Investigating how the hand interacts with different mobile phones

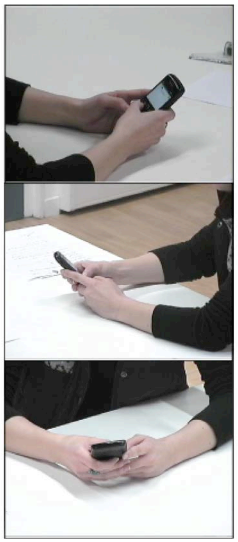

Figure 1: Example footage acquired during the sessions.

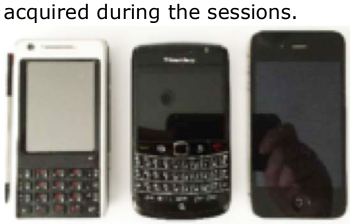

Figure 2. The mobile phones used during the sessions (Sony Ericson, Blackberry and iPhone4).

Rachel Eardley
Cardiff School of Art & Design
Cardiff Metropolitan University
Cardiff, UK
rachel@racheleardley.net

Steve Gill
Cardiff Metropolitan University,
Cardiff, UK
sjgill@cardiffmet.ac.uk

Anne Roudaut
University of Bristol
Bristol, UK
roudauta@gmail.com

Stephen Thompson
Cardiff School of Art & Design
Cardiff Metropolitan University
Cardiff, UK
sthompson@cardiffmet.ac.uk

Joanna Hare
PDR
Cardiff Metropolitan University
Cardiff, UK
jhare@pdronline.co.uk

MobileHCI '16 Adjunct, September 06-09, 2016, Florence, Italy

DOI: http://dx.doi.org/10.1145/2957265.2961840

Abstract

In this paper we investigate the physical interaction between the hand and three types of mobile device interaction: touchscreen, physical keyboard and stylus. Through a controlled study using video observational analysis, we observed firstly, how the participants gripped the three devices and how these grips were device dependent. Secondly we looked closely at these grips to uncover how participants performed what we call *micro-movements* to facilitate a greater range of interaction, e.g. reaching across the keyboard. The results extend current knowledge by comparing three handheld device input methods and observing the movements, which the hand makes in five grips. The paper concludes by describing the development of a conceptual design, proposed as a provocation for the opening of dialogue on how we conceive hand usage and how it might be optimized when designed for mobile devices.

Author Keywords
Hand; Mobile device; Grasp; Design; Interaction; Product Design; Interaction Design

ACM Classification Keywords
H.5.2. User Interfaces: Input Devices and Strategies.

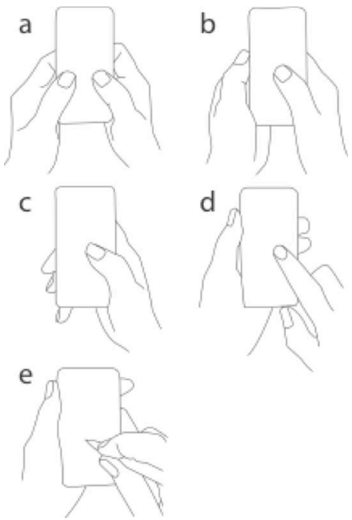

Figure 3. Examples showing the 5 different handholds

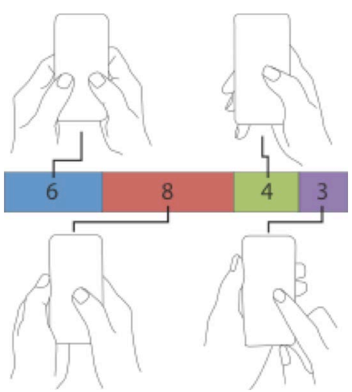

Figure 4. Overall number of participants who used the shown grips with the touchscreen device

Introduction

We use our hands to interact with the physical world in numerous ways. As Napier [8] points out, our handgrip changes, depending on the affordances of the object and the context of the interaction. For example, we use a 'power grip' to initially loosen the top of a jar and then a 'precision grip' to remove the lid. When completing certain tasks it is also common to use both hands. Guiard [1] stated that hands are used together to divide the work; when writing, for example, the non-dominant hand supports by holding the paper, while the dominant hand uses the pen to write.

With such knowledge about the hands' capabilities, it is surprising that so much of the field of mobile interaction focuses on the screen in isolation, ignoring the richness of handgrip that users can perform. This is somewhat ironic when these devices are termed *handheld*. Some researchers have explored how to use grasp and orientation information to enrich the interaction, e.g. help selecting an action item on the device through pointing [6,7,11] or changing the orientation of the phone to landscape [4]. However these works only focus on specific applications or hardware implementation. There is a lack of empirical research that investigates the combination of movements and grips that the hand makes when performing a common task. More importantly we are not aware of any work exploring different interface types such as touchscreen, physical keyboard or stylus. Evan though, touchscreen devices have been a commercial success, it is important, to investigate other interface types. For example manufactures (Samsung) have re-introduced the stylus and current research appears to be reviving the physical keyboard via shape-changing technology (Tactus) [12].

To address this question we performed a controlled study where participants completed a task on three types of mobile phones, each with different forms of physical interaction (touchscreen, physical keyboard and stylus). The results show that the participants used a range of 5 grips to interact with the three mobile phones. These grips differed for each phone type and a number of those participants changed their grips as they completed the task. Focusing on these 5 grips, we compared how the three devices were manipulated through horizontal and vertical tilts. We are calling this maneuvering of the mobile phone, *micro-movements,* proving that the hand is used for more than just activating action items such as on screen buttons.

Understanding the fluidity of 'hand interaction' and the context within which it is used will enable designers to understand how to improve mobile device design. To demonstrate how designers can use our findings, we conclude this paper by proposing four designs. This final exercise has the intention to initiate discussion around the current approach to mobile device design.

Related work

Previous work has used sensory technology to map the placement of the static hand when completing a number of tasks in three ways: Firstly, they use static grips to predict the mode in which the mobile device is being used (e.g. camera, phone call or game play) [3]. Secondly, they study the context of screen orientation, by defining the grips used when viewing the mobile device in landscape or portrait [4] and thirdly, they seek to identify how sensory technology can differentiate between six static grips defined by the researchers [9]. What these approaches do not do is investigate the hands' fluid transitions or movements. This is critical because movement in between direct

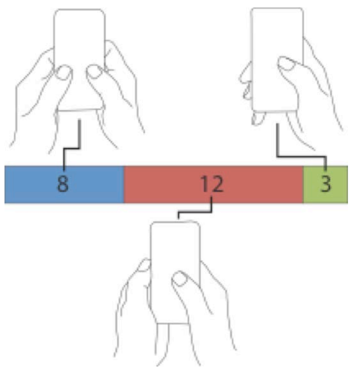

Figure 5. Number of participants who used the shown grips with the button-based device.

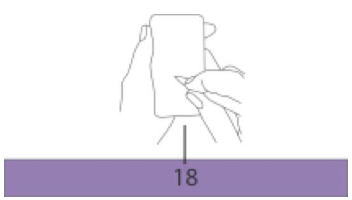

Figure 6. Number of participants who used the shown grip with the stylus-based device

interactions are actually key to the interactions themselves, with each movement setting up the conditions for the next interaction.

Existing research into transitions or movements have focussed on the constraints of using a single-handed grip to interact with the device by tilting it to bring it into range of the thumb [6,7,11]. These works focus on single device types. What this research does not consider is a comparison of device types with different grip types and how this movement is used when the participant completes a task.

Other research has looked at tablet devices and how UI elements could be adapted, depending on the grip used [5]. The focus on devices too large for single-handed use, is bound to give different insights. Furthermore the researchers were focusing on the keyboard, rather than the full user journey to task completion.

The Study

The goal of this study is to understand how users are grasping and handling mobile phones with different interactions. We were not interested in measuring efficiency or usability issues but rather in understanding human behaviour in an ecological setup. Owing to this, we selected three commercially available devices, representing three different types of physical interface; touchscreen, button-based keyboard and stylus.

18 participants were invited into a purpose built university research lab for a one-to-one session with a moderator. Each participant sat at a table to complete the tasks, ruling out interference from posture or whole body movement. This position also enabled us to gather consistent video data of the hands' interaction via three synchronous cameras (Figure 1).

Participants were permitted to choose the grips that they used and, if desired, change the grip during the task. When using the device with the stylus, it was specified that the participants needed to use the stylus (it also has a keyboard).

The apparatus

The three different types of mobile phones were: for 'touchscreen' the iPhone 4 (H:115.2mm, W:58.6mm, D:9.3mm) for 'keyboard' the Blackberry Bold (H:109mm, W:60mm, D:14.1mm), and for 'stylus' the Sony Ericsson P1i (H:106mm, W:55mm, D:17mm) (Figure 2). The devices were selected due to their similarities in size and differences in interaction type.

The Task

The participants were presented with the three devices pre-set to there homepage. The task required participants to pick up the phone from the table, open up the texting application, write the text, enter the phone number and then send the text. The pre-defined text message and number were given to them on an A4 printout. The order in which the devices were tested was randomised using the 'Latin Square' method.

In between using each mobile device, the participants were asked about their familiarity with the next device. Each participant had a short time to get acquainted with the mobile devices before the task started.

The 18 participants either worked for or studied at the university. There was a 50% gender split and the age ranged from 18 to 31. 16.6% of the participants were left-handed (a greater proportion than the estimated 13% within the UK [10]).

All participants owned mobile phones; 16 of these being touchscreen and 2 button based. 10 of the

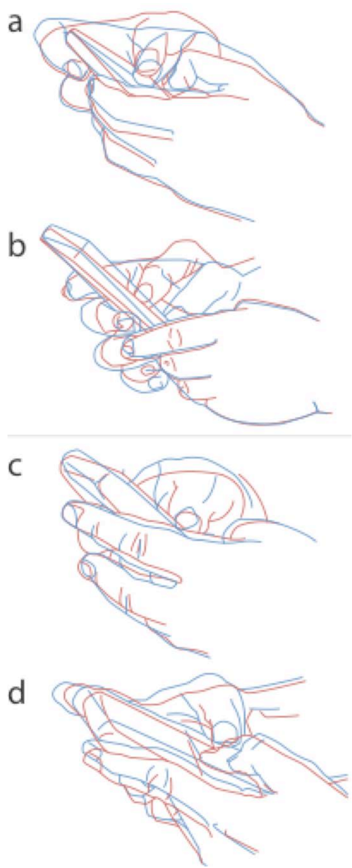

Figure 7: Movements for the symmetric bimanual grip (a and b) touchscreen and (c and d) button-based interaction

participants had modified their mobile phones by adding an external casing. 18 participants had used a touchscreen mobile device, 14 a button based device and 1 participant had familiarity with a stylus-based mobile phone although 9 participants had used a stylus with either a tablet or Nintendo DS device.

Data collection

We recorded a total of 44.7 minutes of video, were the participants completed the task. The data collection occurred over three stages:

- In Step 1 the videos of the sessions were analyzed and 'key moments' identified (movement of hands or change of grip) and printed on paper with participant information (video time stamp, participant number, right or left handed and male or female).
- Step 2 used the printouts of these key moments to help categorize specific types of grips used.
- Step 3 regarded these grips and reviewed how the hands moved the mobile device. The micro-movements were visually represented by tracing still images from the video of the hand at the extreme ends of the movement: red is the starting position and blue the end (Figure 7).

We noticed that when pressing down on the phones, the devices moved. However we discarded these results because we did not consider them as micro-movements but rather natural reaction to pressure.

The Results

The study brought to our attention two areas for consideration. Firstly, when completing the task the participants used numerous grips. Secondly, the observations highlighted that participants made slight movements in order to reach key interactive areas on the mobile device, these are what we have termed 'micro-movements'

Step 1: Handheld Grips

We observed that the participants used 5 specific grips: Symmetric bimanual (Figure 3a); asymmetric bimanual with the thumb (Figure 3b); single-handed (Figure 3c); asymmetric bimanual with the finger (Figure 3d) and asymmetric bimanual with the stylus (Figure 3e). Perhaps unsurprisingly, there is a strong correlation between the type of grip(s) used and the interaction style.

Touchscreen

When interacting with the touchscreen mobile device the participants used a range of 4 grips. 15 participants used just 1 grip to complete the task, whereas 3 participants switched and used 2 grips (Figure 4).

Button-based

The button-based mobile device had the participants using a range of 3 grips. 14 participants used just 1 grip to complete the task, whereas 3 participants switched and used 2 grips while 1 participant used 3 grips (Figure 5).

Stylus-based

The stylus-based device was the most constrained and consequently all 18 participants used 1 grip (Figure 6).

Summary

If we break down these observed grips to the types of interaction devices we see that there does appear to be a difference. However, for the button and touch interaction, the most common grips for this controlled study were the symmetric bimanual and asymmetric bimanual with the thumb. The 6 participants who changed grips did so in response to context. Using one

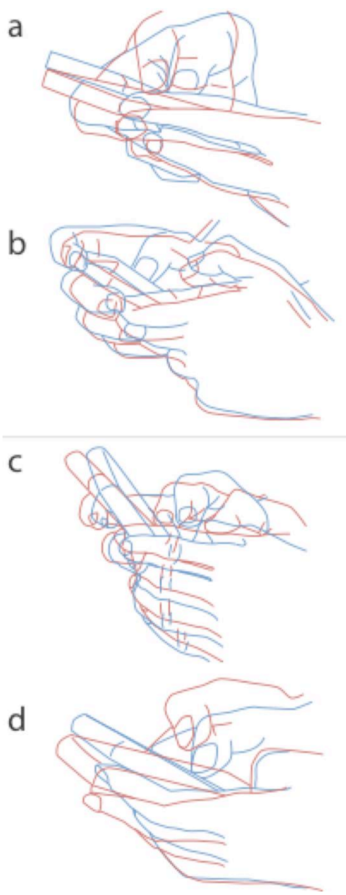

Figure 8: Movements for the asymmetric bimanual with the thumb grip (a and b) touchscreen and (c and d) button-based interaction

grip to select a menu item and changing to another in order to input data through a keyboard.

Step 2: Micro-Movements

All 18 participants were observed performing micro-movements during the task. 17 participants moved the touchscreen device, 16 participants did so with the button-based interaction and 14 participants using the stylus-based interaction. As previously stated the participants used 5 different grips to interact with the mobile devices during the task (Figure 3). Each of the grips required the participant to make small movements with the mobile device so that they could reach interactive areas.

SYMMETRIC BIMANUAL

A total of 10 participants used the symmetric bimanual interaction (6 touchscreen and 8 button-based). Grasping the phone in both hands and using both thumbs to interact (Figure 3a).

Through observation, we found that the micro-movements for symmetric bimanual occurred when the participants alternated between thumbs to type on the keyboard (Figure 7). This interaction occurred for both touchscreen and button-based interaction.

What was notable is that one participant using the touchscreen device rotated the phone 90 degrees in order to have better access to the keyboard (Figure 7a).

ASYMMETRIC BIMANUAL WITH THE THUMB

14 participants were observed using the asymmetric bimanual with the thumb interaction (8 touchscreen and 12 button-based). Grasping the phone in both hands and using one thumb to interact (Figure 3b).

For each participant who employed the asymmetric bimanual method with their thumb, we observed that both the dominant and non-dominant hands gripped both the touchscreen and button-based devices. The non-dominant hands were observed supporting the phone either by using the index finger on the side or with the whole hand cupping the device (Figure 8). In both instances both hands manoeuvred the phone so that the dominant hand’s thumb had greater access to the target area.

For the touchscreen and button-based devices the micro-movements occurred when the participants changed approach, from typing on the keyboard to selecting the next step or mode. Additionally movement was observed when the dominant hand’s thumb moved around the keyboard. What differed between the two phones was the size of interactive area. The touchscreen, showing more obvious movements as its interactive area covered the majority of the device’s frontage.

SINGLE-HANDED

Four participants used their dominant hand alone to hold and interact with the devices (4 touchscreen and 3 button-based). When using single-handed interaction participants held the device in their dominant hand and used their little finger to anchor the bottom of the phone (Figure 3c).

The majority of single-handed micro-movements occurred when the participant attempted to move their thumb around the keyboard, by lifting the phone up with the little finger (Figure 9c) to get better access to the lower part of the keyboard. Participants tilted the phone so that, for the touchscreen the thumb could reach the top of the phone (Figure 9a) and for the

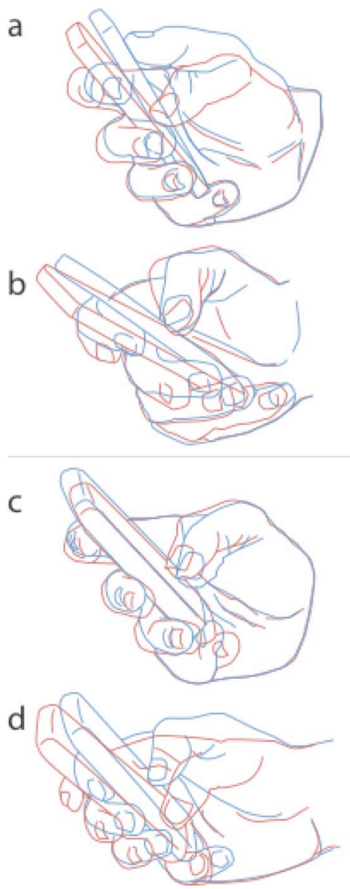

Figure 9: Movements for the singlehanded grip (a and b) touchscreen and (c and d) button-based interaction

button-based device they could reach the upper part of the keyboard (Figure 9d).

ASYMMETRIC BIMANUAL WITH THE FINGER

Out of the 18 participants, 3 participants interacted with their finger while interacting with the touchscreen device. They were grasping the phone in the non-dominant hand and interacting with the index finger of their dominant hand (Figure 3d).

We observed that two types of movement of the finger occurred with the asymmetric bimanual method. Firstly the dominant hand's finger moved towards the screen, while the phone, being held in the non-dominant hand, did not move (Figure 10a). Secondly, the non-dominant hand aided interaction by moving the phone towards the dominant hand's index finger (Figure 10b).

ASYMMETRIC WITH A STYLUS

We specifically asked all 18 participants to use the stylus with the stylus-based device. We found that the asymmetric bimanual method of interaction with the stylus (Figure 3e) was similar to that of the finger-based asymmetric bimanual method and so the participants' micro-movements were unsurprisingly similar.

Participants manoeuvred the stylus-based phone in two ways: The first method was to grip the phone, in the non-dominant hand and assist interaction by moving the device towards the stylus being held in the dominant hand (Figure 11a). In the second method the participants kept the device stationary and only moved the stylus (Figure 11b).

SUMMARY

Due to their seated posture all of the participants had their forearms on the table. This placement enabled the use of a rolling motion of the participants' wrists that helped them manoeuvre the device.

We observed a horizontal side-to-side tilt being used with the symmetric bimanual method (Figure 7), Participants employing the asymmetric bimanual method with the thumb also used side-to-side movement but added a horizontal twisting motion (Figure 8). Participants using single-handed interaction exploited similar movements but with greater emphasis (Figure 9). The asymmetric bimanual with a finger (Figure 10) and asymmetric bimanual with a stylus methods (Figure 11) had similar micro-movements, each using a twisting motion that maneuvered the phone towards the dominant hand.

Discussion and Application proposal

This controlled study has shown that the hand adapts fluidly to the device type and its context of use such as menu selection or typing on the keyboard through a combination of grips and micro-movements. Can designers use this knowledge to create more compelling interactive experiences?

We attempt to answer this through four rough concepts that use the insights gained from the above study to develop appropriate design responses.

Conceptual design

Current touchscreen mobile phone operating systems such as Apple's iOS are designed around a series of UI components [2]. Using these components as a foundation, we generated a number of concepts around an adaptive UI method where UI changes are triggered by a combination of the task and its known micro-movements associations.

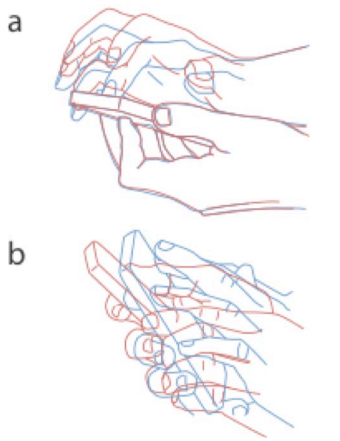

Figure 10: Movements for the asymmetric bimanual with the finger grip (a and b) touchscreen

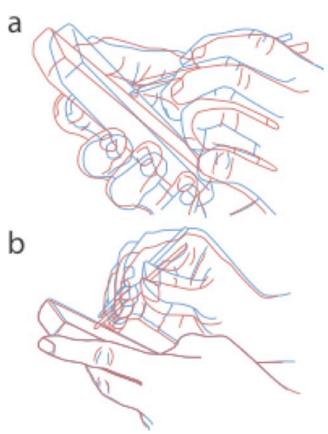

Figure 11: Movements for the asymmetric bimanual (a and b) with the stylus grip.

Adaptive keyboard

Insight 1: When typing on a screen-based keyboard, participants tend to move the device from side-to-side.

The research above demonstrated that participants moved the mobile device from side-to-side to gain better access to the keyboard (Figure 7). The adaptive keyboard concept places keys in a more reachable position in a manner similar to the iGrasp technique [5]. Contrary to iGrasp, which triggers the keyboard depending on the grip, the adaptive keyboard (Figure 12a) would be activated if a side-to-side micro-movement were initiated. Here the keyboard component slides as the phone tilts, placing the required letters in an easier to reach position for the thumb. This concept not only works for touchscreen interfaces but also button based interaction through shape-changing technology such as Tactus [12].

Adaptive scrolling

Insight 2: Participants tended to tilt the device vertically to enable the selection of navigation options from the top bar.

A similar technique could be used for scrolling: In Figure 9a and 10b we see that the phone has been tilted vertically to allow for easier access to the top of the screen. Similar to the adaptive keyboard, the adaptive scrolling concept is activated when a navigation bar is on the screen and the micro-movement has occurred. The adaptive scrolling lowers the navigation bar on the screen placing it within reach of the thumb (Figure 12b).

Adaptive homepage

Insight 3: When reaching across the device to select an action item the device is twisted through both the vertical and horizontal planes.

Our research showed that when the participants reached for the top corner opposite the dominant hands thumb (single-handed and asymmetric bimanual with a thumb) that the phone twisted both vertically and horizontally (Figure 8b and 9b). This area appeared to be difficult to reach and presented the greatest micro-movements observed during the study. In the adaptive homepage concept, which is similar to that of the "tilt slide" [11]. We shift the homepage icons closer to the dominant hand when the tilt is sensed (Figure 12c). Reducing the amount of reach that the participant needs to complete in order to interact.

In-air stylus

Insight 4: When using the stylus to select an action item, the device tilts and moves towards the stylus.

This research demonstrated that the participants coordinated their hand movement. The dominant hand holding the stylus appeared to move in sync with the non-dominant hand holding the phone. Tilting the phone so that it met the stylus during interaction (Figure 11a). The in-air stylus concept reduces this movement by operating without the need of the stylus and mobile phone screen to touch. The stylus location is shown on the screen and through a flicking gesture, action items can be selected (Figure 12d).

Conclusion and future work

In this paper we investigated how the hand grasps and manipulates different interaction style handheld devices. We used the insights gathered from a controlled study to propose four concepts, which demonstrate how designers can benefit from understanding how the hand is used to interact with different mobile phone types.

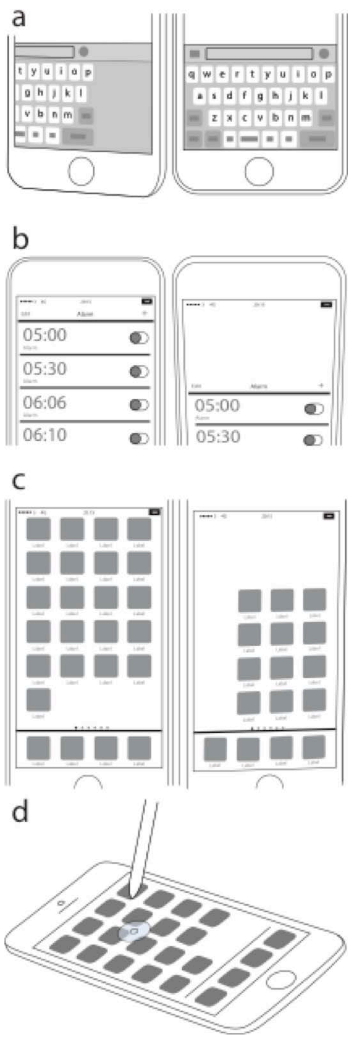

Figure 12: Illustrations of the conceptual design.

To progress this research we will firstly, question how the micro-movements compare when using different sized devices. Discovering if interacting with larger phones produce, the same type of micro-movements or if they are simply exaggerated. Secondly, we intend to investigate how the participant's location and posture may alter the micro-movements. Comparing a participant's action when standing with one of sitting without resting or as shown in this current study sitting while resting. Thirdly, we intend to prototype and test a number of these concepts to understand their effectiveness.

This research has enabled us to understand micro-movements through the observation of participants. The next stage of this research will be to gather empirical evidence through the devices inbuilt sensors.

References

1. Guiard, Y. (1987). Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model. *J. Motor Behavior,* 19(4), 486-517.
2. iOS App Anatomy Retrieved February 9, 2016 from https://developer.apple.com/library/ios/documentation/UserExperience/Conceptual/MobileHIG/Anatomy.html#//apple_ref/doc/uid/TP40006556-CH24-SW1
3. K. Kim, W. Chang, S. Cho, J. Shim, H. Lee, J. Park, Y. Lee, and S. Kim. Hand Grip Pattern Recognition for Mobile User Interfaces. In Proceedings of the National Conference on Artificial Intelligence, vol 21, page 1789. Menlo Park, CA; Cambridge, MA; London; AAAI Press; MIT Press; 1999, 2006.
4. Lung-Pan Cheng, Fang-I Hsiao, Yen-Ting Liu, and Mike Y. Chen. 2012. iRotate: automatic screen rotation based on face orientation. Proc. CHI '12. ACM, New York, NY, USA, 2203-2210.
5. Lung-Pan Cheng, Hsiang-Sheng Liang, Che-Yang Wu, and Mike Y. Chen. 2013. iGrasp: grasp-based adaptive keyboard for mobile devices. Proc. CHI EA '13. ACM, New York, NY, USA, 2791-2792.
6. Matei Negulescu , Joanna McGrenere, Grip Change as an Information Side Channel for Mobile Touch Interaction, Proc. 33rd Annual ACM Conference on Human Factors in Computing Systems, April 18-23, 2015, Seoul, Republic of Korea.
7. Mohd Noor, M.F., Ramsay, A., Hughes, S., Rogers, S., Williamson, J., and Murray-Smith, R. 28 Frames Later: Predicting Screen Touches from Back-of-device Grip Changes. *Proc. CHI'14*, ACM (2014), 2005–2008.
8. Napier, J., (1993) Hands, Published by Princeton University Press.
9. R. Wimmer, S. Boring, HandSense: discriminating different ways of grasping and holding a tangible user interface, Proc. 3rd International Conference on Tangible and Embedded Interaction, February 16-18, 2009, Cambridge, United Kingdom
10. Research Into Left-Handedness And Its Effects. Retrieved September 25, 2015 from http://www.anythinglefthanded.co.uk/research/lefthanded-research.html#sthash.9u4nKjNS.dpbs
11. Youli Chang, Sehi L'Yi, Kyle Koh, and Jinwook Seo. 2015. Understanding Users' Touch Behavior on Large Mobile Touch-Screens and Assisted Targeting by Tilting Gesture. Proc. CHI '15. ACM, New York, NY, USA, 1499-1508.
12. Tactus
Retrieved May 3, 2016 from
http://tactustechnology.com/technology/