Wearable Remote Control of a Mobile Device: Comparing One- and Two-Handed Interaction

Jessica Speir
Carleton University
Ottawa ON K1S 5B6, Canada
jessica.speir@carleton.ca

Rufino R. Ansara
Carleton University
Ottawa ON K1S 5B6, Canada
rufino.ansara@carleton.ca

Colin Killby
Carleton University
Ottawa ON K1S 5B6, Canada
colin.killby@carleton.ca

Emily Walpole
Carleton University
Ottawa ON K1S 5B6, Canada
emily.walpole@carleton.ca

Audrey Girouard
Carleton University
Ottawa ON K1S 5B6, Canada
audrey.girouard@carleton.ca

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Abstract
While wearable technologies are suitable for remotely controlling mobile devices, few studies have examined user preferences for one- or two-handed touch interaction with these wearables, especially when worn on the wrist and hand area. As these locations are recognized as socially acceptable and preferred by users, we ran a study of touch interaction to remotely control mobile devices. Our results suggest users prefer swipe gestures over touch gestures when interacting with wearables on the wrist or hand, and that users find both one- and two-handed interactions suitable for wearable remote controls.

Author Keywords
HCI; E-textiles; Wearable Computing; Conductive Fabric; Wearable Controls; Mobile Controls

ACM Classification Keywords
H.5.2 User Interfaces: Haptic I/O, Prototyping

Introduction
Electronic textiles (e-textiles) are the product of integrating textiles with electronic technologies. The term describes a variety of fabric, yarn, and thread merged with electronic components such as sensors,

Figure 1. Final Wristband Prototype

Figure 2. Final Glove Prototype

processors, and/or actuators [5]. The textile itself can contain embedded electronic components which are connected by either thread or standard wires. Many e-textiles together can produce more complex electronic devices such as those used in wearable technologies (WT) [5]. Some examples of WT include clothing for monitoring body metrics [10] and wearable solar panels for charging mobile devices [12].

One application of WT is remotely controlling mobile devices. Previous work suggest s that users prefer interacting with a small WT device on the wrist or hand [4], and that the hand and wrist are also the most socially acceptable areas for on-body interaction [8]. However, there has been little research on whether users prefer using one or two hands to interact with WT devices. It is also unclear what type of gestures users prefer to make with WT devices. In this study, we aim to investigate these aspects of wearable remote controls for mobile devices.

Music and phone applications for mobile devices are particularly suited for remote control as they allow users to perform simple tasks "eyes-free", when interaction in inhibited by sun glare [3] and environmental distractions [6], for instance. We believe the suitability of music and phone applications for remote control by WT warrants further investigation.

We conducted a study on the use of WT for remote control of mobile devices with two prototypes, a wristband and a glove (Figure 1 and Figure 2). Participants interacted with the prototypes via swipe and touch gestures, using one hand for the glove and two hands for the wristband. Both prototypes remotely controlled music and phone applications on a mobile device. We concentrated on user preference and performance of one- and two-handed gestures and the effectiveness of swipe and touch gestures. Here we present our results and discuss the lessons learned when designing for gestures and WT prototypes.

Related Work

In this section we review relevant research and identify the gaps we aim to address in our study.

Wristbands and Circular Interfaces

Wrist-mounted systems are significantly faster to access than a device stored in a pocket or on the hip [1]. Several wrist-mounted WT systems have been developed in the past decade. The GestureWrist system [9] is based on wrist-shape changes and forearm movements, and was developed for hands- and eyes-free interactions for remote control. Zeagler et al. [14] designed a jog-wheel using multilayer embroidery capable of remote control. However, little work has been done with these systems beyond the initial prototype design. Ashbrook et al. [2] modeled the error rate for buttons placed around the edge of a circular touch-screen watch, but their study did not consider eyes-free interaction. Consistent with other circular interface literature, Ashbrook et al. defined two regions of interaction, the rim and the centre of the circle [2], which influenced our design of the wristband interface in this study.

Gloves

In a survey of WT and glove devices, Sturman and Zeltzer [11] summarize the basis for most glove interactions as either finger-bend or movement detection, with none focused on swipe or touch. When users are given the choice they often prefer to use their

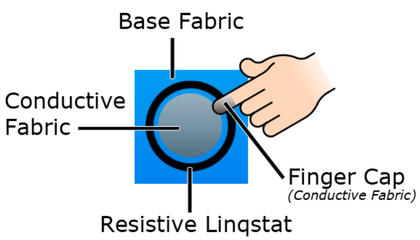

Figure 3. Fabric Potentiometer Elements

Action	Wristband Gesture	Glove Gesture
Play/ Pause	Touch and Hold - 6 O'Clock	Touch and Hold - Middle
Next Song	Touch and Hold - 3 O'Clock	Touch and Hold - Top
Previous Song	Touch and Hold - 9 O'Clock	Touch and Hold - Bottom
Increase Volume	Swipe Clockwise	Swipe Upwards
Decrease Volume	Swipe Counter Clockwise	Swipe Downwards

Table 1. Actions and gestures for the Music Application

index finger for mid-air or surface gestures [13]; this influenced the design of our prototypes.

Remote Control

Many WT devices developed can remotely control other devices (e.g. the jog-wheel [14] and GestureWrist [9]). However, these prior works rarely focused on use cases, for instance to remotely controlling music or phone applications. There is also little work on the swipe or touch gestures that can be used with the WT devices. Our study explores both of these aspects of remote control with WT.

Prototypes

We created two prototypes aimed to emulate a real product's aesthetics and functionality (Figure 1 and Figure 2). We built our wristband according to Perner-Wilson's Time-Sensing Bracelet instructions [7] for a circular potentiometer and adapted those guidelines to create the linear potentiometer on the glove (Figure 3).

Wearable Components

We were unable to obtain the resistive fabric used in the original design [7] , so we replaced it with plastic resistive Linqstat™. When users connect the Linqstat™ and the conductive fabric with the conductive finger cap, the system outputs a value that varies with the location of the touch. We used this value to determine the location of the contact and the direction of movement, if any. To build the glove, we adapted the circular potentiometer of the wristband to work as a linear potentiometer, placed along the thumb. We used the same conductive-fabric pairing and maintained the same surface area on each component as on the the index finger of the glove. The glove works on the same principle as the wristband.

Hardware and Software Applications

Our hardware consisted of a circuit that read the input values from both prototypes and transmitted them over Bluetooth® to an Android™ phone. We filtered the raw data captured from the prototypes as the Bluetooth® connection was not fast enough to stream directly. Our prototypes controlled two custom-made applications: a Music Application and a Phone Application. Both applications took the same prototype-specific gestures as input, but mapped them to different tasks.

Study Design

We conducted a within-subject factorial experiment with both applications and both prototypes. Table 1 and Table 2 list the set of gesture-action combinations for the Phone Application and Music Application.

We chose the swipe gestures to match the directionality of the actions (e.g. increase volume by swiping upwards). We chose the touch-and-hold areas on the wristband to match those of the older-model click-wheel iPods (e.g. iPod™ and iPod™ Nano 1st to 5th generation). On the glove, these touch-and-hold locations were evenly spaced along a straight line, in the same order moving down the thumb as moving clockwise on the wristband (next song, play/pause, previous song).

Participants

Seventeen participants (8 females) with a mean age of 22 participated in our one-hour user study. One participant was left-handed. Eleven participants (64.7%) had previous experience with a click-wheel iPod™. None of the users were familiar with wearable technologies. We offered the participants $10 as compensation for their time.

Action	**Wristband Gesture**	**Glove Gesture**
Answer/ Hang Up	Touch and Hold - 6 O'Clock	Touch and Hold - Middle
Increase Volume	Swipe Clockwise	Swipe Upwards
Decrease Volume	Swipe Counter Clockwise	Swipe Downwards

Table 2. Actions and gestures for the Phone Application

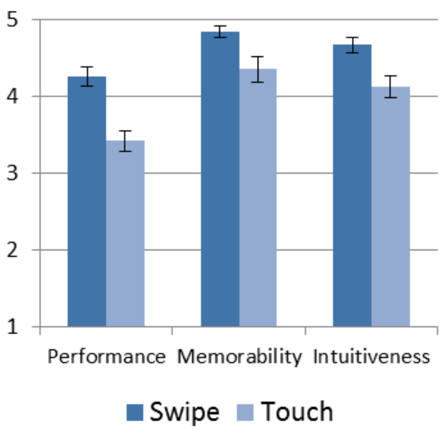

Figure 4. Mean rating for swipe and touch gestures for ease of performance, memorability, and intuitiveness. Error bars show the standard error.

Procedure

We demonstrated the gestures and actions before each participant used each application with both prototypes. We counterbalanced the order of the prototypes and the applications. The software presented all tasks in a randomized order (5 times each). The researcher told the participant which task to complete, to help participants to focus on the prototype instead of on the mobile device. At the end of the study, participants filled out a detailed survey that recorded their impressions and comments on the prototypes and the gestures.

RESULTS

Performance

The system logged the time taken in milliseconds from the start of each task until the system detected the gesture. As the study progressed, wear-and-tear on the prototypes caused erratic detection of the touch gestures on the glove. To adjust for this, we excluded any times over 8 seconds as likely caused by prototype failure. This resulted in an average of 5 cases of excluded data for each glove-touch gesture, with little-to-no missing data for the other gestures. This missing data prevented us from accurately comparing the gestures task by task, hence we compare the mean detection times for gestures by the prototype, application, and by type of gesture (swipe or touch).

We performed a 2 x 2 repeated-measures ANOVA on prototype (wristband, glove) x application (music, phone) on the average gesture-detection times. The wristband detected the gestures significantly faster (M=2974ms, SE=94) than on the glove (M=3543ms, SE=154), $F(1,16)$=13.98, p=.002, η_p^2=.466. There was no significant main effect of the application ($F(1,16)$=1.54, p=.233) on gesture-detection time and no significant interaction effect ($F(1,16)$=0.073, p=.790) between the application and the prototype.

We also compared the detection times of the swipe gestures with the touch gestures. The prototypes detected the swipe gestures (M=2901ms, SE=96) significantly faster than the touch gestures (M=3592ms, SE=114), $t(16)$=8.71, p=.000, r=.91.

Subjective

Participants rated each gesture on ease of performance and memorability on 5-level Likert scales from Strongly Disagree (1) to Strongly Agree (5). Participants rated the wristband gestures (M=4.13, SE=0.14) as significantly easier to perform than the glove gestures (M=3.34, SE=0.15), $t(16)$=3.82, p=.001, r=.69. There is no significant difference between the wristband and glove in terms of memorability or intuitiveness.

Participants also rated each gesture and task combination for intuitiveness on the same 5-level Likert scale. We found no significant difference between the ratings for the music-application gestures and the phone-application gestures.

As shown in Figure 4, participants rated the swipe gestures as significantly more intuitive than the touch gestures, $t(16)$=4.98, p=.000, r=.78. Participants rated the swipe gestures significantly easier to perform than the touch gestures, $t(16)$=4.98, p=.000, r=0.78. The memorability ratings were not normally distributed, so we used the non-parametric Wilcoxon Signed-Ranks test to compare the mean ratings. The users rated the swipe gestures as significantly easier to remember than the touch gestures, z=-25.53, p=.012, r=*0.43*.

Discussion

Our results indicate that participants preferred the wristband prototype to the glove prototype and found swipe gestures easier to perform, more intuitive, and easier to remember than touch gestures. Participants were evenly split on which application, music or phone, was most suited to this type of remote control, which confirms our assumption that both are suited to eyes- and hands-free control of a mobile phone. Using the click-wheel iPod™ metaphor for the wristband did not increase the intuitiveness of those gestures over the phone-application gestures.

Wristband vs Glove

Overall, the majority of participants preferred the wristband (77%) prototype to the glove (24%). However, we are unable to attribute this preference to any particular feature of either prototype due to the technical issues we experienced with the glove. When asked specifically which prototype they would prefer for day-to-day use, the split was more even, with only 59% of participants preferring the wristband. This result, combined with participants' comments, suggests that there is no overwhelming preference for one- or two-handed interaction for remote control of a mobile device, but rather that either might be appropriate depending on the user and usage scenario.

The wristband detected gestures significantly faster than the glove, which may have been caused by the difficulties with the glove prototype near the end of the study. However, the participants also rated the wristband gestures as much easier to perform than the glove gestures. We attribute both the difference in gesture detection times and the difference in rating to the physical difficulty of performing some of the glove gestures in the smaller surface area available on the thumb compared to the wrist.

Swipe vs Touch

Participants found swipe gestures more intuitive and easier to perform and remember than touch gestures, likely because the swipe gestures relied only on direction rather than location, requiring a less precise input. We also found that clockwise/upwards movements translate well to an increase in values, whereas counter-clockwise/downwards movements translate well to a decrease in values. In contrast, mapping a right or top touch to "next" and a left or bottom touch to "previous" was not as intuitive as we expected.

Improving the Prototypes

We solicited the participants' opinions on how to improve the prototypes. Many participants wanted visual markers on the wristband to make the touch gestures easier to remember. Notably, two participants wanted the play/pause-touch gesture to be located in the centre of the wristband, rather than at the 6-o'clock position. The comments for the glove were entirely concerned with improving the reliability of the sensor.

Limitations

Some prototype limitations became evident during user testing. We created only one glove due to time and money constraints, and it did not fit tightly to the various sizes of participants' hands. Participants with smaller hands sometimes had difficulty completing the full range of gestures. On both prototypes, the shape of the fabric potentiometer was often distorted by the shape of the participant's hand or wrist. This distortion altered the values read from the circuit, which resulted in a slight shifting of gesture recognition areas between participants. Finally, towards the end of the user study wear and tear on the glove prototype caused touch gesture detection on that prototype to become erratic. This may have affected some of the data collected towards the end of the study.

Conclusion

This study explored how users perceive wearable technology and its potential as a remote control for mobile applications. We defined multiple application-appropriate gestures and determined that participants had an easier time performing swipe gestures over the touch-and-hold gestures. The majority of participants preferred the wristband prototype and rated the wristband gestures easier to perform. However, they were evenly split over which prototype they would prefer for everyday use. This indicates that users have no clear preference of one- or two-handed interactions, suggesting that both may be promising input methods.

Given the limitations of our prototype, future research includes development of more advanced prototypes and involves comparisons of user reactions to prototype rigidity and different interaction zones.

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