Investigating How Smartphone Movement is Affected by Body Posture

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ABSTRACT

We present an investigation into how hand usage is affected by different body postures (Sitting at a table, Lying down and Standing) when interacting with smartphones. We theorize a list of factors (smartphone support, body support and muscle usage) and explore their influence the tilt and rotation of the smartphone. From this we draw a list of hypotheses that we investigate in a quantitative study. We varied the body postures and grips (Symmetric bimanual, Asymmetric bimanual finger, Asymmetric bimanual thumb and Single-handed) studying the effects through a dual pointing task. Our results showed that the body posture Lying down had the most movement, followed by Sitting at a table and finally Standing. We additionally generate reports of motions performed using different grips. Our work extends previous research conducted with multiple grips in a sitting position by including other body postures, it is anticipated that UI designers will use our results to inform the development of mobile user interfaces.

Author Keywords

Handgrip; Mobile device; Smartphone; Grasp; Body posture; Design; Interaction; Standing; Lying down.

ACM Classification Keywords

H.5.2. User Interfaces: Input Devices and Strategies.

INTRODUCTION

Smartphone interaction design is not limited to the creation of touchscreen interfaces. The use of grasp, body posture or device orientation can also supplement interaction (e.g. use the device orientation to select an action item on the screen [20,19,4], use the back of the device as input method [6] or tilt the device to switch the screen orientation [5]). However, current research only focuses on specific applications or hardware implementations, there is no systematic analysis of how hand usage is affected by different smartphone form factors.

Eardley et al. were the first to conduct a more generic empirical approach to investigate this question [9]. They highlighted several factors impacting the way we use our hand around the smartphone, including the type of handgrip, task, position of items on the screen. They subsequently proposed guidelines for mobile UI designers to make use of their findings. In this paper, we follow a similar approach but we go one step further by investigating how the users' body posture affects hand interaction with smartphones.

In particular, we extend previous work by exploring how three body postures (Standing, Sitting at a table, Lying down) and different grasps (Single handed, Symmetric bimanual, Asymmetric bimanual thumb and Asymmetric bimanual finger) affect hand interaction. Our work thus goes beyond [20,16] that focused on single-handed interaction; [2] investigating single handed and bimanual when sitting; or [21] only looking at walking scenarios.

We explore factors that influence hand usages (phone support, body support and muscle usage) and generated hypotheses. We tested these through a controlled experiment measuring phone movements via inbuilt sensors. Our main results are: (1) the body posture with the most movement is Lying down then Sitting at a table and Standing; (2) the orders of overall movement (the sum of movements made in the three rotational direction of the phone) for the grips are consistent throughout all body postures (Figure 1) corroborating [9]; (3) the rotation of the smartphone is dependent on body posture, with Lying down showing different rotational movement than Sitting at a table and Standing. We provide detailed descriptions of motions used in different body postures, using different grips, which should be valuable for mobile UI designers.
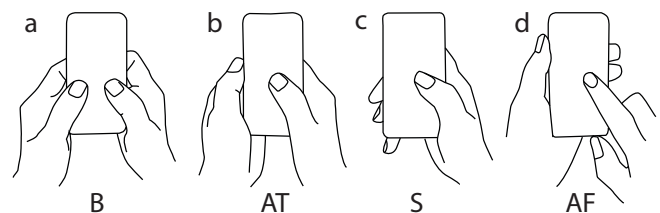

Figure 1. Four handgrips: a) Symmetric bimanual (B); b) Asymmetric bimanual thumb (AT); c) Single-handed (S); d) Asymmetric bimanual finger (AF).

Understanding how users interact with technology is an essential step to better design. We believe that understanding the variability of 'hand usage' in various contexts will enable designers to improve smartphone design. While mobile UIs are fairly well understood in classical conditions (e.g. sitting), they are used in many other ways. Knowing how the manipulation of the device changes within these contexts should substantially aid designers to produce more adapted UIs. For example, this might include avoiding designs that require frequent movements within gestural input or using threshold of movements larger than those empirically observed to trigger certain functionalities.

To summarize; we contribute (1) a study exploring the effect of posture on mobile manipulation as well as (2) insights that can be used by designers for designing mobile UIs more adapted to different context.

RELATED WORK

Our work relates to research on grips used for smartphone interaction and the effect of body posture.

Using grip for interaction

The ways that humans grip a smartphone has been investigated in many ways. E.g. in [9] the authors mapped four grips during an observational study with three different interaction types. [1] Investigated three grips using a touchscreen keyboard and the corresponding accuracy. In [3] the authors mathematically modelled the human hand, looking at the reach of a static grip and the thumb. In [10], the authors virtually modelled the hand by studying the ergonomics of the hand within the virtual word with 3D rendered objects. Other researchers have also compared the use of a static single-handed grip in the dominant and non-dominant hand in order to compare tapping accuracy [22].

Previous work has detected the user's grip and adapted the UIs [27,17]. In [17], grips are used to predict the smartphone's mode (e.g. camera, call, game). In [5], the UI changes from landscape to portrait. Researchers have looked at screen-based sensor technology to create adaptive UIs that update depending on where the fingers are [14]. However, these approaches explore static grips rather than the hands' movements while interacting. Other research looked into the hand movements using a single-handed grip to interact with the device by tilting the device to bring it into range of the thumb [20,19,4]. These works focus on a single device size and body posture. Works has also examined how fingers interact with the back of a device [18,17,29]. Such studies have spurred a number of other studies into using grasp as input to allow users to physically tap or gesture the back face of the phone [24,28].

Physical body posture

Inbuilt sensors have been used to measure information about smartphone orientation [25]. Other studies have sought to account for full body posture. For example one observational study investigated gender differences between standing and sitting body postures [23]. Another

explored the muscles used for single and asymmetric bimanual grips for smartphone interaction sitting down [2]. Researchers have also investigated how text entry on a smartphone can be affected by activities such as walking [12] but while all these studies touch on body posture, they do not empirically examine multiple body posture data.

Both [20 and 16] investigated single-handed interaction in multiple body postures, with [16] comparing the difference between the thumb's biomechanical joint movement and musculature pressures for three different body postures (sitting, sitting at a table and standing). Meanwhile [4] specifically sought to predict how the smartphone movement varied in different physical positions afforded by different activities (sitting, standing, walking and sitting on a moving bus). What that research did not do is to look specifically at the hand-smartphone interaction or compare these body postures with the multiple grips stated in [9].

THEORETICAL EFFECTS OF POSTURE

We examined the factors affecting hand usage with different body postures. We then constructed hypotheses to be tested in a controlled experiment. We will refer to Alpha, Beta, Gamma as the rotational axes of the phone (Figure 2), the *overall movement of the phone* being the sum of movements made in the three directions.
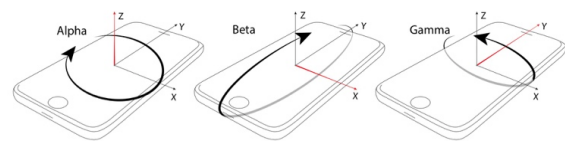

Figure 2. Smartphone orientation (Alpha, Beta and Gamma). Factors discovered for the sitting position

Eardley et al. [8] identified that the interaction type (touchscreen, stylus and keyboard) affects the way smartphones are gripped in a sitting setup. Focusing on the touchscreen interaction method, the authors further investigated the effect of handgrip and smartphone size on hand usage [9]. A study demonstrated the following results:

- A range of four handgrips (Figure 1) were used, with grips depend upon the application and interaction type (touchscreen, stylus, keyboard). The smaller the size of the smartphone the smaller the movements.
- The overall movements of the smartphone depend on the position of the target. Less movement occurs when the targets are in the functional area of the thumb [3] (Figure 3).
- Differences in axes movements were noted, e.g. overall smaller Alpha but larger Gamma. The authors provide a table of movements metrics for each conditions.
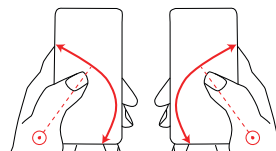

Figure 3. Functional area of the thumb is the thumbs natural area of reach when the grip is static [3]. Factors for different body postures

When moving to different body postures we extrapolate that there are other factors affecting hand usages: smartphone support, body support and muscle usage. We lay down hypotheses regarding objective measurements (quantity of movement performed by the hand in the different axes of Figure 2) and subjective (users' perception of security and comfort). We particularly focused on three body postures (Sitting, Standing, Lying) to have a trackable set for a controlled experiment. To identify these body postures, we first listed common postures using personal experiences and observations. We then reduced the number of postures, selecting the ones that were most affected by our factors. We discarded non-symmetrical postures to ease the comparison of rotations between the postures (e.g. lying down on the left would skew the result to one side).

Smartphone Support
The way a smartphone rests and inclines in the hands varies with body posture (Figure 4). When standing for example, the smartphone rests on top of the hands, while a 'lying on the back' posture means the hands cannot be placed in front, blocking the screen, even to stop the smartphone from falling. Furthermore, smartphone support for all body postures is affected by the grip used. E.g. bimanual grips will offer more contact area between the phone and the hand and should be perceived as more secure than single-handed. We also expect the participants to compensate for the anxiety of dropping the smartphone for two postures: Lying down (falling towards the participants face) and standing (dropping that results in damage).
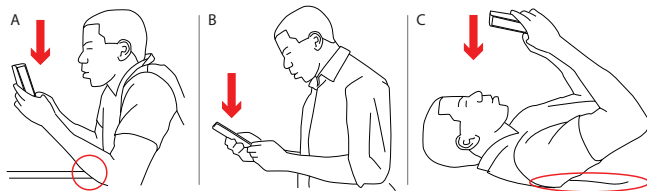

Figure 4. Three different body postures in which different factors affect interaction such as a) Sitting at a table resting arms; b) Standing; c) Lying down with the back to the floor. (Arrows represent gravity and the circles are restrictions)

Body support
In [16] researchers investigated smartphone usage via biomechanical and muscle activity for different postures (sitting, standing and sitting at a table). They concluded that body posture made a difference due to the mobility of the wrist and upper extremities. When sitting at a table arms will be anchored near the elbow and biomechanical restrictions will be placed on the upper arm movement. The participants' perception of the smartphone support could thus be boosted, leading to an increase of smartphone movement. When lying down the participants arms will be lifted upwards in order to bring their hands together, enabling interaction via bimanual grips and allowing a clear view of the screen. Overall, we believe this will reduce the perception of stability and increase smartphone movement.

Muscles usage
When interacting with touchscreen devices (Smartphone, tablet, tabletop, wall display), Bachynskyi et al [2] showed that distinctive body postures use distinctive sets of muscles. This muscle usage relates to differing grips used for smartphone interaction: When sitting, a two-handed grip uses the lower back, upper back and shoulder muscles on the arm of the dominant hand. However, the single-handed grip uses just the upper back and back shoulder muscles of the dominant hand. We believe that this distinctive muscle usage influenced the findings of Eardley et al [9] in which, grips and location of targets altered the tilts and rotations of the smartphone. Following on from these findings, we believe differing body postures will again affect the smartphones' rotations, in particular variances should be seen when lying down, as distinctively different muscles will be utilised in supporting the smartphone.

Hypotheses
From the above we make the following hypotheses.

- H1: The overall smartphone movement will be larger when lying down than other body postures due to the arm muscles being used to lift the smartphone upwards. We also think that the lack of support will deem lying down the less "secure" posture.

- H2: The overall amount of smartphone movement will be lower when standing than in other postures. As participants will have full arm movement and flexibility. Additionally, the participants may be anxious concerning the breakage of the smartphone.

- H3: The directional movement for lying down will be distinctive to the other body postures. We believe this is effected in the way the smartphone rests in the hand involving distinctive muscles (more beta and gamma movements when lying down). Effect should be stronger in S.

- H4: Previous results on grips should be similar for Sitting at a table and Standing, i.e. S will have most movement, followed by AT, B and AF. This should differ for Lying down where AT and AF allow for a firmer grip and more stable hold and thus less movement.

- H5: As before, the total movements of the smartphone will differ according to Target Position for all body postures (targets further away needing more movements and those in the functional area of the thumb, less).

- H6: The lower the movement, the higher the rating for the conditions "secure" and "comfortable" (and those conditions will be preferred). E.g. S should be rated the worst when lying.

CONTROLLED EXPERIMENT
Our goal was to explore if the participants' body posture affects the smartphones' tilt and rotation, in particular how handgrips empirically affect the smartphones movement. We replicated the setup from [9] to ensure study validity. In particular, we used the same user interfaces and graphics.

Participants

20 right-handed participants with no known disabilities (10 males and 10 females) aged between 18yrs to 41yrs took part in the study. All participants either studied at or worked for a university. Their hands ranged from Length 81-117mm, Width 76-100mm, thumb length 52-69mm and finger length 75-92mm. All participants had previous experience with touchscreen smartphones. 19 participants owned touchscreen phones, 14 used smartphone cases, 10 used iOS, 9 used Android and 1 participant used a Nokia device. The top apps used were Social media (Instagram, Facebook, Snapchat), Messaging (Text, WhatsApp) and Calls. The top locations used were Public transport (Bus, Train), Work/University (Breaks, Lectures) and at Home.
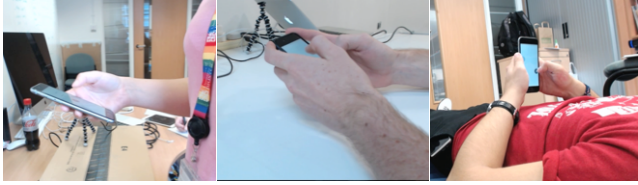

Figure 5. Example of video taken for all three body postures (Standing, Sitting at a table and Lying down)

Task

Each participant was asked to adopt one posture at a time of the three required postures (Standing, Sitting with their arm resting or Lying on their back) randomized using a Latin square. Once comfortable they were given the phone to hold. The screen showed an illustration of the handgrip to assume. When ready they clicked on the center of the screen to launch the trial. Pressing the next button, they began the pointing task where they first select Target 1 and then Target 2. The targets were 14mm in diameter as advised by Holz et al. [15]. Appropriate sounds were played to denote error or success. The participants could take as long as they wanted but had to finish the trial. They were instructed to be as accurate as possible. Once they had completed a task, a "next" button was displayed allowing them to start the next trial. Once a task was complete, the screen showed a new grip to assume. Participants could take a break if needed. At the beginning, participants were asked to place their hands on A3 1mm graph paper and their hands' outlines were traced. At the end, they were asked to complete a 7 pt. Likert questionnaire to grade, for each grip 'How comfortable'; 'How secure (risk of device being dropped)' and 'How popular (user preference for a particular condition of the study)' the handgrip was.

Apparatus

We used an iPhone 6 (H: 138.1mm, W:67mm, D:6.9mm) because it showed the most movement variation [9]. The web application tracked the phones movements (inbuilt accelerometer and gyroscope) and participants' touches. We recorded participants (Figure 5) using two Logitech C920 USB HD Pro Webcams connected to a MacBook Pro, viewed through the 'HeadsUp' camera viewing application by Keisi L.L.C [13]. We repositioned the cameras for each posture. To record the MacBook Pro's screen and synchronized cameras, we used Clearleft Silverback 2 [26]. The web app used the 'Frameless' web browser by Jay Stakelon [11]. For the lying down scenario, we used a single airbed.

Experimental design

We conducted a within-subject experiment with three independent variables: Body Posture (Standing, Sitting at table and Lying down), Hand Grip (Figure 1), and Target Position (8 different combinations of target positions shown in Figure 6). The Grips and Posture were randomized using a Latin square. The Target Positions were randomized within each block. We had 3 Posture x 4 Grips x 8 Targets Positions = 96 double tapping task ≈ 25mins (5mins 27secs of motion collected). We used the same position as in [9] to ensure the validity of our study and extend their results.

Quantitative results

A Shapiro-Wilk test confirmed the assumption of normality was met for our data ($p<0.001$). We first provide an analysis of the overall movement (the sum of movements made in all 3 directions as shown in Figure 2) before detailing the directional movements gathered via the device's inbuilt sensors. We also analyse the post questionnaire using Analysis of Covariance on the sum of the absolute values of the accelerometer movements on each axis. ANCOVA extends the analysis of variance by including additional variables (covariates) that influences the dependent variables - here the size of participants' hands. To generate a unique covariate using the four hand measurements (palm width & palm length, thumb length and middle finger length) we used a Principal Component Analysis to reduce the number of dimensions, similarly to in [9]. This created a metric, the *hand size score*, which is a good indicator of the general hand size. The variances were also not significantly different from each other, thus showing that the assumption of homogeneity of covariance holds. In the rest of the analysis we used a p-value below 0.05.
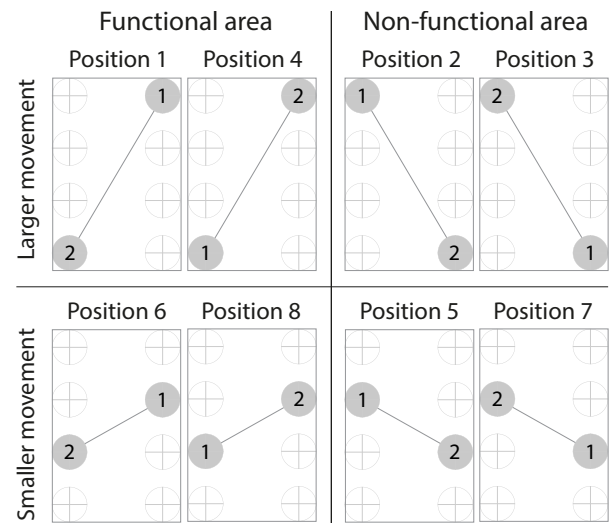

Figure 6. Target positions used in the experiment as a reproduction of the study conducted in [9].

Overall movements

We found a main effect for Body posture ($F_{2,1728}$=119.251), Grip ($F_{3,1728}$=3.901) and for Body posture x Grip ($F_{6,1728}$=2.038). We performed Post-Hoc comparisons using Least Significant Difference (LSD). Figure 7a shows the estimated means, i.e. the hypothetical means unbiased by the hand size scores after correction by the ANCOVA. We found that there was a significant effect for postures, in particular that lying down (LD) produced most movements, followed by Sitting and Standing. We also found significant differences between grips: Single-handed (S) having more movements than Asymmetric bimanual Thumb (AT) and Asymmetric bimanual Finger (AF). Differences were found between Symmetric bimanual (B) and Asymmetric bimanual thumb (AT). The differences between grasp were due to the interaction with Lying body posture for which these results were significant compared to other body postures. There was no effect for target positions.

Directional movements

Now we focus on the movements for each axis (Figure 2): For Alpha we found a main effect for Grip ($F_{3,1728}$=3.025), Body posture x Grip ($F_{6,1728}$=3.552), Body posture x Target position ($F_{14,1728}$=2.535), Grip x Target position ($F_{21,1728}$=3.146) and Body posture x Grip x Target position ($F_{42,1728}$=2.566). For Beta we found a main effect for Target position ($F_{7,1728}$=249.835), Body posture x Target ($F_{14,1728}$=5.345), Grip x Target position ($F_{21,1728}$=20.468) and Body posture x Grip x Target position ($F_{42,1728}$=1.395). For Gamma we found a main effect for Grip ($F_{3,1728}$=3.131), Target position ($F_{7,1728}$=26.897), Body posture x Grip ($F_{6,1728}$=3.914), Body posture x Target ($F_{14,1728}$=2.359), Grip x Target position ($F_{21,1728}$=8.205), Body posture x Grip x Target position ($F_{42,1728}$=2.956).

As before we used Least Significant Difference (LSD) for performing Post-Hoc comparisons. For Alpha, we found that statistically S had the greatest movement, followed by AT, B and AF. We also found that there was a significant difference between S and all other grips. For Beta no significant statistical findings were found. For Gamma, we found that statistically S had the greatest movement, followed by AT, B and AF showing the least movement. We also found that there were significant differences between grips S and the grips B, AT.

Post questionnaire

Using the same analysis tool but for overall movements, we found a main effect for Q1 (Secure) on Body posture ($F_{2,1728}$=161.290) and Grip ($F_{3,1728}$=390.936) and Grip x Body posture ($F_{6,1728}$=42.431); Q2 (comfort) on Body posture ($F_{2,1728}$=60.092) and Grip ($F_{3,1728}$=195.284) and Grip x Body posture ($F_{6,1728}$=37.685); Q3 (popularity) on Body posture ($F_{2,1728}$=51.668) and grip ($F_{3,1728}$=205.344) and Grip x Body posture ($F_{6,1728}$=33.980);

Security: For body postures, participants found that Lying was significantly least secure, followed by Sitting with and Standing being the most secure. For the grips, we found

that in a significant manner S was considered least secure, followed by AT, B and AF. The exception here is the body posture Standing were AF and B were switched. No significance was found for target positions. (Figure 7bi).

Comfort: For body postures, the participants found that Lying was least comfortable, followed by Sitting and Standing. For the grips, we found that in a significant manner S was considered least comfortable, followed by AT, B and AF. (Figure 7bii).

Popular: For body postures, participants found that Lying was significantly least popular, followed by Sitting and Standing. For the grips, we found that in a significant way S was considered least popular, followed by AT, B and AF. The exception is for Sitting were the grips AT and B rated the same in popularity. (Figure 7biii).

DESIGN INSIGHTS

We now revisit our hypothesis in the light of our results. In this study, we looked at hand grip and smartphone interaction, questioning how body posture affects the smartphones tilt and rotation. We found that the body posture with the largest movement to be Lying, this being true for all grip types, partially validating H1. Additionally, Lying down was considered the less secure body posture partly validating H1. However, we only predicted that participants would use their arms to raise the smartphone, we did not expect that participants would rest their arms on their upper torso. This finding needs further investigation to understand how it may impact smartphone interaction.
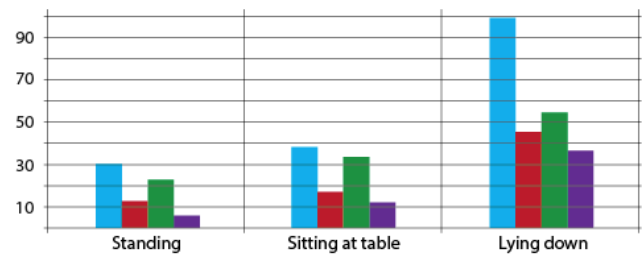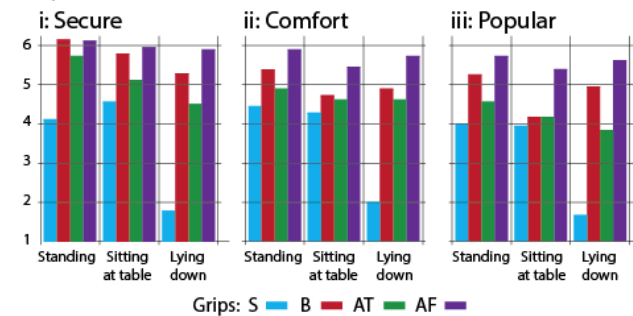

Figure 7. a) Estimated level of phone movement for the interaction between our different factors. b) Questionnaire Results: i) Security ii) Comfort and iii) Popularity.

For the smartphones movement, we found that the body posture Lying had different directional movements to that of Sitting and Standing, thus partiality validating H3. With

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Lying showing the most movement for Beta, Alpha and finally Gamma (Figure 2). Compared to Sitting and Standing that had the most movement for Alpha, Beta and then Gamma. Lying had the greatest movement for Alpha and Beta, but the least Gamma movement. This is different to our prediction, as we believed that there would be more Beta and Gamma movement. We found that the overall grips movement matched the findings of [9] for all body postures. The body posture with the most overall movement was Lying, then Sitting and finally Standing. This partially validates H4. The only difference we found for Lying was an increase in movement for all grips. All body postures mapped the same movements as [9]. With the non-functional targets of the larger distance having the most movement, and the functional targets with the least distance having the lowest movement (Figure 6), thus validating H5. AF, the grip with the lowest movement for all body postures was considered the most secure, popular and comfortable grip, an exception to this is for Standing when B was considered the most secure grip, partially validating H6. S was rated lowest for all conditions and for all body postures, validating this part of H6

We also provide the raw data of the mean angles for each body posture and grip used for the eight target positions (Figure 8). This table extends the data provided in [9] and, we think, will benefit designers. Empirical data have underpinned design and architecture for more than half a century, for example Henry Dreyfuss humanscale metrics [7]. Our goal is similar. For example, we can see from the table that the Y and Z angles for Lying down are greater than other body postures (Sitting and Standing). This data can be used to update physical interaction with the smartphone, by changing the screen lighting for low light conditions when detecting movement patterns typically associated with a user lying down. We can also see that the mean angles are directional by further looking at the targets (Figure 6). Here we see that depending on the grips that Targets 1 and 4 have similar angles, as do 2 and 3. From this mean angle data, designers can start to predict the grip used and the locations in which the users need to reach. We hope that this will lead to the moving of graphical elements to better positions depending on postures or grips, allowing users to interact with minimal hand movements.

CONCLUSION AND FUTURE WORK

We have furthered the research of Eardley et al [9], demonstrating how hand movements are affected by grip and smartphone size. We extended this work by investigating grip and body posture (Standing, Sitting at a table and Lying down) and provided valuable metrics of hand movements for UI designers. We believe that designers can benefit from understanding the variances in smartphone rotations in order to create touchscreen interactions that adapt to the context of use.

Single-handed									
Targets		1	2	3	4	5	6	7	8
Stand	X	18.4	15.5	15.9	15.9	8.4	2.6	9.4	2.9
	Y	9.6	25.9	28.6	9.6	15.1	4.1	14.7	3.8
	Z	6.8	7.6	6.8	7.2	5.6	1.5	4.7	1.7
Sitting at table	X	17.7	18.5	16.7	15.2	8.8	2.9	9.6	3.0
	Y	17.3	35.6	42.4	16.7	21.0	4.2	19.5	5.7
	Z	9.3	10.4	9.9	7.8	5.1	1.8	4.2	2.3
Lying down	X	17.2	24.3	32.4	15.0	16.6	2.3	19.1	2.9
	Y	46.9	46.3	63.4	44.9	44.3	20.7	48.6	13.
	Z	46.1	45.8	71.0	50.4	40.8	19.5	50.7	13.
Symmetric Bimanual									
Targets		1	2	3	4	5	6	7	8
Stand	X	8.8	5.8	6.2	7.6	1.6	2.7	1.2	2.2
	Y	11.1	7.9	7.4	10.1	2.4	3.8	2.4	3.5
	Z	2.9	3.0	4.4	2.3	0.8	0.9	0.7	1.2
Sitting at table	X	11.1	7.7	6.2	11.1	2.1	2.9	2.7	2.8
	Y	12.1	10.8	11.2	12.3	3.4	4.4	2.4	3.1
	Z	4.3	5.2	8.4	6.6	1.2	1.1	1.6	1.4
Lying down	X	12.7	13.7	12.3	14.1	2.9	3.9	2.8	2.3
	Y	16.6	31.4	24.8	27.4	10.1	14.4	14.2	14.
	Z	18.7	30.5	26.7	25.2	8.7	13.2	12.6	13.
Asymmetric with Thumb									
Targets		1	2	3	4	5	6	7	8
Stand	X	8.3	13.3	11.9	7.7	6.7	1.1	6.8	1.1
	Y	7.4	26.3	26.0	8.1	14.1	2.7	14.2	2.2
	Z	5.0	6.4	5.8	4.9	2.6	1.0	2.6	0.6
Sitting at table	X	12.9	19.1	19.6	10.4	8.3	1.2	9.4	1.3
	Y	17.2	33.8	32.0	13.8	17.1	1.7	16.6	2.2
	Z	11.7	13.8	11.6	8.0	4.4	1.6	4.3	0.7
Lying down	X	14.4	21.2	23.0	13.4	9.6	2.4	9.8	2.1
	Y	18.9	35.2	42.6	27.7	23.5	13.7	18.4	4.9
	Z	20.5	37.3	27.3	29.3	15.3	11.2	12.3	3.9
Asymmetric with Finger									
Targets		1	2	3	4	5	6	7	8
Stand	X	1.4	3.4	3.1	1.6	1.2	0.5	1.2	0.3
	Y	1.2	5.2	4.4	1.3	3	0.7	2.7	0.8
	Z	1.6	4.4	3.2	1.6	1.6	0.4	1.9	0.2
Sitting at table	X	2.6	6.1	5	2.2	3.1	0.7	2.7	0.5
	Y	3.7	11.4	11.7	3.2	6.9	1	5.3	0.7
	Z	3.2	8.2	8.4	2.6	3.6	0.8	2.6	0.4
Lying down	X	2.9	6.4	7.9	2.4	3.7	1.5	4.8	0.3
	Y	9.8	25.3	28.2	10.3	12.6	12.2	25.3	3.2
	Z	11.4	26.7	31.5	11.8	11.4	12.2	27.1	3.7

Figure 8. Mean angle data for all targets and grips.

To progress this research, we intend to run a number of design workshops where we provide designers with the output from our research to gather examples of new UI based on our results. Note that, in this work, we choose the pointing task as it is arguably the most common smartphone input. We contend that the UI of our study is basic enough to generalize the results to interaction styles based on pointing (selection of keys, items, etc.). We also conducted a lab study and loaned the participants the equipment used, the participant having no attachment to the devices used. This has consequently limited our results concerning any anxiety in dropping and breaking the devices.

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