Design Recommendations to Improve the User Interaction with Wrist Worn Devices

Byron Lowens, Vivian Motti, Kelly Caine
School of Computing – Clemson University
Clemson, SC, USA
{blowens,vgenaro,caine}@clemson.edu

***Abstract*— Wrist worn devices (WWDs) including fitness trackers and smart watches have been successfully employed to support various applications, ranging from gesture recognition to authentication. Despite the increasing number of WWDs in the market, their limited dimensions and capabilities make their interaction design challenging. Designers struggle to downsize interactions originally designed for mobile phones, and end users wish for interactions that are easy to use. To better understand the users' concerns regarding the interaction with WWDs, we collected feedback about existing wearable bands, and analyzed the most critical issues currently faced in the interacting interaction with such devices. The analysis of the findings enabled us to derive 10 design recommendations that can aid to improve the interaction design in novel WWDs.**

Keywords — wrist worn devices, wearable devices, interaction design, multimodality, user-centered design

I. Introduction

The recent advances in technology, with miniaturization of components, more efficient power sources, and novel sensors boosted the development of wearable devices. Wrist-worn devices (WWDs), in particular, significantly increased in number and variety in the past decades. Their conventional form factors and ability to house different sensors enable these devices to support a variety of applications in both industrial and academic settings. Mainly employed as fitness trackers (e.g., FitBit and Nike+) and smart watches (e.g., Samsung Galaxy Gear and Pebble), WWDs have been successfully applied to support less conventional activities as well, including gesture recognition (e.g., Thalmic Myo) and authentication (e.g., Nymi).

Despite the growing number of brands, models, and versions available, designing the interaction and interfaces for WWDs is still challenging. First, the small dimensions of WWDs limit the possible solutions for alternative designs. Second, WWDs are a reasonably novel trend. The designs of their interaction and interfaces is still in an exploratory phase, making it harder to find standard solutions (well-known and largely accepted) and best practices in this field. Finally, the users interact with WWDs in dynamic contexts, for instance while they are walking or driving, which requires interactions in a short period of time, with brief, but effective notifications.

The inherent complexity and challenges associated with the design of efficient interfaces for WWDs, summed with the lack of guidance for stakeholders, can result in low wearability levels, and consequently dissatisfied users. By analyzing the feedback of wearable users [1], we note that the interactions with WWDs still suffer from important issues, which results in dissatisfaction, high abandonment rates, [2] and lack of sustained engagement among WWDs' users.

To identify key user concerns in the interaction with WWDs, as well as to gain a better understanding of what can be improved in their design, we collected the user feedback about 11 existing devices, including fitness trackers, armbands, and smart watches. We then identified and analyzed the main issues currently faced by end users. Finally we derived a set of 10 design recommendations that can help stakeholders (such as designers, developers and researchers) to improve the design of the human-device interaction with WWDs. The number of previous research findings that can in fact encourage stakeholders to improve on the acceptability of wearables is very limited [1]. We believe the recommendations proposed in this paper can offer a greater degree of success for the future development of WWDs, as well as contribute to the acceptance and long-term engagement of users with these devices.

This paper is organized as follows: Section 2 presents related work, Section 3 describes the methods, Section 4 presents the findings (users' concerns about their interaction with WWDs and respective design recommendations), Section 5 discusses this work and Section 6 concludes it.

II. Related Work

In this section, we present and discuss previous related work highlighting examples of WWDs' applications, benefits, and drawbacks of online reviews, as well as previous work on interaction, support, design, and current solutions for WWDs.

A. Online Reviews

User-reviews have become an important source of information about the users' perception on products and services [3]. These reviews are considered as instruments that facilitate customers to evaluate products, while providing to potential stakeholders recommendations for improving products [4]. The analysis of online reviews present stakeholders with a comprehensive insight on user perception and suggestions for improvements on existing products.

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While consumer evaluations in online reviews are often perceived as credible and trustworthy [5], previous research has identified certain limitations that are associated with the validity and usefulness of online reviews. In certain review instances, it is not clear whether typical users or malicious parties wrote and published online reviews. Sometimes users with unintentional purposes may have written comments to sound authentic and deceive the readers [6], [7]. Although there is a growing concern about this issue, there is not much literature to support the actual prevalence of deception in online review communities [7]. By collecting a large number of online commentaries, one minimizes the bias that unintentional reviews can introduce in their analysis.

Online reviews are often the valuable voice of the customer, which benefits both consumers and stakeholders [8]. Customer reviews on commercial and dedicated review sites not just summary assessments or recommendations, but are also self-reports of the end users personal experiences with certain products [6]. Usability testing on products often provides stakeholders with a general and limited perception from users on a product, but certain technologies, such as WWDs, may need frequent usability testing since the interaction approaches with these devices are novel. Usability studies also focus on short-term product use, which may cause limitations for a design [6]. Hedegaard et al. noted that in previous research studies, online reviews described user opinions and experiences after a more prolonged use, which motivated us to use this approach to understand the user perception about the interaction with WWDs. Online reviews also focus on studying the users' in the wild and voluntarily, as they use their devices in conventional situations and express self-reports of their perceptions.

B. WWDs

Wearable computing comprehends a large range of devices characterized by body-worn computers, including clothing and accessories. In order to be most beneficial for users and provide efficient interaction solutions, these devices must be designed properly in terms of performance and reliability [1], [9].

Previous research conducted on wearable devices has effectively addressed the issues of frequent access to computing resources by employing a wearable device that is constantly at the user's disposal [10]. Pascoe et al. believe that a more subtle form of wearability, such as with WWDs, can combine the benefits of a persistent and readily accessible device with a more socially and fashionably acceptable form that does not distract or hinder the users from their main activities.

WWDs are affixed to the user's wrist and are out of the way of the user's hands and eyes, which places minimal requirements on the user [11]. The wrist has always been a usual place for wearable technology. While smartphones offer interfaces for display and control for many users, they are generally kept in the users' pocket or bag, which limits their pervasiveness when they are not actively being operated. This limitation has presented a platform for WWDs to make a comeback as wearable information displays which can be paired with smartphones [12].

C. Applications of WWDs

In recent years, the personal fitness industry has seen an explosion and increased popularity of wrist worn devices, such as fitness trackers with sensors for monitoring users' physical activity levels, including the number of steps taken, distance walked or ran, and caloric expenditure [13], [14]. Along with fitness trackers are actigraphs (activity trackers), which are some of the most commercially successful types of wearable devices that have made their way into the lives of millions of consumers worldwide [15].

Despite the large number of WWDs in the market, this study focuses on a sample of 11 devices with four main purposes. We briefly exemplify 5 of these devices below, illustrating their different applications:

1) Jawbone Up: Jawbone Up focuses on helping users to live healthier. The primary function of this WWD is to track and monitor physical activity and sleep. The device app displays the data collected and lets users to be more informed about the changes they should make to achieve healthier lifestyles [16].

2) Fitbit Flex: Fitbit Flex is a WWD similar to the Jawbone Up. This device tracks steps, distance, and calories burned throughout the day. It permits users to track their sleep patterns and quality and to set a silent alarm when needed [17].

3) Nymi: Nymi allows the users to authenticate themselves, using their unique cardiac rhythm as identity. This allows users to wirelessly take control of their computer, smartphone, car, and so on [18].

4) Thalmic Myo: The Myo WWD is a gesture-controlled armband that uses EMG signals of the muscle activity of the user arm to control digital devices over Bluetooth 4.0 Low Energy. This WWD permits users wireless control of computers, smartphones and other technologies with arm gestures [19].

5) Samsung Galaxy Gear: The smartwatch industry has seen a tremendous growth within the past year and these WWDs are being rendered as a novel technology that might bring wearable computing to the masses [20]. Samsung Galaxy Gear is an example of smartwatch that is included in our list of devices for data collection and analysis. This versatile WWD offers users a wide array of features such as: the ability to receive notifications, locate a misplaced smartphone, keep smartphone contents secure, and make hands-free calls [21].

D. Limitations

Wrist worn devices have been demonstrated to be successful to many users in a variety of scenarios. However, along with their benefits come certain limitations [1]. WWDs represent a current extreme in computing because stakeholders have not thoroughly studied the tradeoffs associated with the design of these devices' interfaces [22]. One of the most immediately striking challenges for researchers and designers of WWDs is creating appropriate interfaces, along with addressing interaction design, and privacy related issues [9], [21].

When considering the interaction design for WWDs, stakeholders typically focus on explicit interaction instead of implicit interaction with the device [11]. Explicit interaction refers to a device being used in its active state, while implicit interactions refer to passive interaction with the device, e.g. when it is not being used, but still on the body [11], [24]. It is necessary to consider both types of interactions with WWDs because a user tends to shift between a set of dispositions based on the usage needs of the device [11].

Undeniably, WWDs have inherited many of the concerns associated with the design of mobile computing systems. However, WWDs do not have past models that are suggestive enough to make sense of this new paradigm [23], [26]. There is no precursor to a full-scale of the novel WWD platform. These highlighted issues should be addressed to ensure the continuous improvement in the design of WWDs [24].

III. Methods

To identify the users' concerns about their interaction with WWDs, we first selected a set of 11 devices, and 59 web sources (IT forums, social media, e-commerce sites), then we accessed the sources, searched for the devices, identified reviews and commentaries, and extracted those to external reports (text documents). Then we read all comments, identified the comments related to the user interaction, tabulated the comments according to the modality (audio, graphic, gesture and tactile), highlighted the pros and cons, and analyzed those. The analysis focused on current users' concerns and enabled us to group these concerns in specific categories of problems and recommendations. To summarize the findings of our analysis, we identified the users' comments related to interaction concerns (negative aspects), and derived a retrospective set of design recommendation to address users' issues and as such to prevent or mitigate potential problems. The users' commentaries involving positive feedback about the devices assisted us in defining the design recommendation as well.

To ensure protection of the human subjects, before data collection started, this study was approved by the Institutional Review Board (IRB) of the Clemson University as exempt. We opted to perform an online search to collect updated data about an extensive set of devices, regardless of their purpose, and user profile (e.g. age, gender, expertise level). Only commentaries related to the research themes were selected, covering WWDs, and the user feedback about interaction. Even though some devices are more popular (e.g., FitBit vs. Nymi) and more recent than others, we aimed at extracting a representative sample of comments.

Before the analysis of the contents, no pre-defined hypotheses were adopted, thus the research findings emerged from a bottom up approach, using a qualitative analysis of textual contents, inspired in ground theory and aiming at identifying users' concerns with the interaction with WWDs and at deriving respective design recommendations.

Table 1. List of WWDs selected for data collection and analysis

Device	Purpose	Comments
Basis B1 www.basisb1.com	Fitness and sleep tracker	276
BodyMedia www.bodymedia.com	Activity tracker, sleep monitor	76
FitBit Flex www.fitbit.com/flex	Fitness tracker	83
Jawbone Up www.jawbone.com/UP	Fitness tracker	78
Microsoft Band www.microsoft.com/Microsoft-Band	Fitness tracker	408
Misfit Shine http://misfit.com/products/shine	Activity tracker (fitness, sleep)	163
Nike Fuel Band http://www.nike.com/us/en_us/c/nikeplus-fuelband	Activity tracker	78
Nymi www.getnymi.com	Authentication via heart beat	59
Samsung Galaxy Gear www.samsung.com/us/mobile/wearable-tech/SM-V7000ZKAXAR	Smart watch	82
Sony SWR10 www.sonymobile.com/global-en/products/smartwear/smartband-swr10/	Smart band	197
Thalmic Myo www.thalmic.com/en/myo/	Gesture control armband	265

A. Data Collection

From May 2014 to November 2014, we collected users' commentaries about 11 devices of different purposes including: fitness trackers, smart watches, gesture recognition, and authentication. The contents were extracted from a total of 59 sources, resulting in a total of 1349 comments. The online sources used comprised of a combination of e-commerce websites that offer access for customers to read about and review the products sold online and other companies that provide a forum that permits people to share their opinions, recommendations and discuss about products.

B. Data Analysis

To analyze the data we searched for commentaries related to the end user interaction with wrist-worn devices, their interfaces, key users' concerns, and preferences (design recommendations). In order to prevent possible threats to external validity, and cover different users' profiles, for our set of 11 devices, we collected data from 59 sources, with a mean of 134 (n=1349).

Table 2. Percentage of comments per interaction modality

	Graphic	Gesture	Tactile
Positive	8 %	7 %	19 %
Negative	9 %	35 %	7 %

C. Findings and Design Implications

With the identification and analysis of key users' concerns about the interaction with WWDs, and aiming at improving existing WWD interfaces for future devices, we derived design recommendations. Focusing on interaction design, 297 key concerns emerged from a bottom up content analysis.

IV. Design Recommendations based on Users' Perceptions about their Interaction with WWDs

Based on the shortcomings identified in our related work, we can conclude that there is room for improvement in the usability of WWDs. The main results of our analysis of users' concerns indicate that users are mainly concerned with the (lack of) accuracy of their devices, likely because existing devices tend to ignore the contexts of the user during the interaction. Although our study focused particularly on users' concerns about interaction, we did notice reoccurring issues associated with privacy and battery power in our qualitative list of frustrations. These issues are out of the scope of this paper, but will be briefly mentioned for information purposes. Issues specific to privacy and battery power deserve further attention in future studies. In this paper we present the key users' concerns with WWDs and respective recommendations that can aid stakeholders in the future to improve the interaction design of WWDs in future generations.

One of the main findings, suggests that existing devices are not able to properly identify, understand, and interpret the current user contexts, leading to a data collection and interpretation oftentimes inaccurate (e.g., users sweat and the sensors loose contact with the skin, users move and the heart rate is higher than the sensor can collect, the arm is involved in numerous different activities which does not imply in steps). As a consequence the devices are ineffective with regards to their main purpose.

Users' complaints about these issues include:

"...if you sweat too much I guess, the watch looses contact with your skin or something and fails to even record data points that it was designed to record in the first place. The buttons used for toggling displays stop working too! "

"The Flex relies on moving your wrist, so it doesn't track accurately if you run/walk on a treadmill and don't swing your arms. I played a couple hours of roulette one night and logged 10K steps just playing with my chips. I've experimented with the dominant vs. non-dominant hand and changing the sensitivity but it still doesn't work well. Very disappointing when you are using it for motivation to achieve a daily goal."

Additional concerns were also noticed, for instance regarding the durability of the screen and buttons:

"I rated durability low partly because of the waterproof issue but also because they say that it's water resistant but that's not entirely true. When in the shower the buttons on top all fire and forums say the display can lose lines. Also the face scratches easily"

"*I am a Pebble owner, and I definitely have to agree that the durability of the front display is a big problem. I already managed to scratch mine (through carelessness), and I hate to think what would've happened if I had scratched the center of the watch, rather than the edge."*

Further concerns involve issues with privacy and battery:

"The first thing a normal user would think of when wearing this wristband would be is it secure? With the number of recent attacks on different companies and the large scale data loss would wearing this device truly be secure? After all the recent thefts of data users would really consider the effects that stolen data from this device would have"

"This watch is absolutely terrible. Impossible to charge. You have to remember to keep syncing the watch or it might get FULL. Once it gets full, you're in trouble, you've got to erase all your data and after a few times hope you can get the thing going again."

Besides identifying key users' concerns, this study also focused on providing design recommendations for improving the users' interaction with WWDs. These recommendations include:

- **Definition of the device dimensions.** The device should fit users' wrists (respecting both dimensions and shape), being compact, light, and comfortable, minimalist and unobtrusive;
- **Durability of the display.** The device needs to be resistant to be worn in a daily basis, standing shocks without scratching the front display;
- **Context-awareness.** The device should be designed with more efficient algorithms to properly detect the movements and react accordingly based on user context;
- **Accuracy of data collection.** The device should be able to more efficiently analyze user performance and activity level and make adjustments based on the user context;
- **Definition of interfaces and interaction.** Improving user interface and employing a more efficient display. Minimize physical display buttons and incorporate touch screen for more efficient use of the device;
- **Availability of visualization tools.** Offer solutions to analyze user performance and activity level while offering tools to interpret data;
- **Ease of use.** The gestures should be intuitive, i.e. ease to learn and to remember but still detected accurately;

Not all recommendations are generic, some depend on the modality employed, others on the purpose of the device. All recommendations are based largely upon user perception from online reviews, but they are not exhaustive, therefore there is opportunity for more comprehensive empirical studies for this work. In addition to creating further research opportunities, these recommendations might be useful to other designers of wearable computing devices in the future.

The key user concerns identified involving both the input and the output of data are presented below according to their respective modality.

TABLE 3. KEY USERS' CONCERNS ABOUT THE INTERACTION WITH WWDS, PRINCIPLES AND RECOMMENDATIONS FOR IMPROVING THEIR INTERACTION

	Users Quotes	***Principles***	***Recommendations***
Graphic	"And I haven't found a face that displays at least heartrate and distance that I can see well on my bike. The viewing angle takes some getting used to, but that was probably a 1 hour thing for me yesterday. I suggest wearing it with the display inside your wrist, not on the outside. It's much easier to read that way."	Readability	Improving user interface and employ more efficient display
	"**Scratches** easy. Invest in a screen protector early"	Durability	Must be resistant to be worn in a daily basis, standing shocks without scratching the display;
Gesture	"Activity monitor on your wrist is a horrible location, **too many errors** in the device trying to figure out what is a step & what is a hand movement"	Accuracy	The device should be able to properly detect the movements and react accordingly based on user context.
	"There is absolutely no correlation between calories burnt and heart rate. I do Bikram Yoga and since I was not running laps in the yoga room (though I had my heart rate well above levels seen in many cardio sporting activities) **the watch seemed to think I was probably sleeping** (it showed the same calorie burn rate!). what a joke of an analysis. Oh btw, **if you sweat too much I guess, the watch looses contact with your skin** or something and **fails to even record data points that it was designed to record in the first place**. **The buttons used for toggling displays stop working too!** So the **buttons are not only meant to look like screws, they are screwy too**."	Accuracy, Context-Sensitivity, Effectiveness, Ease-of-Use	The device should be able to more efficiently analyze user performance and activity level and make adjustments based on user context. Improve sensor processing software that will better understand contextual awareness of user Design display where the user does not have to touch any buttons or interface menus to begin logging an activity. This process should be more pervasive for the user.
	"**This is very inaccurate.** Buried in the Basis web page and forums is the fact that the **B1 is only able to track resting heart rate**. As soon as you start being active, **it can't detect your heart rate at all.** I sent mine back for this reason"	Accuracy, Context-Sensitiveness, Effectiveness	Incorporate a three-axis accelerometer inside that tracks movements
	"... I absolutely HATE the Flex. **It doesn't seem to track activity nearly as accurately and since it is worn on the wrist, I get a lot of "noise" in my daily results.** I was wearing my Zip clipped to the center of my bra and it was almost flawless. **The Flex relies on moving your wrist, so doesn't track accurately if you run/walk on a treadmill and don't swing your arm**s. I played a couple hours of roulette one night and logged 10K steps just playing with my chips. I've experimented with the dominant vs. non-dominant hand and changing the sensitivity but it still doesn't work well. Very disappointing when you are using it for motivation to achieve a daily goal."	Accuracy	Device should be flexible. The core of the device could be placed elsewhere based on user activity.
Tactile	"Don't need--or want--**touch for such a small screen**. The touch targets would be too small, and touch functionality would add unwanted bulk"	Ease of use	Advance the design of the device to where the users can interact using a pico projector and proximity sensor that can project and detect an interface onto the user's forearm

A. Graphic and Visual Interfaces

1) Size: the device should fit the users' wrists or be adjustable, the display size should respect the dimensions and shape of the user's wrist, being compact, light, and comfortable, minimalist and unobtrusive;

2) Content: display time; use a numeric display; be easy to interpret in a quick glance; display interesting data;

3) Readibility: must adjust the font type, size and colors of the display to be readable outdoors;

4) Durability: must be resistant to be worn in a daily basis, standing shocks without scratching the front display;

5) Design: WWDs can be considered as jewelry or status symbol, requiring a cool look;

B. Tactile, Touch and Vibration Interfaces

1) Simplicity: a simple control mechanism enables users to quickly check information;

2) Feedback: the lack of feedback is not intuitive for the user interaction, presenting unpractical solutions;

3) Responsiveness: quick reactions to the user touch;

C. Gesture Interfaces

1) Sensitiveness: recognition should detect movements of different granularity levels;

2) Comfort: fatigue for long term interaction or complex movements should be prevented;

3) Ease of use: the gestures should be intuitive, i.e. ease to learn and to remember but still detected accurately;

4) Accuracy: even if calibration is needed, the device should be able to properly detect the movements and react accordingly;

5) Context-sensitivity: the scenarios where the interaction takes places should be known and properly considered;

V. DISCUSSION

This study methods aimed at avoiding bias, ensuring its quality, and validity, still there are limitations that are worthy to discuss:

Reliability. Collecting commentaries from online sources enables us to analyze a large amount of data voluntarily expressed by users. However, among all comments, even with the website moderation, some noisy artifacts are included (e.g., advertisement, spam), thus to focus our findings on actual comments, we manually filtered all the contents to remove unrelated data. For the text analysis, although an automated approach outperforms, manual reviews aid to properly interpret sarcasm, analogies and irony in the comments selected.

Representativeness. Since it is impossible to be exhaustive, covering all WWDs, their users, online sources and comments, we focus on covering a representative sample of online comments and devices, identifying a wide range of concerns.

Limitations. Theoretically the web sources selected in this study are universally accessible to an open public, however in practice, the contents gathered were mainly generated by an English-speaking population, interested in new trends in technology and most likely with regular access to the Internet.

Time-frame. The latest comments were generated and collected in November 2014, however, despite data collection started in May 2014, it is not clear when the first comment was generated as not all websites provide this information.

Method. Despite previous works also analyzed online reviews (e.g., [25], [3]), they focus on different topics (e.g. mobile apps) and to the best of our knowledge no consolidated method exists to analyze online comments (especially about WWDs), thus we rely on empirical methods, ground theory and qualitative analysis of the contents to structure our research, we identify themes (initial and focused) with a bottom up approach, determining a set of codes that best suits the contents retrieved.

VI. Conclusion

By collecting and analyzing users' concerns about their interaction with WWDs, we gained insight about key problems that users currently face. Based on user feedback we derived design recommendations targeted at improving the interaction with novel WWDs. While identifying key concerns in the interaction with WWDs enables us to identify main user problems and derive recommendations, the work presented in this paper could be extended: first, by complementing the findings with additional user studies (e.g., interviews, observation and questionnaires), aiming at better understanding users' issues and confirming the findings of the online reviews; and second, by validating the design recommendations proposed, for instance by incorporating them into the development phases of WWDs and assessing their potential to concretely improve the end user interaction.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. 1314342. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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