Comparative User Experience Analysis of Pervasive Wearable Technology

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Abstract. Although the growing market of wearable devices primarily consists of smartwatches, fitness bands, and connected gadgets, its long tail includes a variety of diverse technologies based on novel types of input and interaction paradigms, such as gaze, brain signals, and gestures. As the offer of innovative wearable devices will increase, users will be presented with more sophisticated alternatives: among the several factors that influence product adoption, perceived user experience has a significant role. In this paper, we focus on human factors dynamics involved in the pre- and post-adoption phase, that is, before and after customers buy or use products. Specifically, objective of our research is to evaluate aspects that influence the perceived value of particularly innovative products and lead to purchasing them. To this end, we present the results of a pilot study that compared performance expectancy, effort expectancy, social influence, and facilitating conditions, in the pre- and post-adoption stages of three types of wearable technology, i.e., brain-computer interface, gesture controllers, and eye-tracking systems.

Keywords: Technology Acceptance Model · Unified Theory of Acceptance and Use of Technology · Performance expectancy · Effort expectancy · Social influence · Eye tracking · Gaze tracking · Gesture controllers · Brain-Computer Interface

1 Introduction

In the last decade, the evolution of mobile devices and their market penetration resulted in the capillary adoption of the smartphone as a wide-spread platform for human-computer interaction; also, the introduction of smartwatches and fitness bands demonstrated the potential of wearable consumer electronics and simultaneously rendered them mainstream. As a result, the market of wearable technology has experienced a constant growth, in the last years. Moreover, the success of smartphones and smartwatches accelerated the development of miniaturized components (e.g., cameras and inertial measurement units) that can be embedded into eyewear, head-mounted displays, clothing, wristbands, gloves, and several types of body attachments. Nowadays, more sophisticated components, such as, electroencephalograph, myoelectric sensors, vibration and ultrasound actuators are incorporated in consumer wearable devices that enable novel interaction modalities. Consequently, the segment of smartwatches and fitness bands has reduced significantly, as demand has recently shifted to head mounted displays (HMD) and novel types of devices, such as, gestures controllers, body cameras, glasses that support augmented reality, and smart clothing. Recent statistics about the next 5 years project that 25% of the wearable device market will consist of a fragmented ecosystem of different types of products, each representing a niche consisting of innovative products offering non-conventional interfaces and interaction paradigms [1]. Moreover, as new technology will be developed, the segment of non-mainstream wearable devices will grow and, simultaneously, its internal fragmentation will increase, producing a broader and richer galaxy of choices.

The market of wearables is unique in terms of breadth and variety: the presence of recent and non-conventional technology, in addition to the many available alternatives results in more difficult buying decisions. This, in turn, is particularly interesting from a user experience standpoint, in specific regard to the human factors that influence the decision-making process for adopting a non-mainstream technology and buying a specific product. Indeed, marketing and sales strategies are crucial for creating awareness and for incentivizing prospect customers. Also, users might finalize a purchase considering aspects, such as, technical specifications (e.g., product longevity, battery life), opinions and reviews, and price. These factors are especially significant for intra-category decisions, that is, choices between two alternatives of the same product (e.g., different brands, versions, or technical characteristics). Nevertheless, several other factors, more strictly related to the intrinsic aspects of user-product interaction, might play a significant role in influencing buying patterns and have a broader impact in inter-category decisions.

Several studies investigated human factors dynamics that occur during or after product adoption. Conversely, in our work, we are especially interested in analyzing user experience in the context of innovative and non-conventional pervasive wearable devices, with particular regard to user-product interaction in the pre-purchase (or pre-adoption) phase. Specifically, in this paper, we investigate the human factors involved in the awareness and evaluation stages of the sales funnel. To this end, we use the Unified Theory of Acceptance and Use of Technology (UTAUT) [2] to analyze measures that help assess the behavioral intention to use a technology, such as, performance expectancy, effort expectancy, social influence, and facilitating conditions, which might be utilized as a predictor of acquisition and discontinuation dynamics in early adopters as well as other types of customers. Moreover, we present the results of a study that analyzed three types of non-mainstream consumer technology in the context of pervasive wearable devices, that is, brain-computer interfaces (BCIs), eye-tracking systems, and gesture controllers. Incorporating human factors in the earliest stages of the sales funnel might help vendors design marketing strategies that align better with user expectations before the purchase, deliver consistent user experiences without solution of continuity, and, consequently, decrease post-adoption dissatisfaction, frustration, discontinuation, and product abandonment.

2 Related Work

Nowadays, the design of novel, user-centered products is supported by a growing repository of methodologies, guidelines, and patterns. Furthermore, research on usability and acceptance led to inspection methods (e.g., heuristic analyses, interviews, and observational studies) that enable the evaluation of devices and software before they are marketed. In contrast, several communities are still contributing to define the fuzzy boundaries of user experience: as UX covers a broader spectrum of aspects, the design and evaluation of technology and processes often rely on tools and practices from different domains rather than on a coherent set of practices [3]. Moreover, typically user experience is regarded in the post-adoption phase, and earlier stages of the sales funnel deserve more research. Studies that observed the pre-sale stage of products focused on extrinsic factors of user-product interaction, such as, marketing. Indeed, ancillary aspects of the product, such as, package design and other factors related to brand identity, influence user experience and buying patterns [4]. In the last decades, holistic models and frameworks have been developed to extend the analysis of user experience to aspects beyond product interaction that occurs after purchase or adoption. Specifically, customer journey [5] takes into consideration prospect users as well as loyal customers, and helps investigate factors that incentivize purchase, motivate adoption, and reduce abandonment. Conversely, the Unified Theory of Acceptance and Use of Technology (UTAUT) [2] was developed with the aim of synthesizing several models (e.g., the technology acceptance model) that describe the behavioral intention to use a technology and help compare it with dimensions perceived in the actual adoption. The meaningful role of temporality in product use is analyzed in [6], which showed that early experiences and prolonged use are characterized by very different user experience dynamics. The authors of [7] investigated sensory modalities in user-product interaction with three categories of articles (i.e., high-tech devices, shoes, and coffee maker) before purchase and at different stages of adoption: sensory dominance (i.e., the relative importance of vision, audition, touch, smell, and taste) change over time depending on product type, relevance of the sensory channel to product interactions, and familiarity with the product. Also, it significantly varies between pre- and post-purchase and, thus, demonstrate the need of investigating user experience of prospect customers from earlier stages of the sales funnel.

Nevertheless, most of research focused on direct user-product interaction, whereas indirect user experience, which typically occurs in the pre-adoption phase, received less attention [8]. The relationship between extrinsic elements, such as, online customer reviews, on user experience and their relationship with buying patterns was investigated by [9], which showed correlation between customer decisions and features, such as, level of experience of the author and social metrics of the of the review. The role of simulated user-product experience has been investigated in [10]: virtual reality (VR) is utilized for enabling prospect customers to experience products, with specific regard to items that introduce novelty in the market and devices that incorporate highly innovative features. Also, simulated products were utilized in [11] to create hedonic user experiences that could influence user satisfaction and increase willingness to adopt product. Unfortunately, there is a lack of studies that compare indirect and direct dynamics that specifically regard user-product relationships at the individual level in the pre-purchase phase.

3 Experimental Study

The objective of our study was to evaluate the human factors that influence the adoption of non-mainstream innovative devices, with specific regard to pervasive wearable technology. To this end, we analyzed intrinsic and extrinsic aspects that characterize user-product experience in the pre- and post-adoption phases and compared indirect and direct experiences. In our study, we modeled human factors utilizing the UTAUT model, which consists of five dimensions that can used as predictors of the intention to adopt and use technology, as well as validation criteria.

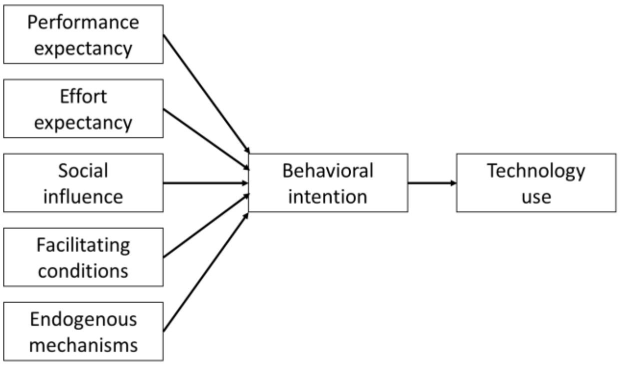

Fig. 1. Diagram representing the UTAUT, which incorporates several user experience measures as drivers for the behavioral intention to buy a product or adopt a technology.

Performance expectancy. This aspect refers to the belief that the use of a particular technology will enhance the performance of an individual or will produce some advantage in realizing a task. This is particularly relevant to non-conventional wearable technology, as signals acquired from the body can be utilized to seamlessly control interaction, make it more efficient, or improve the range or accuracy of commands.

Effort expectancy. This is a two-fold measure: on the one hand, it refers to the perceived skillset required to be able to utilize a system and the expected learning curve (human-machine co-evolution). Simultaneously, it relates to the extent of convenience perceived in using the system. Innovative wearable devices that recognize gestures, brain signals, or gaze simplify input, though mastering their use requires training.

Social influence. This component refers to user's perception of beliefs or impressions that the product will generate in others (their milieu, their social group, or the external community). This includes the ability of a device to improve the social status of an individual or to create a desired social image. Moreover, this measure involves social acceptance of technology in a given context of reference. This dimension is particularly relevant in wearables, especially if they are visible or intrusive: they could be perceived as innovative gadgets or associate the user with some medical condition and, depending on the social context of use, pose risks to users' safety (e.g., theft).

Facilitating conditions. Extrinsic factors, such as, battery life, device compatibility and availability of product accessories and features that render the product more versatile might be a driver for adoption. Also, presence of technical support and user's guide might increase the likelihood of acquiring products. Moreover, individuals might consider expected product longevity, which, in turn, is influenced by the presence of a number of applications, features that demonstrate other options for potential use, or an active community or marketplace.

Endogenous mechanisms. Intrinsic factors that are not related to product experience are associated with individuals' conditions or beliefs, social background, and education. As this often is a multifaceted aspect, we included open-ended questions to elicit participants' impressions.

3.1 Technology

Three devices were chosen for this study, involving diverse types of innovative wearable technology. Products were selected among non-conventional interfaces that are representative of a niche of wearables involving more sophisticated human-computer interaction dynamics compared to fitness bands and smartwatches. Although the devices had diverse levels of maturity, all of them were non-mainstream technology. This was to avoid any confounding effect introduced by individuals' familiarity with brand. Figure 2 shows the three products.

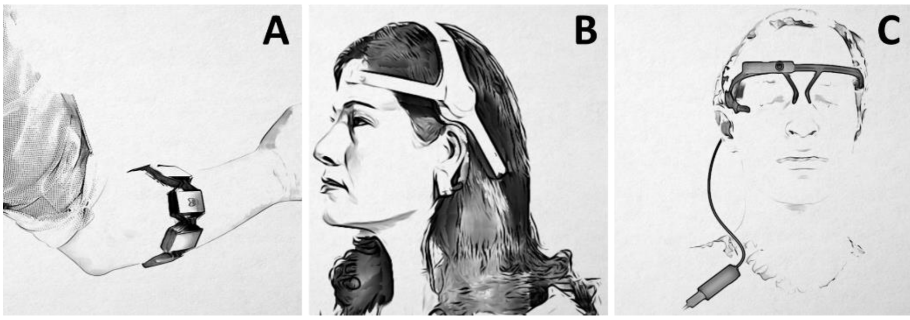

Fig. 2. The products utilized in the study: Gesture controller (A), a Brain-Computer Interface device (A), and eyewear integrating gaze tracking (C).

Gesture controller. Myo is a wristband equipped with electromyographic sensors [12] that convert electrical activity in the muscles of a user's forearm into gestures for controlling computers and other devices. Different types of gesture controllers have been embedded in wearables [13] and utilized for enabling more realistic control especially in tasks that involve manipulation [14]. Although sales have been discontinued, documentation and videos are available on the Internet.

Brain-Computer Interface. Mindwave [15] is an affordable commercial EEG device for non-medical use that utilizes one electrode placed on the forehead to sense the electrical activity of the occipital area of the brain and detect attention and concentration. It is one of the several attempts to introduce BCI in scenarios that primarily are associated with clinical conditions [16].

Eye tracking. Pupil is an eyewear that incorporates high speed cameras that capture movements of the pupil, so that the position of the eyes can be calculated and represented over the video stream acquired using a front camera, which represents user's perspective [17]. Typically, the wearable eye-tracking devices are utilized in the evaluation of immersive and physically-immersive experiences [18] [19].

3.2 Protocol

The experimental protocol was divided in three phases based on three stages of user experience: indirect, direct, and early use.

Task 1 – Indirect use. Participants were provided with the description of the three products and a survey that asked them questions that assessed different items in the five dimensions of user experience defined in UTAUT. Respondents were given one week to complete the questionnaire and evaluate the devices based on indirect use, that is, by experiencing the technology through information available on the Internet (e.g., product website, tutorials, reviews).

Task 2 – Direct use. Subjects were provided with the three devices: they were asked to install and use each of the products for 20 minutes, and to rate them by filling a questionnaire similar to the one they received for task 1, which captured their direct experience with products.

Task 3 – Early use. Subjects were provided with the three devices for four days, and they were asked to realize three simple projects each involving a technology. Also, they were asked to complete a questionnaire similar to the one they received for task 1, so that we could compare their direct experience over a longer period.

3.3 Participants

A total of 14 subjects (7 females and 7 males) were recruited for this study, 14 (43%) aged 18-24, 11 (36%) were in the 25-34 range, and 3 (21%) were in the 35-44 bracket. None of them had previous experience with the devices utilized in this study, though all of them were familiar with information technology and high-tech gadgets. All of them had basic programming skills (i.e., they utilized Arduino). Also, 3 of them (21%, 2 males and 1 females) reported themselves as early adopters, whereas the others (79%) showed different patterns in regard to the adoption of new technology.

4 Results and Discussion

The objective of our study was not to evaluate the specific products or technologies, as preferences can be influenced by several factors that were not under our control.

Moreover, as products in each category come in different versions and have diverse characteristics and advantages, we did not compare individual devices with one another. Conversely, our objective was to evaluate how user experience of different types of innovative wearable technology changes over time and, specifically, between indirect and direct use. To this end, we calculated the behavioral intention to use as a compound measure of the five items in the UTAUT inventory, in addition to assessing its individual dimensions separately, to identify their role at different stages of user-product experience. Figure 3 describes users' behavior after indirect use.

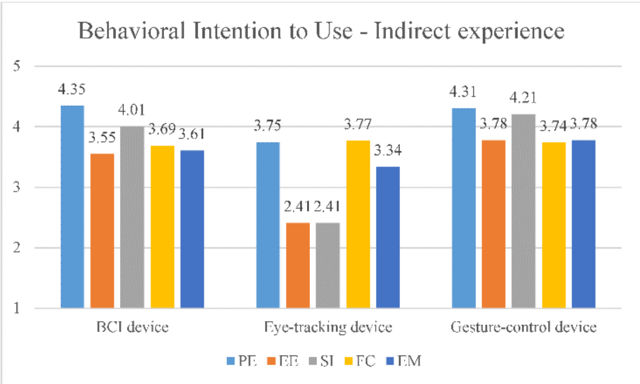

Fig. 3. Behavioral intention to use the technology based on indirect user-product experiences. Performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC), and endogenous mechanisms (EM) were considered for each technology.

Participants considered performance expectancy as their most important drivers (see Figure 1). As users were familiar with technology gadgets, they described the eye-tracking device as a less user-friendly system. However, this was mainly due to the fact that they recognized that it is mostly available to researchers in the field of gaze tracking, whereas the other products appeared specifically geared towards consumers. Therefore, subjects expected the eyewear to be more difficult to operate and less impactful from a social standpoint. Moreover, the form factor of the wearable eye tracker resulted more intrusive than other products and less suitable for social interactions.

Despite specific differences due to the design of the products and their documentations, all the wearables considered in the study were well received by participants during indirect user-product experiences. In this phase, the compound measure of the behavioral intention to adopt a technology aligns with the actual willingness to buy stated by subjects, as shown in Figure 4. The eye tracking device represents an exception for the reasons discussed earlier in this Section. In the second part of our study, subjects received the devices and tried to install and use them. In this phase, effort expectancy had a significant impact on the results. Consequently, as the eye-tracking device is tailored to a technical audience, its setup time affected users' willingness to adopt it. Finally, data from early direct user-product interaction show an overall decrease in the likelihood to adopt the three products. In this case, the actual and compound measure of the willingness to adopt are not statistically comparable, though the data from the eye tracking device might introduce some bias in the outcome.

Furthermore, our findings show that users' perceived importance of the aspects described in UTAUT changes in the three phases of product use. Specifically, performance and effort are considered key factors during indirect use, whereas effort is considered as a crucial aspect during the first phase of direct experience. As users become more familiar with the product, the importance of performance and facilitating conditions increases. As shown in Figure 5, the human factors that are involved in indirect use could be considered as a predictor for performance expectancy, effort expectancy, social influence, and facilitating conditions, though users tend to underestimate the importance of the latter.

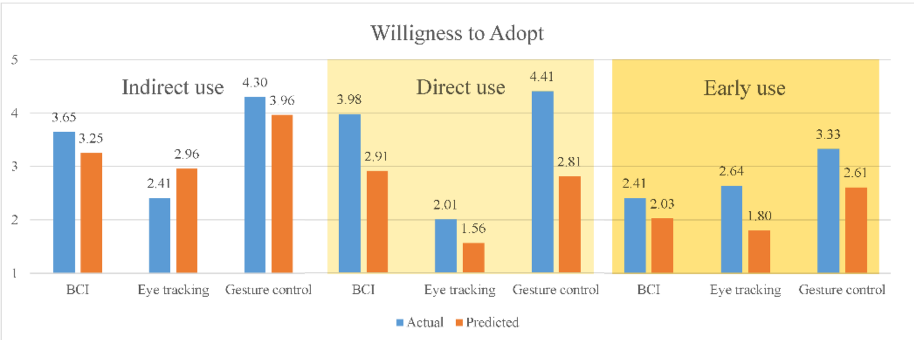

Fig. 4. Individuals' willingness to Adopt a technology based on user experience in indirect, direct, and early user-product interaction. The predicted value is calculated as a compound measure of the five dimensions of UTAUT, whereas the actual value represents subjects' response to a question that explicitly asked their willingness to buy the product.

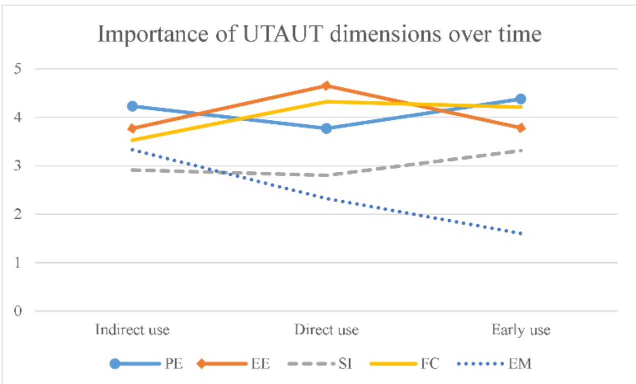

Fig. 5. Perceived importance of each of the five UTAUT dimensions in the three stages of product use recorded in the study.

Finally, as users became more proficient with the use of technology, they mentioned lack of applications as one of the factors related to facilitating conditions that affected user experience in the early adoption of all the devices. Although companies offer software development kits that enable creating new opportunities to use the technology, users perceived the three wearables as very situation-specific, which contrasted with the performance expectancy fostered experienced during indirect interaction.

5 Conclusion

In this paper, we analyzed user experience in user-product interaction and compared three categories of innovative wearable interfaces, with the objective of understanding dynamics of user adoption in indirect and direct use. Assessing the criteria that guide choice and abandonment of technology is relevant especially considering that the offer of alternative, non-mainstream input and output interfaces is expected to grow in the next years. In our study, we utilized the Unified Theory of Acceptance and Use of Technology to model and capture the diverse human factors that occur at different stages of user-product experience. From our findings, we can conclude that endogenous mechanisms played a secondary role in indirect and direct use; also, social influence was a minor factor, though it might be due to individuals' low awareness of the types of technology assessed in our study. Furthermore, our results show that the dimensions of the behavioral intention to buy have different weights depending on the stage: users have high performance expectations when they indirectly interact with wearables, whereas effort expectancy is considered the main factor in direct user-product experience. Moreover, facilitating conditions play an increasing role as users become more proficient with the product and, simultaneously, discover the lack of available applications, which results one of the main motivations for potential product discontinuation. In conclusion, the main long-term challenge in the introduction of novel interfaces for pervasive interaction consists in increasing product longevity by providing users with more applications and usage scenarios that align their direct experience with performance expectancy and product expectations generated in indirect interaction.

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