the problem of obesity, people also use their intelligent wearables for sleep quality monitoring and stress management. Despite those diverse functions, whether intelligent wearables can help people manage their health not only depends on the devices themselves, but also on whether people can use those devices effectively (Patel, Asch, & Volpp, 2015). One survey showed that almost half of people stop using the wearable devices after a year (Ledger & McCaffrey, 2014). It seems that only people who already live a healthy lifestyle or have strong motivations to manage their health can use the wearables for a long time, while those who attempt to motivate themselves through using wearable devices often unable to use them effectively. More longitudinal, randomized controlled studies, and field experiments are needed to examine how intelligent wearable usage influence users' health behaviors and fitness.

2.2.3 | Workplace

The workplace is another common setting in people' lives, and it is also one main potential application field for intelligent wearables. Intelligent wearables can help people work more effectively and efficiently, monitor and maintain their physical and mental conditions in work settings, and improve safety in workplaces, especially in hazardous situations. First, functioning as an extension of human bodies, the wearable devices are able to improve information presentation, management, and exchange, as well as enhance people's operational capabilities. For example, head-mounted display devices including smart glasses can be used for remote guidance (Nee, Ong, Chryssolouris, & Mourtzis, 2012); exoskeletons can considerably reduce physical load on human bodies by enhancing their power (De Looze, Bosch, Krause, Stadler, & O'Sullivan, 2016; Khakurel et al., 2018). Second, just like its application in the clinical field, the ubiquitous nature of intelligent wearables enables them to continuously monitor employees' physical and psychological conditions, such as stress (Muaremi, Arnrich, & Tröster, 2013; Setz et al., 2009) and inappropriate joint angles which may lead to musculoskeletal disorders (Wang, Dai, & Ning, 2015; Yan, Li, Li, & Zhang, 2017). Third, wearable technologies could also be used as personal protective equipment in the workplace (Kritzler, Bäckman, Tenfält, & Michahelles, 2015). Those technologies could assist in monitoring and detecting hazards in the environment, as well as sending alarm notifications automatically.

However, there are still many issues and risks people tend to consider before they adopt the wearable devices (Kritzler et al., 2015; Schall, Sesek, & Cavuoto, 2018). One survey among registered members of the American Society of Safety Engineers and professionals certified by the Board of Certification in Professional Ergonomics showed that employee privacy-related issues are the most concerned. Employee compliance, sensor durability, and costs of using the devices are also greatly concerned by people.

It should not be surprising that intelligent wearable technologies also show great application potential in many other fields, such as education and scientific research. One main feature of intelligent wearables is that it can collect personal data effectively, making it more feasible and reliable to quantify human behaviors. In that case, intelligent wearables should have a place in any application fields that can take advantage of the feature.

3 | RISKS OF INTELLIGENT WEARABLES

3.1 | Background

Every new technology is designed to solve certain problems and bring benefits to human life. Intelligent wearable, as one emerging technology, offers new possibilities for improving human life both personally (e.g., driver monitoring, physical activity monitoring, diet monitoring) and professionally (e.g., rehabilitation and elderly care).

However, the technology still brings new risks to human life. The final effects of technologies on human life both depend on whether the technologies function as expected, which related to performance risks, as well as the interaction between human beings and technologies. For example, inappropriate physical loading of wearable devices may lead to the development of musculoskeletal disorders (Knight & Baber, 2007). Moreover, even if intelligent wearables work properly,

improper use of those technologies will cause much loss. Take security issue as an example, false data resulting from tampering would lead to incorrect actions and therefore bring financial or health loss to users. Thus, we should not ignore the potential risks while embracing the new technology. In the following parts, a scoping review further discussed the risks in the existing literature.

3.2 | Method

A scoping review was conducted to introduce the risks being concerned in the previous research. Scoping review usually aims at preliminarily mapping available research literature without formal quality assessments and it can help to decide whether a further systematic review is needed (Grant & Booth, 2009; Peters et al., 2015). According to the steps of scoping reviews proposed by Arksey and O'Malley (2005), the present review searched the existing literature in two major relational databases, PsycINFO (includes PsycARTICLES) and Web of Science. Two groups of keywords being related to intelligent wearable (e.g., smart wearable, wearable IoT, smartwatch, and smart clothes) and risk (e.g., risk, perceived risk, and harm) were used to search the literature in those databases. In addition, reference lists of primary studies were screened.

Several exclusion and inclusion criteria were used to select articles that retrieved.

First, since the review focuses on the human side rather the technical side of intelligent wearables, one of the main criteria is to include articles from various disciplines in behavioral sciences but to exclude those from complete technical perspectives.

Second, the review included articles that provide empirical evidence or theoretical thinking concerning the risks of intelligent wearables. However, it excluded articles that only simply mentioned certain risks.

The last, journal articles and proceedings papers published in all years were included (i.e., 1983–2019 for Web of Science and 1887–2019 for PsycINFO). The review limited research to English language publications.

3.3 | Results

Here, 879 articles were initially retrieved (32 articles from PsycINFO and 847 articles from Web of Science) and 870 articles were left after duplicates being moved. Then, through title and abstract screening, the review excluded articles from complete technical perspectives and those were not actually related to intelligent wearables or did not have a main discussion on risks. As a result, 21 articles were left. Furthermore, 23 potentially relevant articles were identified by reviewing the reference lists. Finally, using the same criteria and full-text screenings, the literature search generated a total of 31 articles concerning the risks of intelligent wearables.

According to the articles generated, there are two main approaches in the existing research. The first approach is based on laypeople's perspectives. Those studies more or less referred to the dimensions of perceived risk proposed by Cunningham (1967). In this line of studies, researchers examined users' or consumers' perceived risks of intelligent wearables and how those perceptions influenced their intention to adopt and use certain wearables. The second approach is based on the experts' perspectives. In this line of studies, the risks of wearables were raised theoretically by researchers from relevant fields including engineering and behavioral science who are familiar with wearable technologies. And many of them also empirically examined whether certain risks exist.

In the exiting literature, perceived risks of intelligent wearables include privacy risks, safety risks, performance risks, social and psychological risks, and other risks. Of those risks, privacy risk was the most common concern of users as well as the most studied by researchers. It should be noted that the taxonomy of these risks is not exclusive. For instance, disclosure of personal privacy may threaten one's safety and property.

3.3.1 | Privacy risks

Among the retrieved literature, more than two-thirds of the articles are mainly concerned with or involve considerations of privacy risks, which indicates that privacy issues are indeed a topic of concern for people using intelligent wearables. However, when comparing to other smart devices, such as smart phones, people still showed a relatively low risk perception of privacy issues (Lee, Yang, & Kwon, 2018).

In a world of ubiquitous smart technologies, the issue of privacy may be more serious than people thought. In fact, researchers have already proven that our sensitive data collected by intelligent wearables are easy to be transfused (Lee et al., 2018). One line of studies even showed a privacy risk caused by the keystroke inference attacks. These attacks are realized by analyzing users' hand movements tracked by sensors (e.g., accelerometer) built in the smartwatches, which makes it possible to accurately collect the inputs information on keyboards (Liu, Zhou, Diao, Li, & Zhang, 2015; Maiti, Armbruster, Jadliwala, & He, 2016; Maiti, Jadliwala, He, & Bilogrevic, 2015; Wang, Guo, Wang, Chen, & Liu, 2016; Wang, Lai, & Roy Choudhury, 2015). Unfortunately, a recent survey showed that most of the users were unaware of the new type of motion-sensor-based threat to their privacy (Crager & Maiti, 2017).

Although laypeople seem to know little about specific privacy risks, such as the keystroke inference attacks, they usually show generalized concerns about privacy issues. One line of studies examined how users' perceived privacy risks influence their acceptance of wearable devices. The results commonly showed that perceived privacy risks of smart wearables significantly decreased their perceived usefulness of the devices and their intention to use them (Li, Ma, Chan, & Man, 2019; Li, Wu, Gao, & Shi, 2016; Mani & Chouk, 2017; Rupp, Michaelis, McConnell, & Smither, 2018) and good privacy images of certain manufacturer related to better attitude on their wearable products and higher intention to use them (Rauschnabel & Ro, 2016).

Factors such as cultural differences, user characteristics, and the application fields affect people's perception of privacy risks (Gao, Li, & Luo, 2015; Martin, Jovanov, & Raskovic, 2000; Moran, Nishida, & Nakata, 2013; Spagnolli, Guardigli, Orso, Varotto, & Gamberini, 2015).

For instance, fitness device users concerned more about privacy risks than medical device users (Gao et al., 2015).

Although privacy issues seem to be widely noticed, many people did not conduct any particular privacy-enhancing behavior or precaution (Lee, Lee, Egelman, & Wagner, 2016; Udoh & Alkharashi, 2016). This inconsistency between users' intention to protect private information and their actual behaviors not to do so refer to a phenomenon called the privacy paradox (Norberg, Horne, & Horne, 2007). Researchers even proposed that this phenomenon would aggravate due to the new features of the IoT technologies (e.g., intelligent wearables), such as constrained user interfaces, ubiquitous device presence, and vast data collection (Williams, Nurse, & Creese, 2016).

3.3.2 | Safety risks

The safety risk is another common challenge that was often concerned in the existing literature. According to the research, the safety risks are mainly caused by two factors, the physical attributes of the intelligent wearables and the way people interact with those devices.

Since wearable devices are often worn closely to human bodies or even directly attached to human bodies for a long period of times, potential damages caused by risk factors such as radiation and electric shock should be considered when designing a wearable device (Li et al., 2019).

Due to the different physical attributes of certain intelligent wearables, the potential safety risks are different. For example, smart glasses often present information on a screen that is very close to people's eyes, from which long-term use might bring side effects such as headaches, dizziness, and other discomforts (Zhao, Heida, van Wegen, Bloem, & van Wezel, 2015); wearing wearable devices for a long time may put burdens on human bodies or even result in musculoskeletal disorders (Knight & Baber, 2007). An empirical study examined the biomechanical workload of five tasks completed by participants in sitting and standing postures while using smart phone or smartwatch (Jin et al., 2019). The results showed that prolonged use of smartwatch would generate negative biomechanically impacts on human bodies, which indicated that only short usage on simple tasks should be conducted with the smartwatch.

Another line of studies concerns about the safety risks people face when they use smartwatches while driving. A lot of research has already paid attention to the phenomenon of phoning while driving (Yan, Chen, & Yu, 2013). Recent studies focused on the features of using a smartwatch while driving and comparing these features with the smartphone usage (Perlman et al., 2019). Smartwatches are able to realize some functions of smart phones and they are more portable. Thus, it seems reasonable to think that using a smartwatch while driving is safer and more convenient than a smart phone.

However, existing research results did not support such inferences. Giang, Hoekstra-Atwood, and Donmez (2014) found that although the engagement in using smartwatches is faster than smartphones, it took more time to read the notifications. The results preliminary indicated that the smartwatch usage may have more adverse effects on driving behaviors. A subsequent study replicated the result and further showed that participants needed more time to perform a brake response after receiving notifications from a smartwatch (Giang, Shanti, Chen, Zhou, & Donmez, 2015). More importantly, the study also found that though the use of smart phones and smartwatches while driving seemed to generate relatively equivalent risk, participants' perceived potential risk of using smartwatches was lower. And that may make people less cautious about using smartwatches while driving, resulting in more accidents.

3.3.3 | Performance risks

Performance risk refers to the potential that the products cannot work as expected. It has great influences on consumers' intention to adopt certain products including intelligent wearables. For example, Hwang, Chung, and Sanders (2016) found that U.S. consumers' perceived performance risks of the smart clothing negatively affected their attitude to it and hence reduced their intention to buy the product. Another study on elder Chinese adults also showed that participants' higher perception of performance risk led to a lower perception of health monitoring wearables usefulness, which could further prevent them from buying the wearable devices (Li et al., 2019).

One of the major functions of intelligent wearables is that they can continuously monitor people's daily behavior and activities. Therefore, whether one wearable device could accurately detect and measure the target parameters is an important performance issue (Rupp et al., 2018; Shih, Han, Poole, Rosson, & Carroll, 2015). In some contexts, such as clinical medicine, incorrect measurements may result in irreparable losses.

3.3.4 | Social and psychological risks

Wearing intelligent wearables is not just a behavior resulted from technological development. It is also driven by social and psychological factors. The psychological risk refers to the risks at the individual level, while the social risk refers to the potential risks caused by wearing smart wearable devices during the interaction among people. Those two kinds of risks often occur simultaneously and are intertwined.

The development of smart phone has made people unprecedentedly close to technological devices and the more portable wearables are making smart devices even more ubiquitous in human life. As mentioned before, intelligent wearables are able to work autonomously, together with its character of ubiquitous, those devices could be considered intrusive (Mani & Chouk, 2017). People may even feel a sense of autonomy loss on their use of intelligent wearables (Rauschnabel, He, & Ro, 2018). Those feelings of intrusiveness and loss of autonomy could lead to negative affect and reduce intrinsic motivations.

Some people may become too dependent on or even addicted to those intelligent wearables (Mani & Chouk, 2017). Take smart glasses as an example. When people are very accustomed to relying on their smart glasses to deal with various issues, they may get too distracted by the visual information on their smart glasses and lose awareness of what is happening around them (Hein, Jodoin, Rauschnabel, & Ivens, 2017). Moreover, this addiction may lead to a risk of social cohesion, which refers to a reduction of social interaction activities caused by

the frequent use of those devices (Hein et al., 2017). The usage of intelligent wearables can indeed harm others' interests, such as threats to others' privacy, and may further put a risk on social relationships (Kalantari, 2017).

3.3.5 | Other risks

Other risks include time and economical loss and the potential damage to environments. Time and financial risks refer to the possibility of losing time or money when investing, purchasing, or repairing wearable devices. Research indicated that those two risks negatively influence users' perception of wearable devices and could further reduce their intention to accept and purchase the devices (Ko, Sung, & Yun, 2009; Yang, Yu, Zo, & Choi, 2016). The above-mentioned risks are discussed from the perspective of general devices use. The use of smart devices can even increase the likelihood of time and economic loss. For example, the privacy leakage may cause huge economic loss in the field of mobile payments.

One article also proposed the risk of damage to the environment caused by smart clothes and wearable technologies (Timmins, 2009). Our clothes are often constructed from various substances which are not textile in origin. The electronic components incorporated in smart clothing make the recycling and reuse of those materials from abandoned clothing much more complicated and even impossible. Therefore, in the design and production of intelligent wearables, it is necessary to consider the potential burden and threat to the environment.

4 | FINAL THOUGHTS

Intelligent wearable technologies have already shown great application value and still have much potential yet to be developed. However, as intelligent wearables become more common, even laypeople could easily use those technologies to enhance their capabilities (e.g., gain accurate personal data), which may put themselves in risky situations without fully awareness of the potential risks (i.e., privacy risks, safety risks, performance risks, social and psychological risks, and other risks). Thus, researchers must put enough emphasis on the risks and familiarize the public with them.

Future research needs to provide a more precise definition of intelligent wearables. From a practical point of view, it is hard to absolutely distinguish between nonintelligent wearable devices and intelligent wearables. Most of the studies in behavior science focused on features and functions base on wearability, that is, how those devices ubiquitously exist in human life and monitor their behaviors. However, how do those devices connect with other objects and how does this connection interact with humans receive less attention. Therefore, it is suggested that more attention be paid to this feature of intelligent wearables.

Furthermore, the privacy issue is one of the most concerned risks. However, the existing studies mainly considered privacy risks from technical perspectives whereas privacy risks caused by people's uses of those wearable devices receive less consideration. Moreover, the phenomenon of privacy paradox suggests that although people tend to explicitly express their concerns about privacy, they do not always take actions to protect their private information. Therefore, studies on people's implicit attitude to privacy risks and their actual behaviors related to privacy issues are needed.

Last but not least, intelligent wearable technology is becoming an inevitable trend in people's life. From a marketing perspective, it is valuable to consider why people adopt certain wearable devices. However, what we also need to consider is, if we cannot stop this emerging technology from entering our lives, what forms we should let it exist in our lives.

ORCID

Yukang Xue https://orcid.org/0000-0002-6127-4836

REFERENCES

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8* (1), 19–32. https://doi.org/10.1080/1364557032000119616

Baca, A., Dabnichki, P., Heller, M., & Kornfeind, P. (2009). Ubiquitous computing in sports: A review and analysis. *Journal of Sports Sciences*, *27* (12), 1335–1346. https://doi.org/10.1080/02640410903277427

Baig, M. M., Gholamhosseini, H., & Connolly, M. J. (2013). A comprehensive survey of wearable and wireless ECG monitoring systems for older adults. *Medical & Biological Engineering & Computing*, *51*(5), 485–495. https://doi.org/10.1007/s11517-012-1021-6

Crager, K., & Maiti, A. (2017). *Information leakage through mobile motion sensors: User awareness and concerns*. Proceedings of the European Workshop on Usable Security (EuroUSEC). https://doi.org/10.14722/eurousec.2017.23013

Cunningham, M. S. (1967). The major dimensions of perceived risk. In D. Cox (Ed.), *Risk taking and information handling in consumer behavior*. Cambridge, MA: Harvard University Press.

De Looze, M. P., Bosch, T., Krause, F., Stadler, K. S., & O'Sullivan, L. W. (2016). Exoskeletons for industrial application and their potential effects on physical work load. *Ergonomics*, *59*(5), 671–681. https://doi.org/10.1080/00140139.2015.1081988

Fernández-Caramés, T., & Fraga-Lamas, P. (2018). Towards the internet-of-smart-clothing: A review on IoT wearables and garments for creating intelligent connected E-textiles. *Electronics*, *7*(12), 405–440. https://doi.org/10.3390/electronics7120405

Gao, Y., Li, H., & Luo, Y. (2015). An empirical study of wearable technology acceptance in healthcare. *Industrial Management & Data Systems*, *115* (9), 1704–1723. https://doi.org/10.1108/IMDS-03-2015-0087

Giang, W. C., Hoekstra-Atwood, L., & Donmez, B. (2014). *Driver engagement in notifications: A comparison of visual-manual interaction between smartwatches and smartphones*. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Sage CA: Los Angeles, CA: Sage Publications. https://doi.org/10.1177/1541931214581454

Giang, W. C., Shanti, I., Chen, H. Y. W., Zhou, A., & Donmez, B. (2015). *Smartwatches vs. smartphones: A preliminary report of driver behavior and perceived risk while responding to notifications*. Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 154-161), ACM. https://doi.org/10.1145/2799250.2799282

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information &*

Libraries Journal, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, *29*(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010

Hein, D. W., Jodoin, J. L., Rauschnabel, P. A., & Ivens, B. S. (2017). Are wearables good or bad for society?: An exploration of societal benefits, risks, and consequences of augmented reality smart glasses. In *Mobile technologies and augmented reality in open education* (pp. 1–25). Hershey, Pennsylvania: IGI Global. https://doi.org/10.4018/978-1-5225-2110-5.ch001

Heydarian, H., Adam, M., Burrows, T., Collins, C., & Rollo, M. E. (2019). Assessing eating behaviour using upper limb mounted motion sensors: A systematic review. *Nutrients*, *11*(5), 1168–1192. https://doi.org/10.3390/nu11051168

Hiremath, S., Yang, G., & Mankodiya, K. (2014). *Wearable internet of things: Concept, architectural components and promises for person-centered healthcare*. Paper presented at the 2014 4th International Conference on Wireless Mobile Communication and Healthcare-Transforming Healthcare through Innovations in Mobile and Wireless Technologies (MOBIHEALTH) (pp. 304-307), IEEE. https://doi.org/10.1109/MOBIHEALTH.2014.7015971

Holzmann, S. L., & Holzapfel, C. (2019). A scientific overview of smartphone applications and electronic devices for weight management in adults. *Journal of Personalized Medicine*, *9*(2), 31–42. https://doi.org/10.3390/jpm9020031

Hwang, C., Chung, T. L., & Sanders, E. A. (2016). Attitudes and purchase intentions for smart clothing: Examining US consumers' functional, expressive, and aesthetic needs for solar-powered clothing. *Clothing and Textiles Research Journal*, *34*(3), 207–222. https://doi.org/10.1177/0887302X16646447

Jin, S., Kim, M., Park, J., Jang, M., Chang, K., & Kim, D. (2019). A comparison of biomechanical workload between smartphone and smartwatch while sitting and standing. *Applied Ergonomics*, *76*, 105–112. https://doi.org/10.1016/j.apergo.2018.11.009

Kalantari, M. (2017). Consumers' adoption of wearable technologies: Literature review, synthesis, and future research agenda. *International Journal of Technology Marketing*, *12*(3), 274–307. https://doi.org/10.1504/IJTMKT.2017.089665

Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People*, *31*(3), 791–818. https://doi.org/10.1108/ITP-03-2017-0076

Knight, J. F., & Baber, C. (2007). Assessing the physical loading of wearable computers. *Applied Ergonomics*, *38*(2), 237–247. https://doi.org/10.1016/j.apergo.2005.12.008

Ko, E., Sung, H., & Yun, H. (2009). Comparative analysis of purchase intentions toward smart clothing between Korean and US consumers. *Clothing and Textiles Research Journal*, *27*(4), 259–273. https://doi.org/10.1177/0887302X08327086

Kritzler, M., Bäckman, M., Tenfält, A., & Michahelles, F. (2015). *Wearable technology as a solution for workplace safety*. Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia, ACM. https://doi.org/10.1145/2836041.2836062

Ledger, D., & McCaffrey, D. (2014). Inside wearables: How the science of human behavior change offers the secret to long-term engagement. *Endeavour Partners*, *200*(93), 1–17 Retrieved from http://pop.h-cdn.co/assets/cm/15/13/5512f7e752a4e_-_Wearables-and-the-Science-of-Human-Behavior-Change-EP4.pdf

Lee, L., Lee, J., Egelman, S., & Wagner, D. (2016). *Information disclosure concerns in the age of wearable computing*. NDSS Workshop on Usable Security (USEC) (Vol. 1). https://doi.org/10.14722/usec.2016.23006

Lee, Y., Yang, W., & Kwon, T. (2018). Data transfusion: Pairing wearable devices and its implication on security for internet of things. *IEEE Access*, *6*, 48994–49006. https://doi.org/10.1109/ACCESS.2018.2859046

Lewis, Z. H., Lyons, E. J., Jarvis, J. M., & Baillargeon, J. (2015). Using an electronic activity monitor system as an intervention modality: A systematic review. *BMC Public Health*, *15*(1), 585–599. https://doi.org/10.1186/s12889-015-1947-3

Li, H., Wu, J., Gao, Y., & Shi, Y. (2016). Examining individuals' adoption of healthcare wearable devices: An empirical study from privacy calculus perspective. *International Journal of Medical Informatics*, *88*, 8–17. https://doi.org/10.1016/j.ijmedinf.2015.12.010

Li, J., Ma, Q., Chan, A. H., & Man, S. S. (2019). Health monitoring through wearable technologies for older adults: Smart wearables acceptance model. *Applied Ergonomics*, *75*, 162–169. https://doi.org/10.1016/j.apergo.2018.10.006

Liu, X., Zhou, Z., Diao, W., Li, Z., & Zhang, K. (2015). *When good becomes evil: Keystroke inference with smartwatch*. Proceedings of the 22nd ACM SIGSAC Conference on Computer and Communications Security (pp. 1273-1285), ACM. https://doi.org/10.1145/2810103.2813668

Lunney, A., Cunningham, N. R., & Eastin, M. S. (2016). Wearable fitness technology: A structural investigation into acceptance and perceived fitness outcomes. *Computers in Human Behavior*, *65*, 114–120. https://doi.org/10.1016/j.chb.2016.08.007

Maiti, A., Armbruster, O., Jadliwala, M., & He, J. (2016). *Smartwatch-based keystroke inference attacks and context-aware protection mechanisms*. Proceedings of the 11th ACM on Asia Conference on Computer and Communications Security (pp. 795-806), ACM. https://doi.org/10.1145/2897845.2897905

Maiti, A., Jadliwala, M., He, J., & Bilogrevic, I. (2015). *(Smart) watch your taps: side-channel keystroke inference attacks using smartwatches*. Proceedings of the 2015 ACM International Symposium on Wearable Computers (pp. 27-30), ACM. https://doi.org/10.1145/2802083.2808397

Mani, Z., & Chouk, I. (2017). Drivers of consumers' resistance to smart products. *Journal of Marketing Management*, *33*(1–2), 76–97. https://doi.org/10.1080/0267257X.2016.1245212

Martin, T., Jovanov, E., & Raskovic, D. (2000). *Issues in wearable computing for medical monitoring applications: a case study of a wearable ECG monitoring device. Digest of Papers*. Fourth International Symposium on Wearable Computers, IEEE. https://doi.org/10.1109/ISWC.2000.888463

Moran, S., Nishida, T., & Nakata, K. (2013). Comparing British and Japanese perceptions of a wearable ubiquitous monitoring device. *IEEE Technology and Society Magazine*, *32*(4), 45–49. https://doi.org/10.1109/MTS.2013.2286419

Muaremi, A., Arnrich, B., & Tröster, G. (2013). Towards measuring stress with smartphones and wearable devices during workday and sleep. *BioNanoScience*, *3*(2), 172–183. https://doi.org/10.1007/s12668-013-0089-2

Nee, A. Y., Ong, S. K., Chryssolouris, G., & Mourtzis, D. (2012). Augmented reality applications in design and manufacturing. *CIRP Annals*, *61*(2), 657–679. https://doi.org/10.1016/j.cirp.2012.05.010

Norberg, P. A., Horne, D. R., & Horne, D. A. (2007). The privacy paradox: Personal information disclosure intentions versus behaviors. *Journal of Consumer Affairs*, *41*(1), 100–126. https://doi.org/10.1111/j.1745-6606.2006.00070.x

Patel, M. S., Asch, D. A., & Volpp, K. G. (2015). Wearable devices as facilitators, not drivers, of health behavior change. *JAMA*, *313*(5), 459–460. https://doi.org/10.1001/jama.2014.14781

Patel, S., Park, H., Bonato, P., Chan, L., & Rodgers, M. (2012). A review of wearable sensors and systems with application in rehabilitation. *Journal of Neuroengineering and Rehabilitation*, *9*(1), 21–37. https://doi.org/10.1186/1743-0003-9-21

Perlman, D., Samost, A., Domel, A. G., Mehler, B., Dobres, J., & Reimer, B. (2019). The relative impact of smartwatch and smartphone use while

driving on workload, attention, and driving performance. *Applied Ergonomics*, *75*, 8–16. https://doi.org/10.1016/j.apergo.2018.09.001

Peters, M. D., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., & Soares, C. B. (2015). Guidance for conducting systematic scoping reviews. *International Journal of Evidence-Based Healthcare*, *13*(3), 141–146. https://doi.org/10.1097/XEB.0000000000000050

Piwek, L., Ellis, D. A., Andrews, S., & Joinson, A. (2016). The rise of consumer health wearables: Promises and barriers. *PLoS Medicine*, *13*(2), e1001953. https://doi.org/10.1371/journal.pmed.1001953

Rauschnabel, P. A., He, J., & Ro, Y. K. (2018). Antecedents to the adoption of augmented reality smart glasses: A closer look at privacy risks. *Journal of Business Research*, *92*, 374–384. https://doi.org/10.1016/j.jbusres.2018.08.008

Rauschnabel, P. A., & Ro, Y. K. (2016). Augmented reality smart glasses: An investigation of technology acceptance drivers. *International Journal of Technology Marketing*, *11*(2), 123–148. https://doi.org/10.1504/IJTMKT.2016.075690

Rupp, M. A., Michaelis, J. R., McConnell, D. S., & Smither, J. A. (2018). The role of individual differences on perceptions of wearable fitness device trust, usability, and motivational impact. *Applied Ergonomics*, *70*, 77–87. https://doi.org/10.1016/j.apergo.2018.02.005

Saleem, K., Shahzad, B., Orgun, M. A., Al-Muhtadi, J., Rodrigues, J. J., & Zakariah, M. (2017). Design and deployment challenges in immersive and wearable technologies. *Behaviour & Information Technology*, *36*(7), 687–698. https://doi.org/10.1080/0144929X.2016.1275808

Sardini, E., Serpelloni, M., & Pasqui, V. (2014). Wireless wearable T-shirt for posture monitoring during rehabilitation exercises. *IEEE Transactions on Instrumentation and Measurement*, *64*(2), 439–448. https://doi.org/10.1109/TIM.2014.2343411

Schall, M. C., Jr., Sesek, R. F., & Cavuoto, L. A. (2018). Barriers to the adoption of wearable sensors in the workplace: A survey of occupational safety and health professionals. *Human Factors*, *60*(3), 351–362. https://doi.org/10.1177/0018720817753907

Schiboni, G., & Amft, O. (2018). Automatic dietary monitoring using wearable accessories. In *Seamless healthcare monitoring* (pp. 369–412). Cham: Springer. https://doi.org/10.1007/978-3-319-69362-0_13

Setz, C., Arnrich, B., Schumm, J., La Marca, R., Tröster, G., & Ehlert, U. (2009). Discriminating stress from cognitive load using a wearable EDA device. *IEEE Transactions on Information Technology in Biomedicine*, *14*(2), 410–417. https://doi.org/10.1109/TITB.2009.2036164

Shih, P. C., Han, K., Poole, E. S., Rosson, M. B., & Carroll, J. M. (2015). *Use and adoption challenges of wearable activity trackers*. Proceedings of the IConference 2015. Retrieved from http://hdl.handle.net/2142/73649

Spagnolli, A., Guardigli, E., Orso, V., Varotto, A., & Gamberini, L. (2015). *Measuring user acceptance of wearable symbiotic devices: Validation study across application scenarios*. In International Workshop on Symbiotic Interaction (pp. 87-98), Springer, Cham. https://doi.org/10.1007/978-3-319-13500-7_7

Teng, X. F., Zhang, Y. T., Poon, C. C., & Bonato, P. (2008). Wearable medical systems for p-health. *IEEE Reviews in Biomedical Engineering*, *1*, 62–74. https://doi.org/10.1109/RBME.2008.2008248

Timmins, M. (2009). Environmental and waste issues concerning the production of smart clothes and wearable technology. In *Smart clothes and wearable technology* (pp. 319–331). Sawston, Cambridge: Woodhead Publishing. https://doi.org/10.1533/9781845695668.3.319

Udoh, E. S., & Alkharashi, A. (2016, December). *Privacy risk awareness and the behavior of smartwatch users: A case study of Indiana University students*. Paper presented at the 2016 Future Technologies Conference (FTC) (pp. 926-931), IEEE. https://doi.org/10.1109/FTC.2016.7821714

Vallurupalli, S., Paydak, H., Agarwal, S. K., Agrawal, M., & Assad-Kottner, C. (2013). Wearable technology to improve education and patient outcomes in a cardiology fellowship program-a feasibility study. *Health and Technology*, *3*(4), 267–270. https://doi.org/10.1007/s12553-013-0065-4

Viteckova, S., Kutilek, P., & Jirina, M. (2013). Wearable lower limb robotics: A review. *Biocybernetics and Biomedical Engineering*, *33*(2), 96–105. https://doi.org/10.1016/j.bbe.2013.03.005

Vu, T., Lin, F., Alshurafa, N., & Xu, W. (2017). Wearable food intake monitoring technologies: A comprehensive review. *Computers*, *6*(1), 4–31. http://dx.doi.org/10.3390/computers6010004

Wang, C., Guo, X., Wang, Y., Chen, Y., & Liu, B. (2016). *Friend or foe?: Your wearable devices reveal your personal PIN*. Proceedings of the 11th ACM on Asia Conference on Computer and Communications Security (pp. 189-200), ACM. https://doi.org/10.1145/2897845.2897847

Wang, D., Dai, F., & Ning, X. (2015). Risk assessment of work-related musculoskeletal disorders in construction: State-of-the-art review. *Journal of Construction Engineering and Management*, *141*(6), 04015008. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000979

Wang, H., Lai, T. T. T., & Roy Choudhury, R. (2015). *Mole: Motion leaks through smartwatch sensors*. Proceedings of the 21st Annual International Conference on Mobile Computing and Networking (pp. 155-166), ACM. https://doi.org/10.1145/2789168.2790121

Williams, M., Nurse, J. R., & Creese, S. (2016). *The perfect storm: The privacy paradox and the internet-of-things*. Paper presented at the 2016 11th International Conference on Availability, Reliability and Security (ARES) (pp. 644-652), IEEE. https://doi.org/10.1109/ARES.2016.25

Yan, X., Li, H., Li, A. R., & Zhang, H. (2017). Wearable IMU-based real-time motion warning system for construction workers' musculoskeletal disorders prevention. *Automation in Construction*, *74*, 2–11. https://doi.org/10.1016/j.autcon.2016.11.007

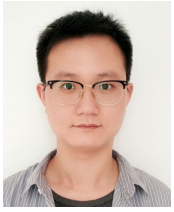
Yan, Z. (2017). *Mobile phone behavior*. New York, NY: Cambridge University Press. https://doi.org/10.1017/9781316417584

Yan, Z., Chen, Q., & Yu, C. (2013). The science of cell phone use: Its past, present, and future. *International Journal of Cyber Behavior, Psychology and Learning*, *3*(1), 7–18. https://doi.org/10.4018/ijcbpl.2013010102

Yang, H., Yu, J., Zo, H., & Choi, M. (2016). User acceptance of wearable devices: An extended perspective of perceived value. *Telematics and Informatics*, *33*(2), 256–269. https://doi.org/10.1016/j.tele.2015.08.007

Zhao, Y., Heida, T., van Wegen, E. E., Bloem, B. R., & van Wezel, R. J. (2015). E-health support in people with Parkinson's disease with smart glasses: A survey of user requirements and expectations in the Netherlands. *Journal of Parkinson's Disease*, *5*(2), 369–378. https://doi.org/10.3233/JPD-150568

AUTHOR BIOGRAPHY



Yukang Xue is a first year PhD student in the Department of Educational and Counseling Psychology at University at Albany, State University of New York. Prior to this, he completed his studies in a Master of Psychology at Central China Normal University in China. His research interests include the learning process of creativity and how creative performances are influenced by social and environmental factors (e.g., extrinsic motivators and digital technique).

How to cite this article: Xue Y. A review on intelligent wearables: Uses and risks. *Hum Behav & Emerg Tech*. 2019; 1–8. https://doi.org/10.1002/hbe2.173