# Preparing for Perceptual Studies: Position and Orientation of Wrist-worn Smartwatches for Reading Tasks

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## Abstract

Despite the increasing demand for data visualization on mobile devices with small displays, few guidelines exist for designing visualizations for this form factor. To conduct perceptual studies with smartwatches under realistic conditions, we first need to know how to position these devices in front of a viewer. We report the results of a study, in which we investigate how people hold their smartwatches to read information. This is the first in a series of studies we are conducting to understand the perception of visualizations on smartwatches. Our study results show that people hold their watches at a distance of 28 cm in front of them, at a pitch angle of ~50 degrees, and at an angle of ~10 degrees from the line of sight.

## Author Keywords

Smartwatch; reading angle; study

## ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

## Introduction and Motivation

The increasing demand for data visualizations on small mobile devices and the fact that few guidelines exist for developing and designing visualizations for this environment motivates our work. The overall goal of our work is to study small data visualizations in display contexts that can only dedicate minimal rendering space for data representations. Ultimately, our research aims to empower people to use visualizations outside of a typical work environment, furthering the research agenda of “beyond-the-desktop” visualizations [11]. Example usage scenarios for small scale visualizations on mobile devices include fitness tracking armbands showing step counts or heart rates, hand-held GPS trackers showing elevation profiles, or mobile phone visualizations used in emergency response scenarios.

User studies of human perception often use controlled conditions. In these controlled conditions several contextual factors of the environment are fixed, for example, the lighting conditions, viewing angles, or head positions. Studies conducted under less controlled conditions, in which environmental factors can vary, lead to more ecological validity. Our goal is to begin our line of research with studies that balance control and ecological validity. In particular, in our studies we want to use the same display surfaces that are used later to run the visualization applications we envision. For our studies of visual perception on smartwatches we first need to understand how participants position and orient wrist-worn watches so we can place watches at ecologically valid positions in front of participants.

In this paper, we present the results of our study to investigate how participants hold smartwatches while reading information. We used a motion capturing system that tracked participants' head position as well as the position and orientation of the watch. Our results show that participants place their watch on average at a distance of 28 cm. A range of 10 cm around this mean accounts for more than 70% of our data, indicating it is an interesting range to use in future experiments. Participants' line of sight offset is on average $10^\circ$ with a range of $16^\circ$ around this mean, which accounts for more than 70% of our data. Finally, participants tilt their watch by $50^\circ$ on average, with a larger range around this mean (almost $30^\circ$) accounting for 70% of our data.

## Related Work

Our work builds on three existing research streams: small-scale visualizations, basic perception studies in visualization, and related work from the mobile HCI community.

In particular, we begin by studying fundamental components – visual variables introduced by Bertin [1] – of visualizations at micro scale. Visual variables such as position, length, brightness, color hue, orientation, or shape modify the marks (i. e., points, lines, areas, surfaces, volumes) that make up visualizations. For example, a bar chart is created with rectangular areas whose length (size) encodes quantitative information. Fundamental studies by Cleveland & McGill [3, 4, 5] suggested a first ranking of several visual variables for quantitative data with position and length as the most effective variables. The visualization community has replicated and confirmed the work of Cleveland and McGill in desktop settings (e. g., Kittur et al. [10]). In our own research [2], we investigated how the perception of visual variables on tiled wall-sized displays changes under different viewing angles and suggested a change in the Cleveland and McGill ranking. We hypothesize that the initial ranking may similarly be affected for small and/or mobile viewing conditions.

For our perceptual studies, we rely on methods from the field of psychophysics [7, 16] that measure the relationships between perceived and actual properties of a visual object. In this domain, researchers have attempted to mathematically describe the differences between physical and perceived magnitude of objects as collected from studies. One popular function describing this difference is Stevens' power

**Figure 1:** A participant wearing both helmet and smartwatch.

**Figure 2:** The bike helmet and smartwatch with four markers.

law [15] : $J = \lambda D^{\alpha}$, with J = judged magnitude, D = actual magnitude, $\alpha$ = exponent, and $\lambda$ = scaling constant. It has been tested under varying conditions and several values for $\alpha$ have been proposed for judging visual variables such as length, area, or position. Wagner [16] presented a meta-analysis of 104 articles, reporting 530 values for $\alpha$ collected under different conditions. No combination of conditions matched those of viewing elements on small (wearable) displays. The reported exponents can, however, help us hypothesize but not predict how reading elementary graphical variables may be affected in our work environment. Like many previous studies (e. g., [3, 4, 5, 10]) we use the magnitude estimation method that requires participants to judge the magnitude of a modulus object in comparison to a stimulus presented in parallel [16].

Considerable research on smartwatches has been conducted in the field of HCI. Much of this research concerned input modalities such as touch or gestures [6, 9, 13], the use of tilt [8] or orientation [12] of the smartwatch, or even tracking the 3D posture of the entire arm [14]. However, we are not aware of any studies systematically analyzing position, orientation and distance of wrist-worn smartwatches for reading tasks. To conduct perceptual studies we want to control how people position and orient a smartwatch while they are reading information. Therefore, we systematically investigate this in our study presented in the following.

## Study

The goal of this study is to investigate at which viewing angle and distance smartwatches are commonly held while people are reading information. The study used a within-subjects design varying one factor: whether the participant was sitting or standing. We hypothesized that a seated position would potentially change the distance of the watch to the eyes or even the angle at which the watch was held.

### *Study Design*

Twelve participants performed 20 trials in each condition: they read 20 short sentences of text while sitting and another 20 while standing. We chose an easy and quick task that each participant could perform while allowing us enough time to capture the needed data. Participants read the same 20 sentences in both conditions as recall would unlikely influence how participants position the watch to read them. We extracted the sentences from the Wizard of Oz. Each sentence was displayed on the smartwatch with a font size of 30 sp (scale-independent pixels). The order of conditions was counter-balanced.

Overall, our study consisted of 12 participants × 20 trials × 2 conditions (sitting, standing) $=$ 480 trials.

### *Participants*

We recruited 12 participants (five female and seven male), with an average age of 29.17 years (*SD* = 6.63). One participant was left-handed, but all reported to wear a watch on the left hand. Only three participants reported to regularly wear a watch and only two own a smart wrist-worn device (Jawbone fitness bracelet and Fitbit bracelet).

### *Equipment and Set Up*

We used a Sony SmartWatch 3 with an Android Wear 2.8.0 operating system. The Sony SmartWatch 3 has a viewable screen area of 28.73 mm × 28.73 mm and a screen resolution of 320 × 320 pixels ($=$ a pixel size of 0.089 mm). We also used a 6-camera 3D real-time tracking VICON system using the VICON Tracker software 3.5.1. To track the head position of each participant they wore a firmly attached bike helmet (Figure 1). On both watch and bike helmet we attached four tracking markers (Figure 2).

To remotely control the watch and tracking system, we used a Samsung Galaxy S6 edge smartphone with Android 7.0.

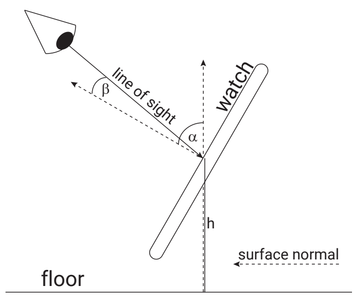


**Figure 3:** Measurements calculated in the study: pitch angle $\alpha$, line of sight offset $\beta$, and the smartwatch distance.

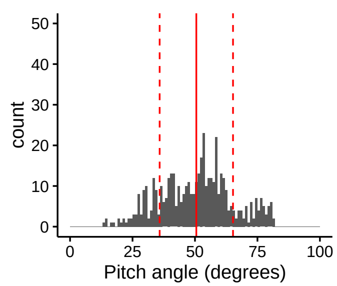


**Figure 4:** Angle by which participants oriented their watch (pitch angle) in degrees. Red line indicates mean and dashed red lines the range defined by the *SD*.

The experimenter pressed a button on the phone to send a message both to the watch and the tracking system. When the two devices received the message, the watch displayed a sentence for the participant to read and send back the current rotation. In addition, the tracking system stored the current position and orientation of the watch and the bike helmet. This setup allowed us to synchronize the data collected from the watch and the tracking system.

*Study Procedure*

Participants first filled in a questionnaire about their demographic information. They then put on the bike helmet and, while they looked straight ahead, we adjusted the helmet using a mechanic's level so that the helmet's tracking marker plane was oriented parallel with the floor. Next, participants put on the smartwatch and then stood up or sat down depending on the study condition they were in. Each trial started when participants rested their arm. When the experimenter sent a sentence to the watch, participants had to position their arm to read the sentence from the watch. After finishing a set of 20 trials, participants immediately continued with the second condition. Last, participants filled in another questionnaire about their experience during the study itself. Participants did not receive any remuneration except for a bar of chocolate.

*Data Collection*

We collected demographic information using a questionnaire. In addition, we used a post-questionnaire to also collect data about the ease of reading the texts, how natural it felt using the watch, fatigue participants experienced during the study, and how tiredness might have affected their behavior and performance. The VICON tracking system logged for both the helmet and the watch: a timestamp, an *x*-, *y*-, and *z*-coordinate for the position, as well as the orientation of the object as a quaternion (*qx*, *qy*, *qz*, *qw*).

In addition, the smartphone recorded the orientation of the watch as a quaternion (*qx*, *qy*, *qz*, *qw*) from the smartwatch rotation vector sensor. After a first data extraction and conversion, we found the data from the watch's rotation sensors were too unreliable. Therefore, for further analysis and we rely only on the VICON data.

## Results

We report on the results leading to watch distance and orientation, as well as the offset to the line of sight, that can be used in future perceptual studies. Figure 3 shows the three measures we calculated. We also report the height at which participants raised the watch when sitting and standing. In addition, we report the results from the post-questionnaire for the sake of completeness.

*Average Pitch Angle*

We consider how participants oriented their watch: pitch angle around the *x*-axis of the watch, which connects through the left and right sides of the watch from its center (cf. Figure 3). We look at outlier trials, examining for each participant average angles that were beyond 2 *SD* from that participant's mean. We removed 4% of the trials: 20 trials out of 480, and calculated that participants placed their watch at a mean angle of 48° (*SD* = 15°) when sitting, and at 52° (*SD* = 13°) when standing. This leads to an average angle of 50° (*SD* = 14°) for both conditions combined (Figure 4).

The mean is a way to represent the watch orientation for all participants but does not account for the variation between them. As our goal is to choose representative orientations to use for future experiments, we need to consider this variation. The range defined by the mean and $\pm 1$ *SD* is [36°, 64°] and accounts for the majority of our trials (69%). This indicates a possible range of angles to consider in future experiments.

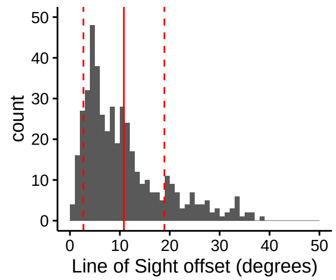


**Figure 5:** Angle between line of sight and smartwatch (LoS offset) in degrees. Red line indicates mean and dashed red lines the range defined by the *SD*.

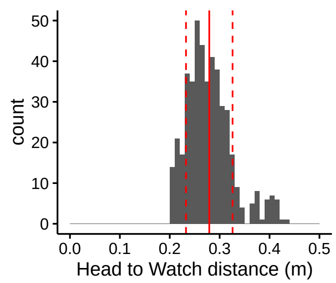


**Figure 6:** Viewing distance used by participants in meters. Red line indicates mean and dashed red lines the range defined by the *SD*.

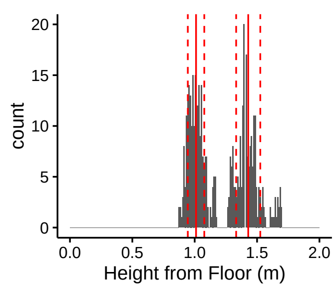


**Figure 7:** Height at which participants raised the watch in meters. Red line indicates mean and dashed red lines the range defined by the *SD* of both sitting and standing conditions.

*Line of Sight Offset*

We also calculate the angle between line of sight and the smartwatch face's normal (angle $\beta$ in Figure 3). We removed 4% of the trials – 23 trials out of 480 – as outlier trials. We found that sitting participants had a line of sight offset with a mean angle of 11° (*SD* = 8°) and standing with 9° (*SD* = 6°). This leads to an average angle of 10° (*SD* = 8°) between the two conditions (Figure 5). The range defined by the mean and $\pm 1$ *SD* is [2°, 18°], which accounts for the majority of our trials (74%).

*Smartwatch Distance*

Next, we investigate at what distance from the center between both eyes to the smartwatch's center participants held their watch. This smartwatch distance corresponds to the length of the *line of sight* in Figure 3. We removed 5% of trials (25 trials out of 480) as outlier trials. Participants placed the watch at a distance of 27.6 cm from their eyes (*SD* = 3 cm) when sitting, and at 28 cm (*SD* = 5 cm) when standing. This leads to an average distance of 28 cm (*SD* = 5 cm) between the two conditions (Figure 7). The range defined by the mean and $\pm 1$ *SD* is [23 cm, 33 cm] and accounts for the majority of our trials (74%).

*Smartwatch Height from Floor*

Last, we investigate at what height from the floor participants held their watch. This smartwatch height corresponds to the distance $h$ between the center of the watch and the floor in Figure 3. We examined the sitting and standing condition separately. We removed 4% of trials (21 trials out of 480) as outlier trials. Participants placed the watch at a height of 101 cm from the floor (*SD* = 6 cm) when sitting, resulting in a range of [95 cm, 107 cm]. When standing, they placed the watch at a height of 142 cm (*SD* = 9 cm), resulting in a range of [133 cm, 151 cm]. These two rages account for the majority of our trials (71%).

*Post-Questionnaire*

On average, participants found reading the texts on the watch easy (*M* = 1.42, *SD* = 0.79, *Max* = 3), rated on a Likert scale with 1 being very easy and 6 being very hard. All 12 participants found that wearing and using the smartwatch felt natural. Eleven participants reported that they would normally wear a watch as worn in the study. Only four participants became tired during the study. While three of them felt that the tiredness did not affect their movement, one participant mentioned that his movements were affected, adding that he moved his hand less and his head more because of the tiredness.

## Discussion and Conclusion

In this paper, we analyzed the way participants position and orient their watch and the offset to the line of sight, when reading short sentences on a smartwatch while participants were sitting or standing. We found that the average pitch angle was at 50° and that a range of 30° around this mean is a reasonable starting point for further experiments, as it accounts for 70% of our collected data. A more tight range of angles was found for the line of sight offset, with a mean of 10° on average and a range of 16° around it, that accounts for more than 70% of our collected data. Finally, we found that on average participants positioned the watch at a distance of 28 cm, and that a range of 10 cm around this mean accounts for more than 70% of our data.

In the future, we plan to use this information to create a static setup of the smartwatch to investigate how participants read visual variables presented on the watch. Given the variability we observed, in particular, how participants oriented their watch, it is likely that this kind of setup needs to consider a range of possible angles as factors, rather than fixing the mean orientation.

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