
Finger Placement and Hand Grasp during Smartphone Interaction

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Abstract

Smartphones are currently the most successful mobile devices. Through their touchscreens, they combine input and output in a single interface. A body of work investigated interaction beyond direct touch. In particular, previous work proposed using the device's rear as an interaction surface and the grip of the hands that hold the device as a means of input. While previous work provides a categorization of grip styles, a detailed understanding of the preferred fingers' position during different tasks is missing. This understanding is needed to develop ergonomic grasp-based and Back-of-Device interaction techniques. We report from a study to understand users' finger position during three representative tasks. We highlight the areas that are already covered by the users' hands while using the on-screen keyboard, reading a text, and watching a video. Furthermore, we present the position of each of the user's fingers during these tasks. From the results, we derive interaction possibilities from an ergonomic perspective.

Author Keywords

Smartphone; back-of-device; ergonomics; touch; grasp.

ACM Classification Keywords

H.5.2 [User Interfaces]: Ergonomics

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Introduction & Background

The most successful mobile devices are currently smartphones. Users mainly interact through the devices' screens which allows a bidirectional interaction. Despite being a highly successful interaction technique, direct touch results in different challenges including the fat-finger [12] and the occlusion problem [14].

A body of previous work investigated approaches to extend the interaction with mobile devices by equipping the device with a touch-sensitive rear to enable Back-of-Device (BoD) interaction. Wigdor et al. [14] explored BoD interaction for different form factors and different tasks. Baudisch and Chu [3] proposed BoD interaction to enable interaction with very small devices. While Hiraoka et al. [6] already proposed BoD interaction in 2003, devices that enable BoD slowly develop into mass market products. Sony's handheld game console Playstation Vita, Motorola's smartphone Charm and Oppo's smartphone N1 are equipped with touchpads on the back of the device. Using BoD has been also proposed for authentication [5, 8] and in combination with the front touchscreen for 3D object manipulation [10]. Bader et al. [2] showed that BoD interaction can improve interaction with 3D content and that users' performance increases if the user can see the finger on the back. Wolf et al. [18] evaluated BoD gestures using two iPads combined to double-sided touch screen device and Shimon et al. [11] developed a set of user-defined BoD gestures.

While interacting with smartphones and especially while using BoD interaction, the users' hands serve two purposes. The hands are used to interact but they also have to grasp the device. Yoo et al. [21] measured the position of the index finger and the thumb on a smartphone with the natural hand posture. They found that the index finger was primarily positioned in the upper left side and proposed us-

ing the index finger for BoD to reach the display areas that are hard to target for the thumb on the front side. As described by Wimmer [15], the way objects are grasped can provide information about its context. As further described by Wolf [17], the way an object is grasped and the physiology of the human hand restricts the ergonomic interaction possibilities. For larger tablets, for example, not all areas of neither the front [9, 19] nor the back [19] can be reached with the fingers while holding the device. For smaller form factors, Wobbrock et al. [16] showed that the posture of the hand has a significant effect on users' touch performance. Trudeau et al. [13] found that the thumb has the best pointing performance on smartphones in a relaxed pose when it is neither fully flexed nor straightly stretched. This has been confirmed by Wolf et al. [20] for both, the thumb for front and the index finger for BoD interaction with held tablets.

Overall, previous work showed that BoD interaction can improve interaction with mobile devices for a number of use cases (e.g. [3, 5, 10, 14]). Previous work also showed that the way users grasp mobile devices affects their performance [13, 16, 20] and restricts how they can interact with devices in the first place [9, 19]. To develop ergonomic BoD interaction it is therefore necessary to know how users naturally hold their smartphones, where the fingers - and not only the index finger - that could be used for BoD interaction are located, and which areas on the device's back are covered by the hands. In this paper we report from a study that investigates hand postures during three representative tasks to inform the design of usable BoD interaction. We describe the areas that are covered by the users' hands during text-entry using the on-screen keyboard, while reading a text, and while watching a video. We show the position of each of the user's fingers during these tasks. From the results, we derive areas which are suitable for BoD interaction.



Figure 1: The study setup consisting of two GoPros and the phone with a colored grid.



Figure 2: Samsung Galaxy S4 with a colored grid clamped between the phone and a transparent hard case.



Figure 3: Marking the spots on the participant's finger that are touching the phone.

Study

We conducted a study to understand how users hold a smartphone during three common tasks. We were particularly interested in where the grasping hand touches the smartphone during the tasks. The study was conducted in a distraction-free environment in which participants were seated and directly focused on the smartphone. We avoided any instrumentation of the participant's hands and the phone to not affect the grasp.

We derived three common tasks from a smartphone usage study by Böhmer et al. [4]. These tasks are: *writing a text message*, in which participants wrote a birthday invitation to a friend using Samsung's pre-installed on-screen keyboard; *reading a text*, in which participants read a Wikipedia article while being instructed to remember arbitrary facts; *watching a video*, in which participants watched a short video clip while being instructed to remember the plot. The writing and reading tasks were conducted in portrait mode, while the video watching task was conducted in landscape mode.

Apparatus

All tasks were performed on a Samsung Galaxy S4 ($137\text{ mm} \times 70\text{ mm} \times 7.9\text{ mm}$; 130 g). Size and weight are similar to other common smartphones, such as the Google Nexus 4 and 5, the HTC One or the iPhone 6. For analysis purposes, we equipped the phone with a colored grid clamped between the phone and a thin transparent hard case (see Figure 2). The grid consists of 16×29 cells with a size of $5\text{ mm} \times 5\text{ mm}$ each, whereas the outer rows and columns are at the edges of the phone. We used two Go-Pro Hero 3+'s to record how participants performed the tasks and a water-soluble pen to mark the parts on the participant's hands which touched the phone. The study setup is shown in Figure 1.

Procedure

After participants understood the purpose of the study and filled the consent form, we started the study with a demographic questionnaire and general study instructions. We then proceeded to conduct the three tasks, which were counterbalanced using Latin squares. Each task started with the researchers handing the phone to the participant and explaining the task.

The tasks were performed until participants found a stable grasp. A stable grasp was found when participants did not change the grasp for at least 30 seconds. Then participants were asked to hold their hands still and to not change the current grasp. Areas at the phone that were touched by the participant due to the grasp were then identified and captured on a sheet featuring the colored grid (grid sheet). This was done as follows: We applied marks at the participants' fingers using a water-soluble pen to tag the spots where the hands were touching the phone (as shown in Figure 3). Supported by these marks, we then captured every touched cell on the grid sheet.

The touched cells on the phone can easily be identified when the participant holds the phone one-handed or two-handed without overlapping the hands. When the hands were overlapping (e.g. Figure 4) we captured the touches of the overlapping hand first and asked the participant to lift that hand afterwards. While lifting the overlapping hand, we instructed the participant to not move the other hand and supported them to hold the phone if necessary. This enabled us to identify the touched spots of the before covered hand and to capture these spots on the grid sheet.

We recorded the procedure (including a 360° view of the participants' hands while holding the phone after applying marks) on video and reviewed it afterwards to ensure that the participants' hands remained still during the capturing.

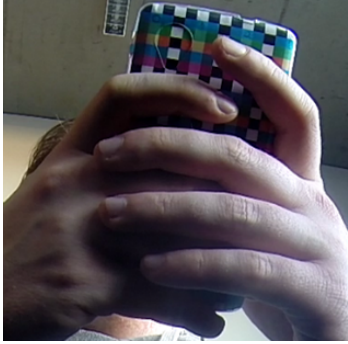


Figure 4: Example grasp: The right hand is holding the phone (and hence touching it) while the left hand is overlapping the right hand.

	Left	Right	Sum
F_0	0.9%	0.0%	0.9%
F_1	11.3%	21.7%	33.0%
F_2	10.1%	21.3%	31.4%
F_3	2.7%	9.4%	12.1%
F_4	0.7%	3.4%	4.1%
Palm	5.0%	13.6%	18.6%
Sum	30.7%	69.3%	100%

Table 1: Distribution of cell touches per finger for the writing task.

Participants

We recruited 10 participants (2 female) through our university’s mailing list. All participants use their phones frequently (9 multiple times per day; 1 once per day) and were between 21 to 28 years old ($M = 24.8$; $SD = 2.1$). On average, participants hand’s height (measured from the carpus to the middle finger’s tip) were 19.5 cm ($SD = 1.6$). People usually tend to use their dominant hand to operate the phone [1]. To avoid this influence, all our participants were right-handed.

Results

We visualized the grid cells participants touched during the study in the heat map shown in Figure 5 and the finger area map in Figure 6, which shows the areas touched by particular fingers. On average, participants touched 13.8% of the 464 grid cells per task ($SD = 3.9\%$). From all touches that we captured, 68.1% were made with the right hand. In the following, we will number the fingers from F_0 for the thumb, F_1 for the index finger to F_4 for the little finger.

Writing a text

On average, participants touched 15.1% of the grid ($SD = 3.3\%$) during this task. Thereby, the left hand is responsible for 4.6% ($SD = 3.7\%$) while the right hand contributes 10.5% ($SD = 3.8\%$) of that average. Although the right hand is touching significantly more cells ($t(18) = -3.47$, $p = .003$), only 2 participants held the phone solely with the right hand, while 8 participants used both hands. The difference in touches is – due to how the phone is held – two-handed: 4 participants were using the right hand as the main holding hand. This means that the right hand is holding the phone, while the left hand is partly overlapping the right hand (see Figure 4). Only 2 participants used the left hand as the main holding hand, while the remaining 2 participants held the phone without any hand overlaps.

The distribution of touches per finger (see Table 1) shows that F_1 and F_2 are responsible for the majority of the touches in this task (64.3%). Further analysis of the finger area map (see Figure 6a) reveals that these two fingers are holding the phone at the middle of the phone’s rear, and hence, they carry the majority of the phone’s weight. The palms account for 18.5% of all touches and stabilizes the phone with the left (5.0%) and the right (13.5%) hand. F_3 and F_4 are used to stabilize the phone at the bottom third (including the edge at the bottom) and account for a fairly small percentage of the touches (16.3%). One participant used the left thumb to further stabilize the phone at the bottom edge while typing with the right thumb.

Reading an article

In this task, participants touched 12.1% of the grid on average ($SD = 3.3\%$) of which 2.4% were touched by the left hand ($SD = 4.0\%$) and 9.7% ($SD = 5.5\%$) by the right hand. 6 participants were holding the phone one-handed (all with the right hand), while the remaining 4 held it two-handed. From the two-handed holders, 3 used a main holding hand (2 left; 1 right) and 1 held the phone without any overlaps. Again, we found a significant difference ($t(18) = -3.30$, $p = .004$) between the number of touched cells for both hands. However, this difference is attributed to the fact that the majority of participants (6 + 1) either held the phone solely with their right hand or used the right hand as the main holding hand.

Table 2 indicates a similar touch distribution per finger for the reading task. Still, F_1 and F_2 are holding the phone at the center (55 mm to 100 mm from the bottom; see Figure 6b) and account for the majority of touches (50.2%). The palm contributes 28.8% of all touches and stabilizes the phone with the left (7.8%) and the right hand (21.0%). 18.5% of touches were contributed by F_3 and F_4 to hold

	Left	Right	Sum
F_0	2.5%	0.0%	2.5%
F_1	3.2%	27.4%	30.6%
F_2	2.1%	17.4%	19.6%
F_3	2.1%	9.8%	11.9%
F_4	1.8%	4.8%	6.6%
Palm	7.8%	21.0%	28.8%
Sum	19.6%	80.4%	100%

Table 2: Distribution of cell touches per finger for the reading task.

	Left	Right	Sum
F_0	4.1%	3.8%	7.9%
F_1	17.6%	24.1%	41.7%
F_2	11.4%	14.0%	25.3%
F_3	2.4%	4.2%	6.7%
F_4	1.2%	3.6%	4.9%
Palm	7.1%	6.4%	13.5%
Sum	43.9%	56.1%	100%

Table 3: Distribution of cell touches per finger for the video watching task.

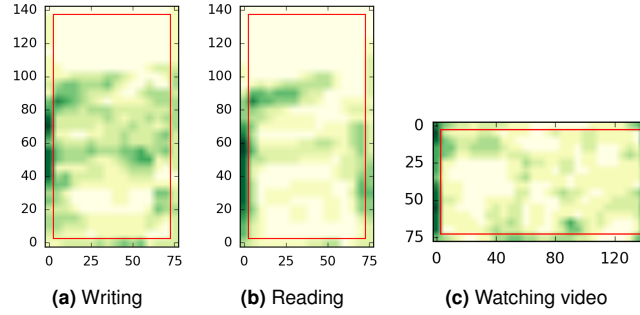


Figure 5: Heat maps with the touched areas. The axes represent the position in *mm* when facing the rear of the phone. The outer rows and columns represent the respective edges of the phone.

the phone at the bottom third of the phone. Two participants who held the phone two-handed with their left as the main holding hand additionally used their thumb to stabilize the phone at the left edge.

Watching a video

While watching a video, participants touched an average of 14.2% ($SD = 4.7\%$) of the grid, with 6.2% ($SD = 3.8\%$) touched by the left and 8.0% ($SD = 1.7\%$) by the right hand (see Table 3). Two participants held the phone solely with the right hand, while 8 participants held the phone two-handed. There were no overlapping hands in landscape mode. Hence, we have no significant difference ($t(18) = -1.31, p = .206$) between the touch contribution of both hands.

F_1 and F_2 are touching most of the cells (67.1%). In comparison to tasks performed in the portrait mode, Figure 6c shows that these two fingers were touching nearly the whole phone. The palm contributes 13.5% (left: 7.1%; right:

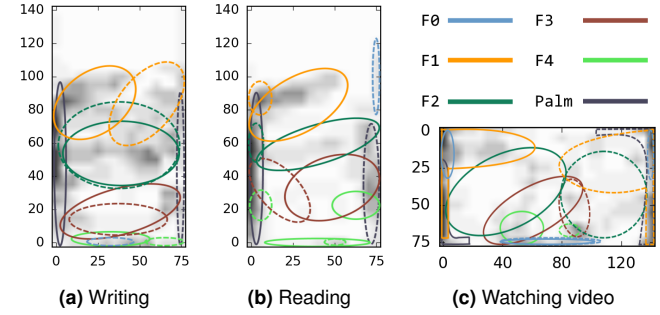


Figure 6: Area maps showing in which areas particular fingers and the palm were placed. Dashed circles represent the left hand while ordinary circles represent the right hand.

6.4%), which is the lowest percentage of all three tasks due. F_3 and F_4 are contributing 11.5% of all touches, while the thumb touches a fairly high amount of cells (7.9%) in comparison to tasks in portrait mode.

Comparison of tasks

The lowest percentage of grid cells were touched during the reading task, followed by the video watching task and the writing task. However, a one-way repeated measure ANOVA did not reveal a significant difference, $F_{2,18} = 1.615, p = .226$. Despite overlapping hands, an independent samples t-Test revealed a significant difference between touched cells in one-hand grasps ($M = 52.9; SD = 16.3$) and two-hand grasps ($M = 69.7; SD = 16.7$), $t(28) = -2.610, p = .014$.

In all tasks, the right hand touched the most. A two-way repeated measures ANOVA revealed that there is a significant difference between the number of cells per hand, $F_{1,9} = 7.910, p = .020$.

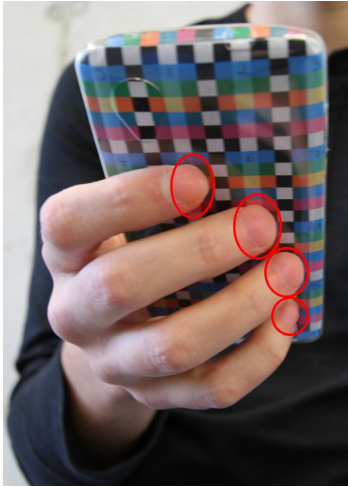


Figure 7: Example for flexed fingers: Not the whole finger is touching the rear side. Instead, there were touches only at the red circles.

Discussion and Implications

The heat maps reveal visible accumulations of touches of the index finger F_1 (90 mm from the bottom for the writing and reading tasks; 10 mm from the bottom for the video task), the middle finger F_2 (50 mm from the bottom for the writing and reading tasks) and the palms for all three tasks. This is a consequence of a rather small spread (see Figure 6) and a large amount of touches that these fingers contribute. In contrast, other fingers F_3 or F_4 are not visible in the heat map as they contribute a lower amount of touches (only the fingertips were touching; see Figure 7), while the spread is still similar to the other fingers. This indicates that the index finger, the middle finger and the palm are more likely to touch the same areas, while F_3 and F_4 vary throughout the participants.

Based on the heat maps and finger area maps, we identified three ergonomic interaction possibilities: (1) the upper third of the phone's rear side (starting at 100 mm from the bottom) using F_1 (and F_2) to perform taps and gestures. While it stands to reason that areas which are not touched accidentally are not comfortably reachable for the particular finger, results by Yoo et al. [21] suggest that the left upper third of an iPhone 6 belongs to the area that can be touched by index fingers comfortably. Alternatively, a second hand can be used to perform gestures in this area resulting in bimanual interaction. (2) The upper third of the right edge can be used for interaction with the thumb as this area is free of touches and reachable by the thumb. A number of smartphones already place the power button as well as for some the volume rocker there (e.g. Nexus 6P). This could be extended to enable localized taps as well as swipe up/down gestures. (3) As the palms stabilize the grasp on the phone's edges and hence are touching them most of the time, pressure sensors on the sides can be used to implement grasp interaction. Holman et al. [7] attached three

button-sized pressure sensors to an iPhone 4's right side to enable zooming or open the context menu. Squeezing the phone can also be interpreted as a modifier (such as the shift key on a keyboard) to augment the functionality of subsequent taps or gestures (e.g. see point 1 and 2). Besides the palms and the right index finger (10 mm from the left and 0 mm to 40 mm from the bottom in Figure 5c), there are no visible accumulations for the video task. This is due to a higher grasp diversity, which makes statements about the finger placements difficult. We had the impression that people are less used to the landscape mode, which might explain why we found a higher number of different grasp postures in landscape than in portrait mode.

Conclusion and Future Work

BoD interaction has been proposed to extend the interaction with mobile devices. Developing ergonomic BoD interaction requires to understand how users naturally hold their phones. The conducted study shows for three common tasks how users grasp a smartphone, which areas on the phone are covered by the hands, and where the fingers are located. We discuss three potential approaches for BoD interaction that are supported by our results. As we conducted the study in a calm lab environment that enabled participants to fully focus on the task, we are interested in repeating the study in the wild. This would allow to not only increase the ecological validity of the results but would also enable to collect significantly more data which would help to identify less common patterns. Therefore, we aim to augment a standard smartphone's rear with a capacitive sensor matrix. Furthermore, we are interested in further exploring the interaction methods that seem suitable for Back-of-Device interaction.

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