Effects of Functionality on Perceived Comfort of Wearables

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Abstract

This paper presents results from a study examining the link between the functionality and the comfort of wearable computers. We gave participants two different devices to wear and varied our descriptions of device functionality. Significant differences in desirability and comfort ratings were found between functional conditions, indicating that functionality is a factor of comfort. Differences were also found between device locations (upper arm and upper/mid back) and participant gender.

Keywords
Comfort, physical comfort, social comfort, comfort rating scales, wearable computers, functionality, desirability

1. Introduction

The decision to wear a computer or device will be an important factor in the eventual widespread use of wearable technology. We know that for most people, the decision to wear anything is based on a number of factors including how it looks and feels and what it does. We hypothesize that these factors are interdependent, and that users negotiate a trade-off between them in determining when to wear a device.

In this study, we examined the relationship between functionality and comfort. Participants tried on two wearable devices, the BodyMedia SenseWear® armband, a medical monitor worn on the upper arm, and the CamelBak® HydroBak®, a drink delivery system worn on the upper back. (Figure 1) Participants were given one of three different functionality descriptions for the device they were wearing: a police monitor, a medical monitor, or a party wearable. They were then asked to rate the devices for comfort and desirability.

2. Background

In 1998, we conducted interviews with "expert wearers" who wear and carry all of the systems and equipment they need to do their jobs. We considered them experts not only because of their extensive experience wearing tools, but also because of their autonomy in making decisions about which tools to wear and how to wear them. Our interviews revealed a number of interesting things, which are reflected in our Design for Wearability [1] work. The most salient idea was the notion that a wearable tool must negotiate a trade-off between functionality and burden. Many times, people told us that a wearable or portable tool must have maximum usefulness in a form with minimum bulk and weight.

We know from the work of others that the decision to wear a tool is also based on a balance of function and social factors. In their study of a wearable device for mobile computer technicians, Kortuem et al. [2] stated that there were "serious social barriers that might prevent technicians from using a head-mounted display in the current form in public. Yet most users expressed their willingness to use HMDs, if the system provides significant benefits to them."

Knight et al. developed a comfort assessment tool that measured comfort along six different physical and cognitive dimensions [3]. By doing this, they suggested that comfort is a multi-faceted construct that is influenced by many factors, both internal and external to the wearer. We hypothesize that device functionality is yet an additional factor of perceived comfort.

We chose to explore the two wearable device locations of the upper arm and upper/mid back so that this research might inform current and future development within our group. The upper arm location is described in [4], authored by designers at BodyMedia. We have used the upper/mid back location for the Spot wearable computer design [5].

Figure 1. BodyMedia SenseWear armband and CamelBak HydroBak backpack.

Proceedings of the Seventh IEEE International Symposium on Wearable Computers (ISWC'03)

3. Method

Forty-one undergraduate students at Carnegie Mellon University (mean age of 20±2 years, 24 females and 17 males) were included in the study. In order to simulate real wearing conditions, the study was administered in public spaces on campus. Potential participants with prior knowledge of the SenseWear armband were not included.

Participants were randomly assigned to try on either the armband or backpack first. They were given instructions on how to don the armband, from which all logos and distinguishing markings had been removed. The backpack had a CamelBak logo on it, and so participants were asked to briefly close their eyes while an experimenter helped them don the device. Both the armband and backpack were adjustable to fit both large and small body sizes, and participants were instructed to adjust the devices to their liking. Both devices were kept out of view while not in use.

Participants were told that the device they were wearing had one of three functions: a police monitor, a medical monitor, or a party wearable. These functions were chosen to present a variety in social desirability. In the police condition, participants were told that the device broadcast information such as their location, name, address, and social security number so that they could be monitored by the police. In the medical condition, participants were told that the device recorded information such as their heart rate, temperature, and heat flow. These descriptions were identical for both the armband and backpack. For the party condition, participants wearing the backpack were told it was a drink delivery system that could be taken to parties. Those wearing the armband were told that it was a tote for keys, money, identification, breath mints, or other items they would need for a night out. We randomized the order of conditions to avoid order effects. Table 1 shows the resulting 2x3 experimental design.

Table 1. Experimental conditions

	Police	Medical	Party
Arm	Police Arm	Medical Arm	Party Arm
Back	Police Back	Medical Back	Party Back

Participants were asked to make a series of movements while wearing each device, including walking, reaching up and down, and moving their arms in various other ways. They were encouraged to continue making movements until they had gotten a feel for the device. Afterwards, they rated the desirability and comfort of the device. The participants generally took about two minutes for each assessment.

3.1. Desirability Ratings

In order to confirm that the functionality descriptions varied in desirability, we asked subjects to rate each device on how useful it would be to them, how useful it would be to their friends, how much they wanted the device, and how cool they thought it was. We chose these specific questions because we felt they covered a variety of factors for desirability of an artifact.

3.2. Comfort Ratings

The comfort rating scales (CRSs) used in this study were based on those developed by Knight et al. They designed sets of statements representing the comfort dimensions of emotion, attachment, harm, perceived change, movement, and anxiety. In our study, we slightly modified these CRSs. In some cases we reduced a two-sentence statement down to one sentence in order to simplify the concept for participants. We also modified the tone of some of the statements to balance the number of positive, negative, and neutral statements used. (Table 2) Participants were read each statement and asked for their level of agreement on a scale of 1 to 10.

Table 2. Comfort rating scales and statements

Emotion	I feel self-conscious having people see me wear this device.
Attachment	I feel the device moving on my body.
Harm	I feel some pain or discomfort wearing the device.
Perceived Change	I feel awkward or different wearing the device.
Movement	I feel that the device affects the way I move.
Anxiety	I feel secure wearing the device.

4. Results and Discussion

4.1. Desirability

4.1.1. Armband. The police function was rated as less useful to you [2.1±1.4 vs. 5.0±1.4 & 6.6±1.4, $t(40)=-4.42$, $p<.001$], less useful to your friends [3.1±1.4 vs. 5.2±1.5 & 6.9±1.4, $t(40)=-3.29$, $p<.01$], and less wanted than the other two functions [1.3±1.4 vs. 4.7±1.4 & 5.2±1.4, $t(40)=-4.27$, $p<.001$]. The medical function was rated as cooler than the other two functions [7.7±1.5 vs. 5.3±1.4 & 4.1±1.4, $t(40)=3.35$, $p<.01$].

Table 3. Armband desirability ratings

	Police	Medical	Party
Useful to You	least useful to you	more useful than backpack	–
Useful to Friends	least useful to your friends	–	–
Wanted	least wanted	more wanted than backpack	–
Cool	–	coolest	–

4.1.2. Backpack. The party function was rated as more useful to you [6.0±1.4 vs. 2.2±1.3 & 2.6±1.3, $t(40)=4.27$, $p<.001$], more useful to your friends [6.3±1.3 vs. 3.8±1.3 & 3.1±1.3, t(40)=3.58, p<.01], and more wanted than the other two functions [5.5±1.2 vs. 2.2±1.2 & 0.8±1.2, t(40)=5.31, p<.0001]. The police function was rated as less cool than the other two functions [3.6±1.5 vs. 6.0±1.5 & 6.0±1.5, t(40)=-2.58, p<.05].

Table 4. Backpack desirability ratings

	Police	Medical	Party
Useful to You	–	less useful than armband	most useful to you
Useful to Friends	–	–	most useful to your friends
Wanted	–	less wanted than armband	most wanted
Cool	least cool	–	–

4.1.3. Interaction of Function and Location. For the medical function only, participants rated the armband more useful than the backpack [5.1±1.4 vs. 2.2±1.4, t(26)=2.38, p<.05]. For the medical function, participants also said they wanted the armband more than the backpack, though this result fell just outside significance [4.7±1.3 vs. 2.2±1.3, t(26)=2.01, p<.06].

4.1.4. Correlations. The "useful to you" and "useful to your friends" ratings were correlated in the following conditions: Overall Arm (.8661), Overall Medical (.8153), Medical Arm (.9145), Overall Party (.8238), Party Arm (.9198), Overall Back (.8056), and Police Back (.8596).

The "useful to you" and "want" ratings were correlated in the following conditions: Overall Arm (.8661), Police Arm (.7769), Medical Arm (.7682), and Party Back (.8202).

The "want" and "cool" ratings were correlated in the following conditions: Overall Party (.8238), Party Arm (.8568), and Party Back (.8326).

4.1.5. Discussion. The desirability ratings of the police and party functions confirm our hypothesis that it is possible to manipulate perceptions of wearable devices by describing device functionality. The strong correlations between the two "usefulness" ratings and the "want" ratings indicate that these factors may be appropriate to group together when trying to measure overall device desirability.

The fact that desirability ratings differed between the armband and backpack, in particular for the medical function, suggests that there is some interplay between functionality, desirability, and location.

From our interaction with the participants, we understood that there may be two different interpretations of the "cool" factor. One interpretation is that of social coolness, which indicates that something is good, hip, or fashionable. The other interpretation is that of technical coolness, which indicates that something is technologically interesting or advanced. This hypothesis was confirmed with data from the desirability ratings. For the armband, the party and medical functions had similar ratings for the two "usefulness" and "want" factors, but the medical function received the highest "cool" ratings. However, there was still a high correlation between "want" and "cool" ratings in the party conditions for both the armband and the backpack. These findings suggest that technical functions may be judged on technical coolness and non-technical functions on social coolness.

4.2. Comfort

4.2.1. Across Functions. Participants felt that the backpack moved more on their bodies [5.9±0.8 vs. 3.7±0.8, t(81)=4.37, p<.0001] and affected the way they moved more than the armband did [4.4±0.7 vs. 2.7±0.7, t(81)=3.48, p<.01]. These results are probably due to the armband's smaller form factor, tighter attachment, and placement on the body.

Table 5. Cross-functional comfort ratings

	Backpack	Armband
Attachment	moved more	moved less
Movement	affected participants' movements more	affected participants' movements less

4.2.2. Effects of Functionality. Effects of functionality were only found for the backpack. This could have been due to the higher overall comfort of the armband, the fact that participants did not see the backpack during the experiment, or a number of other factors.

The police function elicited higher ratings of self-consciousness [6.4±1.3 vs. 4.3±1.3 & 4.7±1.4, t(40)=2.36, p<.05] and higher ratings of feeling awkward or different than the other two functions [6.1±1.3 vs. 3.8±1.3 & 3.9±1.3, t(40)=2.76, p<.01]. The police function was also said to be felt moving on the body more than the medical function [7.2±1.1 vs. 4.8±1.1, F(1,38)=8.89, p<.01]. The medical function was reported to cause less pain and discomfort than the other two functions [1.9±1.4 vs. 4.0±1.4 & 4.0±1.4, t(40)=-2.48, p<.05]. No effects were found for movement or anxiety.

Table 6. Effects of functionality for the backpack

	Police	Medical	Party
Emotion	most self-conscious	–	–
Perceived Change	most awkward or different	–	–
Attachment	moved more than medical	–	–
Harm	–	least painful	–

The police function elicited more negative comfort ratings, while the medical function elicited more positive comfort ratings. These results confirm a relationship between function and comfort. It is not surprising that the police function, because of the social stigma of house arrest and other criminal activities, elicited feelings of self-consciousness and, to a lesser extent, feelings of awkwardness. What is interesting is that these feelings extended to lower ratings of *physical* comfort. The police function presumably needed a higher level of actual comfort to counterbalance its low perceived value. The medical function positively affected perceived physical comfort. This result may reflect a balance between comfort and the necessity for maintaining personal health.

Interestingly, the party function, which received the highest overall desirability ratings, did not receive high comfort ratings. It's possible that the variance in functional descriptions (drink delivery system vs. tote) affected the results. Or perhaps there is something specific about a device worn in social settings that results in higher, or at least different, comfort expectations.

4.3. Gender Differences

Table 7 shows the breakdown of gender for each condition. We did not initially intend to look for gender differences between the conditions and would have been more diligent about equalizing the number of females and males per condition if we had. However, we did find gender effects in four of the six comfort dimensions. No effects were found for attachment or perceived change.

Table 7. Gender demographics

		Police	Medical	Party
Arm	Female	9	5	10
	Male	5	8	4
	Total	14	13	14
Back	Female	8	11	5
	Male	6	3	8
	Total	14	14	13
Total	Female	17	16	15
	Male	11	11	12

4.3.1. Across Functions. Females felt less self-conscious wearing the devices than did males [4.3±0.7 vs. 5.8±0.8, $t(81)=-2.80$, $p<.01$]. Females felt more secure wearing the armband than did males [5.8±1.0 vs. 3.9±1.2, $t(40)=2.47$, $p<.05$]. Females also felt that backpack affected the way they moved less than did males, though this result fell just outside of significance [3.8±1.0 vs. 5.4±1.2, $t(40)=-2.02$, $p<.06$].

4.3.2. Effects of Functionality. Effects of functionality were only found for the armband. In the police condition, females reported less pain and discomfort [2.8±1.5 vs. 6.0±2.0, $t(13)=-2.09$, $p<.05$] and felt less self-conscious than did males [4.5±1.2 vs. 7.6±1.4, $t(13)=-2.14$, $p<.05$].

4.3.5. Discussion. Males generally reacted more negatively to the devices than did females, specifically to the police function and to the armband. These results suggest that differences exist in how males and females perceive the functionality, location, and overall comfort of wearable devices. Past studies have shown gender differences in fashion preferences [6], and these findings may be related. Again, these results should be tempered by the fact that there were unequal numbers of males and females in each condition.

5. Conclusions

We have established that functionality is indeed a factor of the perceived comfort of wearable artifacts. This has important implications for the design of all kinds of wearable systems. The function of any wearable tool must outweigh any physical or social discomfort felt in wearing it, and less desirable devices may meet with higher standards for comfort and fit. For some functions, one body location may be preferred over others. Overall acceptance of wearable devices will rely on both functionality and design for comfort, and so both must be considered early in the development process. Finally, the functionality and benefits of wearable devices need to be made clear to wearers in order to support the acceptance and widespread adoption of wearable technology.

6. Future Research

Alternative device locations should continue to be explored in the context of functionality. Additional work calibrating desirability and comfort ratings and incorporating factors such as stylishness in shifting social settings is needed. A methodology for assessing comfort after prolonged wear needs to be established. The gender differences found in this study need to be investigated in greater depth. Lastly, future research should explore the generalization of this study's findings across wider population demographics.

7. Acknowledgements

We thank Dan Siewiorek for his leadership in the wearable computing group at Carnegie Mellon. Aaron Powers and Darren Gergle provided invaluable assistance in analyzing the data. We also thank Jane Siegel for her feedback on this paper.

8. References

[1] Gemperle, F., Kasabach, C., Stivoric, J., Bauer, M., Martin, R. (1998) Design for Wearability. In *The Second International Symposium on Wearable Computers*, (pp116-122). Los Alamitos, CA: IEEE Computer Society.

[2] Kortuem, G., Bauer, M., and Segall, Z. (1999) NETMAN: The design of a collaborative wearable computer system. *Networks and Applications* (4) pp49-58.

[3] Knight, J.F., Baber, C., Schwirtz, A., and Bristow, H.W. (2002) Comfort Assessment of Wearable Computers. In *The Sixth International Symposium on Wearable Computers*, (pp65-72). Seattle, WA: IEEE Computer Society.

[4] Kasabach, C., Pacione, C., Stivoric, J., Teller, A., Andre, D. (2002) Why The Upper Arm? Factors Contributing to the Design of an Accurate and Comfortable, Wearable Body Monitor. Online at www.BodyMedia.com

[5] Spot wearable computer: www.wearablegroup.org

[6] Kaiser, S.B. (1997) The Social Psychology of Clothing. Fairchild Publications, Second Edition Revised.