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## Eyes-free Circular Gestures on Smartphones

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Fig. 1. Eyes-free circular gestures

Smartphones are used in various situations, such as when users have limited visual focus, such as when walking or driving. Eyes-free gestures offer a way to interact with smartphones without requiring visual attention. This research delves into circular eyes-free gestures and elucidates the advantages they offer over other types of gestures in facilitating eyes-free interaction. We carried out two experiments to explore the ability of participants to accurately draw arcs with varying angles in a smartphone's eyes-free context. The results of the first experiment revealed that participants commonly tended to exceed the intended arc lengths, regardless of whether they were drawing arcs clockwise or counterclockwise. The results of the second experiment showed that there is a high variation in drawing eye-free circular gestures by the same user. However, this variation decreases if the second gesture is produced immediately after the first one.

CCS Concepts: • **Human-centered computing** → **Empirical studies in interaction design**.

Additional Key Words and Phrases: smartphones; eyes-free; circular gestures; human computer interaction; haptic

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## 1 INTRODUCTION

Portable devices like smartphones have become essential in our daily routines. They are no longer just tools for communication, but also for performing various tasks [1]. A common method for using smartphones involves initially grabbing the device and then using it while observing a visual screen. This can cause the user to focus visually on the device for an extended period of time, which is not ideal when attention is required elsewhere. The gesture interaction provides a control interface that reduces the need for visual attention to interact with a device [5]. The number of possible gestures could be as large as more than 1000 [7]. The most common single-touch gestures are clicking (or pressing, tapping), swiping (or flicking), and dragging (or scrolling, panning, sliding). Sliding is commonly used for adjusting continuous parameters, such as sound volume. However, reaching for distant values can be problematic, especially with one hand and as the size of smartphones increases [6]. Users often find themselves in scenarios where one hand is occupied, leaving only the other hand to operate the device. This presents the difficulty of reaching targets that are out of range on large-screen mobile devices [2]. Instead, circular gestures can be used in a smaller area to adjust the parameters. In this study, we focus on circular gestures. The circular gesture paradigm is not only functional, but also engaging, providing users with a natural and fluid means of interacting with digital content.

In the first experiment, we will study the perception of the user about the location of their fingers on the circle. We want to understand when a user is trying to draw a circle partially if their perception of finger location on the circle corresponds to the intended geometrical length. The objective of the second experiment is to assess the effectiveness of circular gesture in Hap2Gest interaction concept [3] for perceiving the angle of an arc. In Hap2gest interaction concept the user will draw two consecutive gestures. In this case, the user will first draw a circle to invoke the command. Then, the user will start producing a circular gesture. However, this time at some point the user will feel a vibration on the gesture path. After feeling the vibration the user will lift the finger from the touchscreen and will estimate the angle of the arc he/she produced. In the second study we assess the effectiveness of two methods for prompting users to estimate the angles of eyes-free drawn arcs on a touchscreen mobile device. By incorporating vibration feedback triggered at specific arc lengths, calculated from different methods, this study aims to evaluate the accuracy of participants' angle estimations.

## 2 DESIGN PRINCIPLES

We introduce three design principles that investigate the use of circular arc gestures with haptic feedback for eye-free interaction. By exploring different combinations of these principles, designers can create a diverse set of interaction techniques tailored to specific user needs and preferences in eyes-free interaction scenarios.

- **Continuous interaction:** a circular trajectory provides an infinite length for exploration without interruption at constant speed. Consequently, the continuous nature of circular gestures should reduce cognitive load by eliminating the need for users to hold and reposition their finger, especially in an eyes-free interaction context. This seamless flow enhances the user experience, making interactions more intuitive and effortless. For example, a linear trajectory, on the other hand, has a limited length, and the user has to lift the finger and move it to the

starting point to continue the interaction. This will result in continues change of exploration speed, especially at the beginning and end of trajectory, which may influence the haptic perception.

- **Reusability:** Gesture reuse involves utilizing the same gesture to perform various tasks by considering gestures primitives, such as gesture dynamics [8]. Using the concept of reuse for circular arc gestures involves utilizing variations in angles to represent different commands or functions in addition to the movement directions (clockwise and under clockwise). By altering the angle of the circular arc gesture, users can trigger distinct actions or operations, enhancing the versatility and efficiency of interaction. This approach allows for a more nuanced and flexible utilization of circular arc gestures, enabling users to perform a wider range of tasks without the need for additional gestures or complex input mechanisms.

Moreover, we extend the principle of reuse to haptic feedback by allowing users to interpret perceived haptic feedback differently based on the gesture performed and where the haptic feedback is perceived along the gesture.

- **Efficient space usage:** Circular gestures allow for long gestures and interaction on very small gadgets such as smartwatches. Beyond merely drawing individual circular arcs, users can execute successive or repetitive circles and arcs, allowing for extended gestures on small gadgets. This versatility enhances the usability of circular gestures on constrained interfaces, ensuring that users can engage with their devices effectively despite limited space. For instance, users may draw consecutive circles to obtain additional details about retrieved information, discerned through the position of the haptic feedback on the circle, i.e., the drawn circular arc. For example, after the first circle indicates receiving an email, subsequent arcs/circles could provide further information like the email category (personal, professional, etc.), number, etc.

### 3 EXPERIMENT 1

The objective of the first experiment is to investigate the accuracy and variability of users' eyes-free drawing of an arc over a circular gestures on a touchscreen mobile device.

#### 3.1 Method

*3.1.1 Participants.* Twelve right-handed participants (5 females and 7 males) were volunteered for this experiment. The ages of the participants ranged from 23 to 32, ( $mean = 25.6$ ,  $SD = 3.5$ ). All participants had been using smartphones for several years.

*3.1.2 Apparatus.* The experiment was conducted using a Samsung Galaxy S7 smartphone. An android application was running on the smartphone which was showing arcs and asking participants to draw the arcs in an eyes-free configuration on the smartphone. The smartphone was held by participants under the table to ensure eyes-free configuration. The smartphone screen was mounted on a 13-inch Dell laptop which was placed on the table in front of the participants, as shown in Figure 1.

*3.1.3 Design.* The experiment utilized a within-subject design with two factor: *angle* and *direction*. *Angle* refers to the degree of the arc to be drawn and encompasses 12 conditions: 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°, and 360°, representing a full circle. On the other hand, *direction* pertains to the direction of the drawing movement and comprises two conditions: clockwise and counterclockwise.

*3.1.4 Task and Procedure.* The task required participants to draw an eyes-free arc of various degrees in both clockwise and counterclockwise directions.



Fig. 2. The setup we used for circular eyes-free gesture evaluation. The user was sitting in front of the computer that was showing instruction. The user was drawing gesture to smartphone which was held under the table to avoid visual cues.

The experiment was conducted in a silent room where participants sat comfortably on a chair in front of a desk. They held the smartphone in their right hand and placed it under the table to restrict the view. The participants looked at the monitor screen placed on the desk that displayed the instructions for the task. Participants were provided with a brief training session to familiarize them with the eyes-free drawing setup. Subsequently, they were guided through a series of trials where they drew arcs of different degrees in both clockwise and counterclockwise directions. Each degree of the arc was repeated four times to account for variability.

In the experimental phase, the two *directions* were randomly presented to the participants. Within each *direction*, the 12 *angles*  $\times$  4 repetitions were randomly presented to the participants, resulting in a total of 96 trials per participant (= 2 *directions*  $\times$  12 *angles*  $\times$  4 repetitions). After each block of trials, participants took a break.

### 3.2 Results

We collect touch gestures on the smartphone that include the coordinates of the drawn trajectory and timestamp. We also recorded the direction, degree, and accuracy of each arc drawn by the participants.

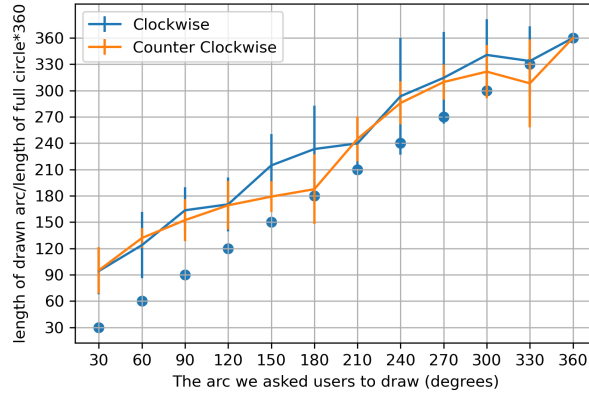


Fig. 3. The mean lengths and standard deviation of different arcs drawn by user in clockwise and counterclockwise direction, on the smartphone.

The ideal geometric length (*idl*) of each arc for each user was calculated by average length of 360 degree arcs for each user ( $360L$ ) and nominal degree of the arc (*deg*) using the following formula:

$$idl = 360L \times \frac{deg}{360} \quad (1)$$

A Shapiro-Wilk normality test was performed to determine whether the lengths of arcs were normally distributed. The results indicate that we must reject the null hypothesis for arc lengths ( $p < 0.001$ ) and conclude that they don't follow a normal distribution. Since the Shapiro-Wilk normality test ( $p < 0.001$ ) shows that the data do not follow a normal distribution, we cannot do parametric tests like t-test or anova. We need to do the non-parametric tests. The Kruskal - Wallis test is the nonparametric equivalent of the one - way ANOVA and essentially tests whether the medians of three or more independent groups are significantly different. The nonparametric version of the independent-samples t-test is known as the Mann-Whitney U-Test. The nonparametric version of the paired-samples t-test is known as the Wilcoxon Signed-Rank Test. A two-way analysis of variance using ARTTool was conducted to examine the effects of direction, and expected angle on *idl*. The two-way ANOVA revealed that there was significant main effect of angle ( $F(11,264)=79.54, p < .001$ ) on *idl*. We ran Tukey Post-hoc analysis on angle factor. This resulted in 66 tests from which 48 pairs of angles had statistically significant means from each other ( $p < 0.05$ ). Here, we will report which arc lengths had the most interfere with other angles, failed to reject the hypothesis that their mean is different from other angles and ( $p > 0.05$ ). The  $120^\circ$  arc's length was not significantly different from that of 4 other arcs ( $60^\circ, 90^\circ, 150^\circ, \text{ and } 180^\circ$ ). The  $150^\circ$  arc's length was not significantly different from that of 4 other arcs ( $90^\circ, 120^\circ, 180^\circ, \text{ and } 210^\circ$ ). The  $180^\circ$  arc's length was not significantly different from that of 4 other arcs ( $120^\circ, 150^\circ, 210^\circ, \text{ and } 240^\circ$ ). The  $330^\circ$  arc's length was not significantly different from that of 4 other arcs ( $240^\circ, 270^\circ, 300^\circ, \text{ and } 360^\circ$ ).

### 3.3 Discussion

The key finding is that, with the exception of larger angles, our study reveals that participants tended to overestimate the length of arcs compared to their ideal geometric length. In addition to the type of touchscreen gestures, it is necessary to pay attention to the directions of the gestures [4]. Our results are consistent in both directions. This tendency suggests

potential challenges in accurately gauging distances without visual feedback, which warrants further investigation into strategies for improving accuracy when drawing precise circular arcs in eyes-free interaction scenarios.

## 4 EXPERIMENT 2

The objective of this experiment is to assess the effectiveness of two methods for prompting users to estimate the angles of eyes-free drawn arcs on a touchscreen mobile device. By incorporating vibration feedback triggered at specific arc lengths, calculated from different methods, this study aims to evaluate the accuracy of participants' angle estimations. The analysis will focus on understanding the sources of error and limitations in the chosen methods, providing information on the challenges of eye-free touchscreen interactions and potential avenues for improvement in future research and interface design.

### 4.1 Method

*4.1.1 Participants.* We recruited a new sample of 12 right-handed participants (7 males and 5 females), aiming for a demographic similar to that of the previous study to ensure consistency and comparability. Participants had prior experience with touchscreen interactions.

*4.1.2 Apparatus.* We used the same Samsung Galaxy S7 smartphone as used in the previous section for this experiment. Participants were asked to draw arcs in both clockwise and counterclockwise directions in an eyes-free configuration. The smartphone was programmed to vibrate when the drawn arc reaches a length calculated on the basis of the angle of the target arc. The gesture length  $gl$  corresponding to each angle was calculated by using the following formula:

$$gl = 360L \times \frac{deg'}{360} \quad (2)$$

where  $360L$  corresponds to length of the full circle user just produced to invoke the command before producing each arc, the  $deg'$  was the modified target angle of the arc and the number we wanted the user to retrieve using the haptic cues. The modified target angle is the angle we derived from Figure 3. We used this modified angle instead of actual angle since we showed in previous experiment that length of the arcs produced by users is not exactly proportional to the angle of the arc and they tend to overshoot.

*4.1.3 Design.* The experiment utilized a within-subject design with three factors: *arc angle*, *arc direction*, and *reference circle*. We used the same *arc angle* and *arc direction* as we used in previous study. However, *reference circle* refers to the full circle which its length is used to calculate the length of the arcs for each angle and in result the length that they will feel the vibration for each angle at. We considered two *reference circles* in this study: *immediate circle*, and *non-immediate circle*. *Immediate circle* refers to when the reference circle was made by the user exactly before each trial and before starting to draw arcs to feel vibration and make the estimation. The length of each full circle was used as the reference circle for each trial. *Non-immediate circle* refers to when we asked each user to draw 5 circles in each direction. We calculated the length of the reference circle as the average length of the five circles in each direction.

*4.1.4 Task and Procedure.* Participants attended two sessions for two *reference circle* conditions. For each participant, the order of these sessions was random. In the *non-immediate circle* condition, we first asked the participant to draw five full circles in clockwise direction and five full circles in counter-clockwise direction. The order of these ten circles for each participant was random. Then, we calculated the average length of the five circles in each direction as the length of the full reference circle for each direction. Then, the length of each arc is calculated by multiplying the ratio

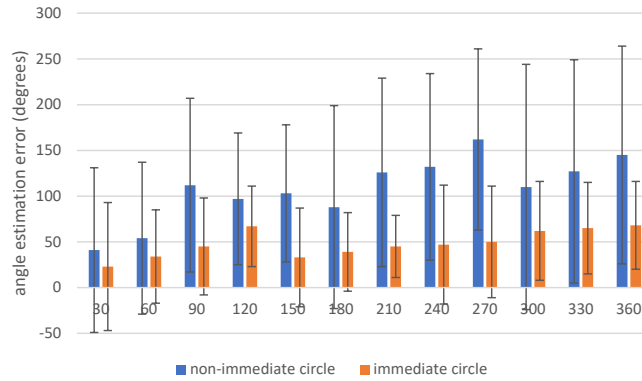


Fig. 4. The mean and standard deviation of two reference conditions (immediate circle, and non-immediate circle) for each target arc angle.

of arc to full circle found for each angle in the previous experiment and the length of the full reference circle found in this experiment. In each session, after the lengths of each arc calculated by our program, the main experiment starts. In each trial, participants were instructed to start drawing circular gestures in clockwise or counterclockwise directions. They had to keep drawing the circular gestures, even if necessary multiple circles, until they felt the vibration. After feeling the vibration they lift their finger from the touchscreen and verbally report to the experimenter what is their estimation of the angle of the arc they drew. The participants were told that the angle can be any number greater than zero. In total we gathered 2880 angle estimations from participants ( 2 arc directions  $\times$  2 reference circles  $\times$  12 arc angles  $\times$  12 participants  $\times$  5 repetitions).

In the *immediate circle* condition unlike the *non-immediate circle* we did not have one calculated for one full circle length. Instead, before each trial and each angle estimation, participants were instructed to draw a full circle in the same direction as the next trial. So, before each trial, the full-length circle was calculated independently of other trials. After the full-length circle was calculated, the arc estimation phase was similar to *non-immediate* condition. Our hypothesis was that when the reference circle is drawn immediately before the arc estimation phase, there will be less variance in the arc shapes and the participant's estimation would be more accurate.

## 4.2 Results

A three-way ANOVA was conducted to examine the effects of arc degree, arc direction, and reference circle on angle error. The means and standard deviations for angle error across different levels of *arc degree*, *arc direction*, and *reference circle* are reported below.

**Arc degree:** There was a significant effect of *arc degree* on *angle estimation error* ( $F(11, 2843) = 2017.86, p < 0.001$ ). The mean and standard deviation of angle estimation errors are shown in Figure 4. Generally the higher the *arc degree* caused higher *angle estimation error*.

**Arc direction:** We didn't find a significant effect of arc direction on *angle estimation error* ( $F(11, 2843) = 3.49, p = 0.06$ ).

**Reference circle:** There was a significant effect of *reference circle* on *angle estimation error* ( $F(11, 2843) = 2017.86, p < 0.001$ ). The mean angle estimation error of immediate circle ( $48.17^\circ$ ) was significantly less than the mean angle estimation error of non-immediate circle ( $108.08^\circ$ ).



We didn't find any interaction between any of the variables.

### 4.3 Discussion and Future Work

The results indicate that the reference circle used has a significant impact on angle error, with the *immediate circle* method resulting in significantly lower angle errors compared to the *non-immediate circle*.

*Arc angle* also significantly affects angle error, suggesting that different degrees result in varying levels of error. Generally, the higher the "arc angle" the higher error in estimation was observed. However, the error we observed in angle estimation was relatively high. Although the *immediate circle* caused lower error compared to *non-immediate circle*, it's error is still high and makes it impractical to use.

We recommend two possible solutions for this issue. First, one can use a more sophisticated recognizer, which in real-time can analyze the shape of the gesture made by user and tries to locate user's finger position on the circle. This method is relatively challenging, especially at smaller angles, where there is less time and data available for analysis. The second solution is to fix the radius and position of the circle and force the user to move the finger over the predefined circle. Although fix circle or fix knobs are common on touchscreens, using them in eyes-free configuration is challenging as the user needs to locate the knob or circle without visual cues. One possible solution to tackle this problem is to provide a haptic texture on the circle and then use a different haptic feedback on the target points. However, this cannot be achieved using the vibration motors available on commercial smartphones. This solution requires haptic surfaces that can provide reacher-localized haptic feedback to users.

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