FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Creating Mobile Gesture-based Interaction Design Patterns for Older Adults: a study of *tap* and *swipe* gestures with Portuguese seniors

Roxanne Alves Leitão

Master in Multimedia

Supervisor: Paula Alexandra Gomes da Silva (PhD)

October 2012

Creating Mobile Gesture-based Interaction Design Patterns for Older Adults: a study of *tap* and *swipe* gestures with Portuguese seniors

Roxanne Leitão

Master in Multimedia

Approved in oral examination by the committee:

Chair: Eurico Manuel Elias Morais Carrapatoso (PhD)

External Examiner: Carlos Alberto Pacheco dos Anjos Duarte (PhD)

Supervisor: Paula Alexandra Gomes da Silva (PhD)

Paula Alexandra Gomes da Silva

26th October, 2012

ABSTRACT

The focus of this research is to further the understanding of gesture based interaction on smartphones for older adults. The recent proliferation of touchscreen devices, such as smartphones, and the few amount of research regarding this form of interaction for older adults, are our main motivations for carrying-out this research project.

The research approach adopted in this work is divided in four phases of testing with older adult users. The first phase includes a study of the discoverability of existing smartphone gestures for older adults, as well as the exploration of the possibility of creating a novel user-defined gesture set with this group of users. Our findings revealed that existing gestures do not seem to be easily discoverable, or immediately usable by older adults. Where in most cases, the majority of participants would not have been able to solve the tasks we gave them on existing smartphones. Accordingly, the second phase of research aimed to assess if we could effectively teach current gestures to older adults. In order to do so, we created a set of contextual animated tutorials that demonstrate the use of gestures to solve common smartphone tasks. Our findings revealed that older adult participants were in fact capable of learning, and effectively making use, of *tap* and *swipe* gestures. Next, the third phase of research aimed to assess adequate touch-target sizes, and adequate spacing sizes between adjacent-targets, for both *tap* and *swipe* gestures. Accordingly, our results demonstrate that, for *tap* gestures, older adults' performance was best with targets larger than 14 mm square, while for *swipe* gestures, performance was best for targets larger than 17.5 mm square. Which reveals that the end intention of a movement — whether to finalise in a *tap* or *swipe* — influences older adults' performance in target selection, where larger target sizes are needed for *swipe*, than for *tap*. In addition, our results also revealed that spacing between adjacent-targets does not seem to have a significant influence on participants' performance. Finally, the objective of the fourth, and final phase of research was to evaluate the influence of targets' onscreen locations, and *swipe* gesture orientation (e.g., left-to-right, top-to-bottom), on older adults' acquisition of *tap* and *swipe* targets. Our findings reveal that for *tap*, older adult participants' performance was best toward the centre, right edge, and bottom right corner of the smartphones' display. While for *swipe*, participants' performance was better for horizontal *swipe* targets placed toward the bottom half of the display, and for vertical *swipe* targets performance was best for targets placed toward the right half of the smartphone's display. In addition, our results demonstrate that the orientation of a *swipe* gesture does not seem to have a significant influence on participants' performance.

Finally, we documented the main findings of our research in the form of interaction design patterns and constructed a website to host them, with the intention of making our results more easily and readily available to other practitioners involved in creating smartphone interfaces for older adults.

ACKNOWLEDGEMENTS

I would like to thank Paula Silva for supervising this research work, as well as for her motivation, advice, and insightful criticism. Also, her positiveness and her strength have been, and will continue to be, a great source of personal inspiration.

I would also like to thank all the people at Fraunhofer-AICOS Portugal. A special thank you to Francisco Nunes and Sílvia Rêgo.

In addition, I would like to express my gratitude to all the older adults who participated in this work, without whom this research would not be possible. Their contribution and life-stories provided valuable insight to this work, and have ultimately made me a better person.

Furthermore, I would like to thank my family; my brother Mitchell Leitão and my parents. Their support and encouragement over the years have not only made this dissertation, but all my studies, possible.

Thank you to João Menezes for being there when things seemed hard, for the invaluable advice, and for depositing a great amount of confidence in me.

Finally, a special thank you to Miguel Carvalhais for the constant support and guidance. He has been a true mentor and an invaluable role-model, with whom I feel privileged to have worked with.

DISCLAIMER

This dissertation is the result of my own work, under the supervision of Paula Alexandra Silva. It has not been submitted to any other University or academic institution. This dissertation is the result of my own work and research, and does not include other work done in collaboration, except where specifically indicated. Therefore, I acknowledge full responsibility for the work presented. Excerpts of this thesis have been submitted and accepted at PLOP'12 (Conference on Pattern Languages of Programs 2012) as stated in Appendix C.

TABLE OF CONTENTS

LIST OF TABLES

xv

LIST OF GRAPHS

LIST OF FIGURES

LIST OF ACRONYMS

AAL (Ambient Assisted Living)

AMD (Age-related Macular Degeneration)

AR (Augmented Reality)

CHI (Computer-Human Interaction)

CRT (Cathode ray tube)

CSCW (Computer Supported Collaborative Work)

DI (Diffused Illumination)

EU (European Union)

FTIR (Frustrated Total Internal Reflection)

GUI (Graphic User Interface)

HCI (Human-Computer Interaction)

ICT (Information and Communications Technologies)

LED (Light-Emitting Diode)

POS (Point-Of-Sale)

TUI (Tangible Uses Interface)

Ubicomp (Ubiquitous Computing)

UI (User-Interface)

1 INTRODUCTION

A demographic change is occurring in the European Union (EU) (European Commission & Economic Policy Committee, 2011), and in other industrialised nations (see Section 2.1 for further detail). Our population is becoming older, and consequently old age dependency ratios are increasing (European Commission & Economic Policy Committee, 2011).

Accordingly, several efforts are being made to deal with issues resulting from an ageing society. One of these approaches consists in the use of Information and Communications Technologies (ICTs) to provide assistance to the elderly with the intention of allowing them to remain independent, and in their own homes for a longer period of time (Sun, De Florio, Gui, & Blondia, 2009). These technologies have been used within wide range of contexts, from health care, to security, and to communication and leisure (Plaza, Martín, Martin, & Medrano, 2011). In addition, many of these systems integrate, or make use of common mobile devices such as smartphones.

Smartphones are becoming increasingly widespread. These devices account for a total of 44% of the mobile phone market share in the EU5, and nearly 42% in the U.S (comScore, 2012), and this trend is expected to keep increasing. In this context, we expect that in the future smartphones will inevitably be adopted by all groups of the population, including older adults (comScore, 2012).

However, several psychomotor, cognitive and sensory declines unfold with the ageing process (Kurniawan, 2008) making the needs and expectations of older adults different to those of their younger counterparts and issues such as computer anxiety, and technological alienation have been found to be more prominent within older populations (Czaja & Sharit, 1998; Turner, Turner, & Van De Walle, 2007). Furthermore, society often regards the elderly as being too old to learn how to use new technologies (Hawthorn, 2007). Contrastingly, several authors have found that when the correct strategies are employed, in fact older adults are not only interested, but also quite capable of learning to use such devices (Broady, Chan, & Caputi, 2010; Czaja & Sharit, 1998) (see Section 2.3 for further detail). These strategies involve demonstrating the daily benefits of adopting new technologies, the provision of positive experiences in their usage, and the definition of appropriate schedules for teaching and learning (Broady et al., 2010; Czaja & Sharit, 1998; Dickinson, Eisma, Gregor, Syme, & Milne, 2005) (see Section 2.3 for further detail). In addition, it has been found that special design considerations need to be taken into account when designing for this user-population (Czaja & Sharit, 1998; Zaphiris, Kurniawan, & Ellis, 2008; Ziefle, 2010), due to the wide range of sensory, psychomotor and cognitive declines that unfold with the ageing process (Cavanaugh & Blanchard-Fields, 2006; Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Kurniawan, 2008; Pak & McLaughlin, 2010) (further detail on age-related declines can be found in Section 2). However, most designs, until this date, have not yet been considering older adults specific needs and characteristics (Czaja & Sharit, 1998; Ziefle, 2010), by focussing mainly on younger and more technologically proficient user populations.

Nonetheless, several authors have discussed the potential advantages of touch-based interaction,as offered on smartphones, for older adults (Hollinworth, 2009; Loureiro & Rodrigues, 2011; Stößel, Wandke, & Blessing, 2010). On the one hand, these interfaces are generally believed to provide natural and intuitive user experiences, allowing for immediate interaction and reduced learning curves (Loureiro & Rodrigues, 2011; Sears, Plaisant, & Shneiderman, 1990; Wigdor & Wixon, 2011; Wolf, 1986). On the other hand, several authors have raised issues regarding gestural interfaces and the lack of appropriate cues to identify available gestures (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010). The authors argue that the lack of cues on touchscreens result in gesture discoverability issues, where users do not know which gestures to perform, and have to undergo a series of trial-and-error exercises before discovering how to use the system. In this context, we have decided to further investigate the potential advantages and/or limitations of touch-based interaction with older adults. Given the proliferation of touchscreen devices, and mobile phone applications targeted at older adults (Center for Tecnology and Aging, 2011; Fox, 2010; Liu, Zhu, Holroyd, & Seng, 2011; Plaza et al., 2011), added to potential usability issues regarding gestural interfaces (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010), we found it pertinent to further investigate touchscreen interaction with older adult users.

1.1 RESEARCH FOCUS

Although a number of issues have been raised regarding the usability of gestural interfaces (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010), several authors believe that these could in fact provide a privileged form of interaction for older adults (Hollinworth, 2009; Loureiro & Rodrigues, 2011; Stößel et al., 2010) (see Section 3.3 for further detail). These issues have been raised due to the belief that these systems do not provide sufficient clues regarding their specific functionalities and available gestures, where users often do not know which gestures can be used to interact with a specific system. Accordingly, most gestures used to interact with existing touch-surfaces were designed over time by the developers of these systems. In this way, it could be argued that these gestures were designed with more concern regarding system recognition issues, than the end-usability of such gestures (Wobbrock, Morris, & Wilson, 2009).

In this context, several authors have investigated the potential of user-defined gestures for touch-based interaction. In 2002, Beringer conducted a study to gather a set of user-defined gestures and voice commands for the *SmartKom* interface (Beringer, 2002). Later, in 2005 Voida, Podlaseck, Kjeldsen et al., asked participants to creature gesture and voice commands for manipulating 2D objects on common surfaces, such as tables, walls, and floors. In addition, Lui, Pinelle, Sallam et al., (2006) sought to study the manipulation and translation of sheets of paper on a common desk or table, in order to then design the equivalent operation on a touch-surface. In 2009, Wobbrock, Morris and Wilson conducted a study to investigate a set of user-defined gestures for a set of common actions that are generally available on touch-surfaces. A year later, Mauney et al., conducted a study to create a set of user-defined cross-cultural gestures for mobile touchscreens (Mauney, Howarth, Wirtanen, & Capra, 2010). More recently, Ruiz, li and Lank (2011) investigated user-defined motion gestures for smartphones (further detail regarding user-defined gestures can be found in Section 3.2). However, these research efforts were conducted with younger adult users, and therefore cannot be generalised into guidance for developing smartphone interfaces for older adults.

In addition, several research efforts have been conducted to assess the influence of touch-target sizes, spacing sizes between targets, and mobile device activity zones on the performance of common touchscreen gestures. Regarding target and spacing sizes, Kobayashi, Hiyama, Miura, et al., (2011) investigated target sizes for *tap* gestures with older adults on mobile touchscreen devices. However, they considered only three different targets sizes for individual targets with no neighbours (Kobayashi et al., 2011). Jin, Plocher and Kiff (2007) conducted a study to evaluate touch target sizes for older adults on a fixed touch-surface. The authors considered six different target sizes for both adjacent and non-adjacent targets, as well as five spacing sizes for adjacent targets. However, this study was conducted on a large fixed touchscreen and therefore the results are not directly applicable to smaller mobile devices such as smartphones (further detail for research regarding target sizes and spacings can be found in Sections 3.3 and 8). Regarding activity zones, several studies have been conducted with younger adults (Henze, Rukzio, & Boll, 2011; Parhi, Karlson, & Bederson, 2006; Perry & Hourcade, 2008) (for further detail see Section 9), but to our knowledge this has not yet been explored with older users.

Accordingly, the aim of our work is to first investigate the discoverability of current smartphone gestures, and explore the potential of a set of user-defined gestures. After which we intend to assess the influence of certain user-interface (UI) characteristics — target sizes, spacing sizes between targets, and smartphone activity zones — on the performance of such gestures. Lastly, we intend to summarise our findings in the form of interaction design patterns, in order to provide readily available guidance for designers developing smartphone interfaces for older adults.

1.2 RESEARCH QUESTIONS AND OBJECTIVES

In order to investigate the previously mention issues regarding touch-based interaction on smartphones with older adults, we aim to answer the following research questions (RQ):

RQ1: Are current smartphone gestures easily discoverable for older adults?
Objective: Assess whether older adults correctly discover and apply current smartphone gestures for common tasks.
Answer: Section 6.

RQ2: Do older adults, without prior touchscreen experience perform the same gestures as those currently implemented by systems' designers? If not, which gestures do they perform?
Objective: Find out if older adults without prior touchscreen experience perform the same gestures as those that are currently implemented on smartphones. If they do not, assess the main characteristics of the novel gestures performed, in order to understand why they might be more intuitive than existing ones.
Answer: Section 6.

RQ3: What are the main characteristics of performed gestures, such as number of fingers and hands used?
Objective: Assess whether the number of fingers, or hands used is important in distinguishing performed gestures.
Answer: Discussed in Section 6.

RQ4: If current smartphone gestures prove to be problematic, and if older adults do not propose a set of user-defined gestures, can we effectively teach them how to use the current ones?
Objective: Discover if older adults can effectively learn current smartphone gestures.
Answer: Discussed in Section 7.

RQ5: Are recommended touch-target sizes, found in official guidelines, adequate for older adults performing *tap* and *swipe* gestures?

Objective: Assess adequate touch-target sizes for older adults according to each type of gesture. Compare results with recommendations found in official smartphone Operating Systems' guidelines.
Answer: Discussed in Section 8.

RQ6: Are current recommendations regarding spacing sizes between touch-targets adequate for older adults performing *tap* and *swipe* gestures?
Objective: Assess adequate spacing sizes between touch-target sizes for older adults according to each type of gesture. Compare results with recommendations found in official smartphone Operating Systems' guidelines.
Answer: Discussed in Section 8.

RQ7: Are activity zones on smartphones the same for younger and older adults?
Objective: Evaluate targets' onscreen location and assess smartphone activity zones for older adults. Compare these with existing literature regarding younger adults and smartphone activity zones.
Answer: Discussed in Section 9.

RQ8: In the particular case of *swipe*, does gesture orientation influence such activity zones?
Objective: Assess whether gesture orientation influences activity zones for *swipe* gestures. In order to provide guidance comparing horizontal or vertical scrolling.
Answer: Discussed in Section 9.

RQ9: Which is the best form of documenting the knowledge outcome of this research, in order to share it and make it readily available to practitioners involved in creating smartphone interfaces for older adults?
Objective: Review literature regarding existing forms of HCI knowledge documentation, in order to select the form that is most adequate for the documentation, and dissemination of the knowledge outcome of our research.
Answer: Discussed in Section 4.3 and implemented in Section 10.

1.3 THESIS CONTRIBUTION

The research performed in this thesis aims to further the understanding of older adults and touch-based interaction on small handheld devices in a number of important ways: first by (1) evaluating the usability of current smartphone gestures for this user-population; second by (2) exploring the possibility of a set of user-defined gestures for smartphones targeted at older adults; (3) by assessing the possibility of using tutorial mechanisms to teach older adults how to correctly make use of current gestures; (4) by evaluating a set of interface design characteristics that could influence the performance of such gestures; and finally (5) by providing a set of design patterns with the objective of providing guidance to practitioners in developing more usable smartphone user interfaces for older adults.

In addition, our literature review provides context regarding current demographics for an ageing population (Section 2.1), and an overview of several issues related to this social change (Section 2.2). Moreover, it provides a discussion on age-related changes and their potential impact on user interface design (Section 2.3), and older adults' relationship with ICTs (Section 2.4). Furthermore, besides providing a historical contextualisation of touchscreen devices (Section 3.1), we provide a discussion of how these devices could benefit or hinder older adults' interaction (Section 3.3), as well as an overview of research regarding user-defined gestures for touch-surfaces (Section 3.2). Finally, building upon the concept of design patterns in a historical context (Section 4.1), we discuss design patterns' advantages or disadvantages over other forms of Human-Computer Interaction (HCI) knowledge documentation such as claims, heuristics and guidelines (Section 4.2). Finally, Section 4.3 presents the potential of using design patterns when developing interfaces for older adults.

1.4 DOCUMENT OUTLINE

This thesis is structured in twelve chapters.. We will now look at a summary of each chapter's content.

CHAPTER ONE: INTRODUCTION

Chapter one provides the reader with background information on the importance of further investigation into gesture-based interaction on smartphones and older adults. In addition, the specific focus of the research is discussed, and the overall research questions and objectives are identified.

CHAPTER TWO: OLDER ADULTS

Chapter two starts by presenting demographic facts regarding an ageing population, it then discusses the issues related to this social change, as well as an overview of current Information and Communications Technology (ICT) solutions. The chapter then goes on to provide an overview of psychomotor, sensory, and cognitive age-related changes and their potential impact on user interface design. Finally, we address issues surrounding older adults and their relationship with ICT devices.

CHAPTER THREE: TOUCH-BASED INTERACTION AND OLDER ADULTS

This chapter discusses the evolution of touchscreens and gesture-based interaction, as well as the potential benefits and disadvantages of this form of interaction for older adults. It starts by providing an historical review of the evolution of touchscreen technologies and systems, while also discussing the gestures used to manipulate these systems. It then offers a review of other research efforts in identifying user-defined gesture sets with young adults. Finally, the potential advantages and disadvantages of touch-based interaction for older adults are discussed.

CHAPTER FOUR: DESIGN PATTERNS AND OLDER ADULTS

Chapter four presents the concept of design patterns within a historical perspective. It then discusses the advantages of design patterns over other forms of HCI knowledge documentation such as claims, heuristics and guidelines. Finally, this chapter discusses potential advantages of design patterns as a form of guidance when developing interfaces for older adults.

CHAPTER FIVE: METHODOLOGY

Chapter five discusses and justifies the research strategies and data collection techniques adopted in the five phases of our work. It reintroduces the research questions and objectives and then presents the methods used in each of these phases, as well as the techniques employed for the data collection and consequent analysis. In addition, this chapter provides an overview of how each of the five phases is connected to others in a sequential manner, showing how each phase builds upon the results from the previous ones.

CHAPTER SIX: EXPLORING USER DEFINED GESTURES FOR SMARTPHONES WITH OLDER ADULTS

This chapter presents the participants, apparatus, procedure and results for the first phase of testing with users. Firstly, we present the criteria used for defining the gestures and respective tasks for the first test, in light of current smartphone gestures. Secondly, we discuss related work and revisit the research questions to be answered by this phase of testing with users. Then, we report on the method used to elicit gestures from users, as well as details regarding the studies' participants and apparatus used. Finally, the results from the study are presented according to each independent variable, after which follows a discussion of our main findings.

CHAPTER SEVEN: TEACHING SMARTPHONE GESTURE TO OLDER ADULTS

Chapter seven presents the participants, apparatus, procedure and results for the second phase of testing with users. Firstly, we explain how this phase of research builds upon the results from the previous phase. We then describe the studies' participants and apparatus used. This is followed by the procedure and the results of the tests. Finally, we provide a discussion of our main findings.

CHAPTER EIGHT: EVALUATING TARGET SIZES AND SPACING BETWEEN TARGETS FOR OLDER ADULTS

This chapter describes the participants, apparatus, procedure and results for phase three of our research. Firstly we discuss related work and reintroduce the research questions to be answered in this phase. Then we provide details regarding participants and apparatus, followed by a detailed presentation of the results. Finally, we discuss our main findings.

CHAPTER NINE: EVALUATING SMARTPHONE ACTIVITY ZONES AND *SWIPE* GESTURE ORIENTATIONS

This chapter presents our final set of tests with users. Firstly, details are presented regarding the studies' participants and apparatus used, after which we discuss the procedure, and present our results. Lastly, a discussion of our main findings is provided.

CHAPTER TEN: CREATING INTERACTION DESIGN PATTERNS FOR *TAP* AND *SWIPE* GESTURES FOR OLDER ADULTS

Chapter ten presents the user interface design patterns constructed from the findings of the previous four research phases. It starts by presenting the goals of the pattern set, to then discuss the structure of the patterns and the links between them. Finally, it documents all the resulting patterns from our research, and introduces the website were these patterns can be found, and are available to the community.

CHAPTER ELEVEN: DISCUSSION

Chapter eleven discusses the main findings from all of the research phases, and then reflects on methods used in each phase of research.

CHAPTER TWELVE: CONCLUSIONS AND FUTURE WORK

Our final chapter reintroduces the aim of this research, as well as all of the research questions and objectives. It then summarises our main findings, and conclusions according to each research question. Finally, this chapter outlines the contributions of our research, and proposes a set of possible directions for future work.

2 THE OLDER ADULT

This chapter presents statistics and aspects relating to the ageing population in industrialised countries, namely age-related changes to the sensory, motor and cognitive systems, as well as psychological and social alterations associated with later life. Lastly, an overview of older adults and their attitudes and expectancies toward Information and Communications Technologies (ICTs) is discussed.

2.1 DEMOGRAPHICS FOR OLDER ADULTS

There has never been such a high percentage of older adults in industrialised countries as there is now and this trend is to keep increasing. Datasets indicate that the percentage of older people (defined as over 65 years of age) in 2010 were 13% in the United States (AoA 2011) and 17.4% in the European Union (Eurostat, 2011a). By 2030-2035 the percentage of older adults of the total population is estimated to be 19.3% in the U.S (AoA 2011) and 23.8% in the EU (Eurostat, 2011b).

The Portuguese reality also reflects an ageing population. In 2010 adults over 65 years of age represented 18% of the Portuguese population, and by 2030 this number is expected to increase to 24.2% (European Commission & Economic Policy Committee, 2011), a value that is slightly higher than the average for the EU.

When looking at the old-age dependency ratio[1] one find for the EU that this ratio was 25.92% in 2010 and is estimated to increase to 38.33% by 2030 and to 50.16% by 2050. In Portugal this value amounted to 26.7% in 2010 and is expected to reach 37.85% by 2030 and 55.62% by 2050 (European Commission & Economic Policy Committee, 2011).

2.2 ISSUES RELATED TO AN AGEING POPULATION

Several issues contribute to the ageing trend found in the EU and other industrialised nations. Low fertility rates and increasing life-expectancy constitute the two most immediate facets of this topic and are a consequence of several social and economical changes. The first — low fertility rates — can be explained by increasing "difficulties in finding a job, the lack and cost of housing, the older age of parents at the birth of their first child, different study, working life and family life choices" (European Commission. Directorate-General for Employment & Opportunities, 2005); while the second —

1 The old-age dependency ratio refers to the number of older dependent persons (defined as those over 65 years of age) as a percentage of the working-age population (defined as persons between the ages of 15 and 64).

extended life-expectancy — is a result of the continuing improvement of health care and quality of life in the EU (European Commission. Directorate-General for Employment & Opportunities, 2005).

These factors contribute to an increasing old-age dependency ratio (as discussed in the previous section) and consequently can pose serious economic, budgetary and social challenges in the future (Steg, Strese, Loroff, Hull, & Schmidt, 2006). The steady increase of older adults and the decrease of the working-age population poses serious threats to the social support and health care systems in Europe (Steg et al., 2006) as an increasingly aged population requires an ever-growing amount of financial resources.

Over the past few years, as an approach to solving the issues discussed above increasing efforts have been invested in solutions for Ambient Assisted Living (AAL). “AAL aims at extending the time older people can live in their home environment by increasing their autonomy and assisting them in carrying out activities of daily living by the use of intelligent products and the provision of remote services including care services” (Sun, De Florio, Gui, & Blondia, 2009). The integration of these systems into older adults daily routines could contribute to a major reduction in government costs as it enables older adults to remain independent and to live at their own houses, while reducing the need for caretakers, personal nurses or institutionalisation in retirement homes (Sun et al., 2009). Furthermore, previous research stresses that older adults’ prefer to remain in their own homes for as long as possible (Mutschler, 1992), for reasons such as staying in a familiar environment, maintaining access to an informal support network or due to other economic-related issues (Wagnild, 2001).

However, if AAL systems are to be effective and become widespread efforts need to be invested in the appropriate design of these systems for older adults’ specific needs, expectations and characteristics (Steg et al., 2006). For this reason, the remainder of this chapter will discuss several physical, cognitive and social age-related changes.

2.3 AGE-RELATED CHANGES

The design of human-computer interfaces has largely focussed on developing for younger persons (Gregor, Newell, & Zajicek, 2002) and is therefore in danger of excluding specific user-groups, such as older adults, whose needs and requirements differ from those of their younger counterparts (Czaja & Sharit, 1998; Zaphiris, Kurniawan, & Ellis, 2008; Ziefle, 2010). In order to successfully design interfaces that are adequate for older adults, one must understand the diverse age-related changes that occur to the human sensory, motor and cognitive systems, as well as the psychological and social alterations that unfold with the ageing process. The following sections further discuss these age-related modifications and their implications toward interface design.

2.3.1 PHYSICAL CHANGES

2.3.1.1 VISION

All individuals will eventually experience some kind of visual impairment, varying in degree from person to person (Pak & McLaughlin, 2010). Additionally, these impairments can be exasperated by diseases such as age-related macular degeneration (AMD), cataracts, glaucoma (Kurniawan, 2008) and diabetic retinopathy (Jackson & Owsley, 2003).

When designing interfaces for smartphones or other devices with prominent visual displays, understanding age-related changes to the visual system is of paramount importance as most of the information is conveyed visually (Pak & McLaughlin, 2010). Although use of auditory and haptic feedback is also possible, most of these devices and applications rely on the display of a visual interface.

One of the most common visual disorders that result from ageing is presbyopia (Jackson & Owsley, 2003), which is a result of the decline in the eye's accommodation capability. Visual accommodation refers to the process that occurs within the human eye that permits us to focus on nearby or faraway objects. Presbyopia typically starts around an individual's 40s, but is a disorder that eventually affects all people as age progresses (Kurniawan, 2008). Studies have found that as we age the time needed to switch between focusing on closer to further away objects, or vice-versa, becomes substantially longer (Cavanaugh & Blanchard-Fields, 2006).

In addition, visual acuity also suffers age-related declines. Acuity is the degree to which a person is able to see detail in visual images (Cavanaugh & Blanchard-Fields, 2006; Pak & McLaughlin, 2010). There are many physiological changes that happen in the eye that can provoke loss in visual acuity and a number of studies show that with age there is a steady decline in acuity for a large number of people (Pak & McLaughlin, 2010). This loss of visual acuity may start in a person's 20s and then rapidly decline after 60 years of age (Cavanaugh & Blanchard-Fields, 2006). Therefore, user interfaces with small text, icons or other visual elements should be avoided as they can significantly hinder older adults' ability to interact with a system (Kurniawan, 2008).

Another relevant issue to interface design is contrast sensitivity, which refers to the ability to distinguish between dark and light parts of an image. Older adults tend to have poorer contrast sensitivity which makes daily activities likes reading, using a computer or mobile phone, or driving much harder to manage, and may actually have a larger impact on these activities than visual acuity (Pak & McLaughlin, 2010). Regarding interface design, high contrast between visual elements is recommended (Kurniawan, 2008; Pak & McLaughlin, 2010).

Adaptation refers to the changes that occur in the retina due to varying light conditions. There are two types of adaptation, (1) dark adaptation that occurs when crossing from a well-lighted environment into a dark one, and (2) light adaptation which happens in the opposite situation (Cavanaugh & Blanchard-Fields, 2006; Saxon, Etten, & Perkins, 2009). As we age, the process of adapting to changes in illumination takes longer and becomes less effective as the pupil is unable to fully dilate to let in light in dim conditions (Cavanaugh & Blanchard-Fields, 2006; Pak & McLaughlin, 2010). Consequently, interfaces that alternate between light and dark screens should be avoided and substituted by the use of screens with similar levels of brightness.

Visual Threshold indicates the minimum amount of light required to effectively perceive images (Cavanaugh & Blanchard-Fields, 2006). As age progresses the amount of light needed to see becomes increasingly higher. This happens because, with age, the light receptors in our retina gradually lose sensitivity. The retina of a person over 60 years of age may receive up to two-thirds less light than that of a 20 year old (Pak & McLaughlin, 2010). Consequently, seeing in the dark becomes increasingly difficult with age, which could explain why older adults tend to become more reluctant towards going out at night (Saxon et al., 2009).

Furthermore, older adults are particularly susceptible to disability glare. Disability glare refers to losses in visual acuity and contrast perception when an intense light source is present. For example, older adults might have more difficulty in seeing after confronting oncoming headlights when driving (Jackson & Owsley, 2003; Saxon et al., 2009). In this way, driving can become an issue for older adults and therefore compromise factors such as mobility and independence.

Additionally, the perception of colour is also altered by age. The gradual yellowing of the eye lens and the diminished sensitivity of the short wavelength cones makes it harder for older adults to distinguish between colours with similar hues and low contrast (Kurniawan, 2008). Particularly susceptible to these process are colours along the blue-yellow axis (Jackson & Owsley, 2003). When designing user interfaces, highly saturated and contrasting colours are recommended (Kurniawan, 2008).

Moreover, several age-related diseases such as age-related macular degeneration (AMD), cataracts, diabetic retinopathy and glaucoma (Jackson & Owsley, 2003; Kurniawan, 2008) can further affect vision. Firstly, AMD is the leading cause of adult blindness in developed countries (Fine, Berger, Maguire, & Ho, 2000; Jackson & Owsley, 2003). AMD is characterised by the loss of central vision and eventually blindness. Although peripheral vision remains intact, the loss of central vision can be so severe that the patient is considered partially sighted or totally blind (Kurniawan, 2008). Typically, AMD affects persons over 60 years of age and the severe loss of central vision compromises basic daily activities such as reading, recognising faces and driving (Fine et al., 2000). Next, cataracts are characterised by the process of clouding or loss of transparency of the eye lens which limits light rays from entering the eye. Less light entering the eye provokes issues such as decreased contrast and colour perception (Saxon et al., 2009). Colour perception is most affected along the blue-violet axis as cataracts mainly prevent violet light from reaching the retina. Furthermore, the lens looses it's ability to focus the light coming into the eye which results in blurred vision (Kurniawan, 2008; Saxon et al., 2009). Following, diabetic retinopathy is common among persons with diabetes type I and II and refers to alterations to the retina provoked by diabetes. Typically this disease does not present symptoms and therefore diabetic patients should regularly undergo ophthalmologic evaluations. Diabetic retinopathy can result in the loss of visual acuity, peripheral vision, contrast sensitivity and colour perception (Jackson & Owsley, 2003). When diagnosed at an early stage, treatments such as photocoagulation, focal photocoagulation and vitrectomy have been shown to prevent blindness in most people (American Diabetes Association, 2012). Lastly, glaucoma refers to a group of diseases that damage the optical nerve and eventually cause blindness. Glaucoma is not an age-related disease, however manifestations of glaucoma typically increase after the age of 60 (Kurniawan, 2008). The most common consequence of glaucoma is increasingly reduced peripheral vision, but it can also affect motion and colour perception, contrast sensitivity and central vision acuity. The aggravated loss of peripheral vision can hinder a persons' ability to drive, walk, avoid obstacles and all other activities that involve the use of this particular visual function (Jackson & Owsley, 2003).

2.3.1.2 HEARING

Hearing loss is one of the most widespread issues among older adults (Cavanaugh & Blanchard-Fields, 2006), and may be an important factor in reducing the quality of life of an individual (Dalton et al., 2003). Since we mainly communicate with each other in a verbal manner, loss of hearing may hinder the ability to understand and actively participate in a conversation and other social activities. Major hearing loss can often result in withdrawal from society, when an individual ceases to communicate with family and friends due to the difficulties imposed by non-verbal communication (Saxon et al., 2009). Increasingly, loss of hearing can result in loss of independence, social isolation, irritation, paranoia, and depression among older adults (Cavanaugh & Blanchard-Fields, 2006).

Hearing impairments can be grouped into three different categories:

- Conductive Hearing Loss refers to any kind of obstruction that prevents sound signals from effectively reaching the eardrum and ossicles in the middle ear. This usually results in a reduction in perception of sound level, making fainter sounds inaudible (American Speech-Language-Hearing Association, 2012). A common example of conductive hearing loss among older adults is the accumulation of serum in the external ear canal which results in the obstruction of the auditory canal causing hearing difficulties (Saxon et al., 2009).
- Sensorineural Hearing Loss can result from disorders in the inner ear, such as hair cell loss, or from damage to the nerve pathways from the inner ear to the brain (American Speech-Language-Hearing Association, 2012; Saxon et al., 2009). The most common form of this type of hearing loss, is a condition called presbycusis and can be provoked by the continued use of drugs such as aspirin and antibiotics (Saxon et al., 2009).
- Mixed Hearing Loss involves both conductive and sensorineural hearing loss (American Speech-Language-Hearing Association, 2012; Saxon et al., 2009).

Hearing loss starts gradually but increases during an individual's 40s, therefore being an important concern when designing inclusive interfaces, as people in their 40s and 50s are not considered older adults but may already suffer from some degree of hearing loss.

Although loss of hearing is not directly related to touch-based interaction, it emphasises the need to develop more inclusive user interfaces and guidance that could aid designers in developing these interfaces.

2.3.1.3 PSYCHOMOTOR CHANGES

As with the visual and auditory systems, the ageing process involves alterations to the muscular-skeletal system such as the loss of muscle tissue and bone density. These particular losses contribute to the reduction of capabilities such as strength and endurance in older adults (Cavanaugh & Blanchard-Fields, 2006). The loss of muscular strength is particularly accentuated in the lower body, and increases the probability of balance issues that could result in increased risk of falls and difficulty in walking (Cavanaugh & Blanchard-Fields, 2006). Additionally, conditions such as common skeletal diseases — osteoarthritis, rheumatoid arthritis, and osteoporosis — malnutrition (Carmeli, Patish, & Coleman, 2003), declining physical activity and sedentary lives are also common issues affecting older adults' muscular and skeletal capacities (Vandervoort, 2002). These diseases generally lead to some form of weakness, numbness, paralysis, aphasia, muscle rigidity, tremors, or pain that significantly reduce older adults motor capabilities (Kurniawan, 2008).

Accompanying physical changes in muscle tissue and bone density, cognitive and sensory modifications also affect how older adults carry out movement. These alterations are related to poorer perceptual feedback and strategic differences in approaching task resolution (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Goodman, Brewster, & Gray, 2005; Pak & McLaughlin, 2010). Research has shown that older adults take 30% to 70% longer than their younger counterparts to perform certain motor tasks (Ketcham, Seidler, Van Gemmert, & Stelmach, 2002), and are also less accurate in performing those movements (Pak & McLaughlin, 2010). Although some research has shown that older adults tend to favour accuracy over speed, which results in precise but slow movements (Chaput & Proteau, 1996).

Likewise, age-related changes to the central and peripheral nervous systems affect the sensation of touch (Wickremaratchi & Llewelyn, 2006). Older adults have been found to sustain reduced ability in detecting vibrotactile stimulation, perceiving differences in temperature (Nusbaum, 1999), and noticing light pressure touches. Tactile acuity also suffers significant declines, with bodily extremities (e.g., finger-tips, toes) being the most affected body parts (Wickremaratchi & Llewelyn, 2006).

Reductions in mobility, due either to common sensory, motor and cognitive declines or to disease, often compromise independence, ability to accomplish basic daily routines and overall quality of life (Cavanaugh & Blanchard-Fields, 2006).

When considering touchscreen interface design, hand function, manual dexterity and touch sensitivity play important roles, as these devices require precise fine movements in order to be operated. However, the human hand undergoes several anatomical and physiological alterations as the individual ages, and aforementioned issues such as cognitive and sensory alterations, as well as common conditions such as osteoarthritis, rheumatoid arthritis and hormonal changes can have a significant impact in decreased hand function. Common alterations to hand function result from the deterioration of muscle coordination, finger dexterity and hand sensation (Ranganathan, Siemionow, Sahgal, & Yue, 2001). Although, hand function remains fairly stable throughout a large part of adult life, it begins to decrease slowly after 65 years of age and accentuates after 75 years of age (Carmeli et al., 2003).

Older adults have been found to have difficulties in tasks such as mouse cursor control as well as with actions such as clicking and double-clicking (Hawthorn, 2000; Laursen, Jensen, & Ratkevicius, 2001; Smith, Sharit, & Czaja, 1999). Pak and McLaughlin (2010) suggest reducing cursor speed, and gain (the compensation between the users' actual movement and the distance that the cursor moves onscreen) when nearing targets, for indirect input devices such as the mouse, allowing older adults to more easily acquire a target by reducing the speed and distance of cursor movement while allowing larger motor movements. Regarding the performance of gestures on mobile touchscreens, a study conducted by Stößel, Wandke and Blessing (2009) suggests that older adults are capable of accurately performing finger gestures on touchscreens although at a slower rate than their younger counterparts, which is consistent with the above mentioned findings of Chaput and Proteau (1996).

2.3.2 COGNITIVE CHANGES

Cognition is of particular relevance to user interface design, as in many cases a user interface can be adequate to the users' visual, motor and auditory capabilities but may not be understandable. Norman (1990) argues that in order for a product to be usable, the people using it must be able to create an adequate mental model of how the product works. If one cannot understand how an interface works then it will not be possible to create an adequate mental-model of its functioning (Norman, 1990).

However, cognition suffers several age-related changes that might render a product, that is adequate for younger adults, to be unusable by their older counterparts due to increased difficulties in developing adequate mental models. Particularly relevant to UI design are cognitive abilities such as memory, attention spatial cognition.

2.3.2.1 MEMORY

Not all types of memory are affected in the same way by age, some undergo more alterations than others (Fisk et al., 2009). Working memory, which concerns the ability to store information while carrying out a task, is especially affected. It is distinct from short-term memory because it does not just involve remembering a few items for a relatively short period of time but also remembering them while performing another related or non-related task (Pak & McLaughlin, 2010). For this reason, declines in working memory can negatively impact several daily activities such as speech and language comprehension (Cavanaugh & Blanchard-Fields, 2006), reasoning, and problem solving (Fisk et al., 2009). Study results show that working memory is affected by age, by progressively becoming less capable of holding as many items and for shorter periods of time (Cavanaugh & Blanchard-Fields, 2006; Pak & McLaughlin, 2010).

In order to compensate for declines in working memory, Pak and McLaughlin (2010) suggest an interface that adapts to the task being performed by providing all information that is relative to that particular task while it is being carried out by the user. In this way, an interface avoids making use of working-memory by displaying all the necessary information, instead of expecting the user to remember it (Pak & McLaughlin, 2010).

Unlike working memory which is short-term, a few long-term memory capabilities seem to remain stable throughout the ageing process. Long-term memory refers to a more permanent form of storing information, such as learned movements and behaviours (Fisk et al., 2009). One aspect of long-term memory is called semantic memory, which is the ability to remember factual information acquired during one's lifetime, such as the meaning of words, historical facts and general knowledge (Fisk et al., 2009). This type of memory remains fairly unchanged by age (Cavanaugh & Blanchard-Fields, 2006), although older adults may be slower or have more difficulties in retrieving the information, long-term memory is generally not lost entirely (Fisk et al., 2009).

Prospective memory is another form of long-term memory and designates the ability to remember to perform tasks in the future. This kind of memory can be divided into two further sub-types, which are event-based prospective memory and time-based prospective memory. The first refers to remembering to perform a task after a certain trigger event has occurred (e.g., remembering to turn off the bathroom fan after finishing shower), while the second is triggered by time (e.g., remembering to return a book to the public library on a certain date). Age-related declines in prospective memory are usually greater for time-based tasks rather than event-based ones (Fisk et al., 2009).

Lastly, procedural memory is responsible for storing automatic processes required to perform certain tasks (Pak & McLaughlin, 2010) such as riding a bicycle or tying shoelaces. Evidence suggests that processes that were learned and automatized early on in life are not forgotten with ageing. However learning new procedural tasks and developing new automatic processes is difficult for older adults (Fisk et al., 2009). Thus, it is advisable to make use of older adults crystallised knowledge when designing interfaces, by building upon previously learned mental-models and procedures (Fisk et al., 2009).

2.3.2.2 ATTENTION

"Attention refers to our limited capacity to process information" (Fisk et al., 2009), and can be better understood by three interdependent aspects of itself: attentional capacity, selectivity and vigilance (Cavanaugh & Blanchard-Fields, 2006).

Firstly, attention is considered a limited resource and is particularly relevant when considering multitasking, where attention resources need to be divided across various tasks (Cavanaugh & Blanchard-Fields, 2006; Fisk et al., 2009). Research has shown that attentional capacity declines significantly with age (Pak & McLaughlin, 2010).

Next, selectivity refers to the process of choosing one factor on which to concentrate our attention while ignoring all others (Fisk et al., 2009; Pak & McLaughlin, 2010). In other words, it is how we choose the information we will process further and that which we will discard (Cavanaugh & Blanchard-Fields, 2006). Selective attention is more difficult for older adults as they seem to have more trouble in concentrating on one factor while ignoring other distracting stimuli (Pak & McLaughlin, 2010). Additionally, selectivity is significantly tied to visual search capabilities as this consists of visually identifying a target among distracting stimuli (Cavanaugh & Blanchard-Fields, 2006) and is therefore fundamental to interaction with visual interfaces in general (Brewster, 2002; Fisk et al., 2009) and mobile devices in particular, given the amount of information that needs to be shown on small displays.

Lastly, vigilance refers to the ability to maintain concentration on a particular task over a longer period of time (Cavanaugh & Blanchard-Fields, 2006). This could be an issue for older adults seeing as research has shown that they are more susceptible to being distracted by surrounding stimuli that are irrelevant to the task at hand, as well as being slower in performing tasks that take several seconds or minutes to complete (Cavanaugh & Blanchard-Fields, 2006; Fisk et al., 2009).

When designing interfaces for older adults Pak and McLaughlin (2010) suggest that avoiding clutter and removing unnecessary information, while drawing attention to important items or frequently performed actions might be a form of avoiding attentional capacity, selectivity and vigilance issues among older adults.

2.3.2.3 SPATIAL COGNITION

Spatial cognition translates in the ability to retain and mentally reconstruct and manipulate location-based representations of the world (Fisk et al., 2009). This skill is particularly important to human interactions with systems, given that it is responsible for the ability to construct mental models (Pak & McLaughlin, 2010). “Mental models are knowledge structures that are used to describe, predict, and explain the system that they represent” (Gilbert, Rogers, & Samuelson, 2009), and are particularly relevant to tasks that involve navigating information hierarchies (Fisk et al., 2009), like browsing the Web or using a mobile phone menu. Younger adults are believed to significantly outperform older adults in tasks that involve the construction of mental models (Gilbert et al., 2009).

Zielfe and Bay (2005) found that older adults experience difficulty in navigating mobile phone menus. This difficulty is a result of the devices small displays which only show a few menu items at a time and where users navigate complex menu hierarchies without fully understanding their spatial structure and links between each other. Additionally, Zaphiris, Kurniawan, and Ellis (2003) found that older adults prefer shallow navigation systems for online navigation.

2.3.3 PSYCHOLOGICAL AND SOCIAL CHANGES

As has been discussed until this point, performing activities of daily living (ADLs) can become increasingly challenging with age due to several physical and cognitive changes (Murata et al., 2010;

Ranganathan et al., 2001). These changes can also hinder older adults ability to participate in social interactions, to live independently and safely (Bierman & Statland, 2010), as well as provoke alterations in the way they perceive themselves and their social roles within society (Gayman, Turner, & Cui, 2008).

Additionally, the perception of limited time is also a major factor influencing older adults' social goals and motivation (L.L. Carstensen & Hartel, 2006). Older adults tend to prefer investing in existing relationships by making them stronger rather than acquiring new ones. Carstensen, Isaacowitz and Charles (1999), consider that the perception of remaining life time could be a major factor in why older adults generally perceive new relationships as trivial, and why social networks have been found to decrease significantly with age. While younger adults maintain more and novel social partners, their older counterparts tend to select the relationships that are most rewarding. Much in the same way, activities or acquisition of new knowledge that do not demonstrate immediate benefits are not considered to be of high priority (Laura L. Carstensen, Isaacowitz, & Charles, 1999).

However, it has been found that maintaining social relationships could somewhat avoid age-related cognitive declines and dementia (L.L. Carstensen & Hartel, 2006; Seeman, Lusignolo, Albert, & Berkman, 2001) and could point to an important need for technology to aid older adults in sustaining such relationships.

Furthermore, the perception of one's self is also affected by the ageing. Younger adults show a bigger gap between themselves and their ideal self, while older adults seem to better accept who they are, their values, likes and dislikes, appearance and competencies. In addition, self perception seems to influence the ageing process where individuals with positive and strong attitudes live longer than those with negative ones (L.L. Carstensen & Hartel, 2006).

Another determinant factor affecting psychological and social changes are old age stereotypes (Lineweaver & Hertzog, 1998). These stereotypes include the perception of older adults as lonely, dependent on others, cognitively impaired and depressed (American Psychological Association, 2012). Although mostly inaccurate, a few studies have found that these stereotypes significantly influence older adults perception of their own abilities, as well as their performance in certain cognitive-related tasks (Chasteen, Bhattacharyya, Horhota, Tam, & Hasher, 2005; Hendrick, Jane Knox, Gekoski, & Dyne, 1988; Ryan & See, 1993).

With regard to technology, lack of confidence, anxiety and age perception are an important issue, as older adults perceive themselves as being too old and incapable of learning to use new technologies (Hawthorn, 2007; Turner, Turner, & Van De Walle, 2007). Nevertheless, research has shown that teaching, demonstrating benefits of technology and constructing positive experiences can alter older adults perception of their own capabilities toward ICTs (Information and Communications Technologies) (Broady, Chan, & Caputi, 2010; Czaja & Sharit, 1998). The following section discusses the relationship between older adults and ICTs in further detail.

2.4 OLDER ADULTS AND INFORMATION AND COMMUNICATIONS TECHNOLOGIES (ICTs)

According to the International Telecommunication Union (2012), it is estimated that cellular subscriptions in Europe are around 119.5 per 100 people, meaning that there are more cellular subscriptions that individual persons. On a larger scale, 86.7% of the world's population are estimated to have a cellular subscription.

Furthermore, it is estimated that 74.4% of Europe's population are Internet users. Worldwide this figure is considerably lower at 34.7% (International Telecommunication Union, 2012). While Internet usage is not so commonly spread worldwide, the use of mobile phones is considerable in both developed and developing countries.

Considering the clear ageing trend in developed countries (Plaza, Martín, Martin, & Medrano, 2011) and figures for usage of ICTs it becomes clear that as well as living longer and more active lives (Plaza et al., 2011), older adults' needs and expectations are changing (Ellis & Kurniawan, 2000). The need to effectively use new technological devices is of paramount importance to an inclusive society (Czaja & Sharit, 1998; Plaza et al., 2011; Ziefle, 2010), and to bridging the ICT gap between younger and older generations. However the design and development of such devices has not taken into account older adults specific needs and expectations (Czaja & Sharit, 1998; Gregor et al., 2002; Zaphiris et al., 2008; Ziefle, 2010), as this particular audience is often regarded as incapable or unwilling to use new technologies.

Additionally, anxiety (Turner et al., 2007) and low confidence (Czaja & Sharit, 1998) have been reported among elderly users when interacting with ICT devices. Although these issues can constitute severe barriers for technology adoption within this particular audience, studies have reported that they can be overcome by designing products that better match older adults needs and expectations (Ziefle, 2010), by adequately teaching this audience how to use ICT devices (Broady et al., 2010), and by providing environments that allow users to gain positive experience with ICTs (Czaja & Sharit, 1998). It has been found that when older users can understand the benefits of adopting a certain technology, their receptiveness and general attitude toward that specific technology is considerably improved (Broady, Chan, & Caputi, 2010; Dickinson, Eisma, Gregor, Syme, & Milne, 2005; Melenhorst, Rogers, & Bouwhuis, 2006).

Czaja and Sharit (1998), Zaphiris, Kurniawan and Ellis (2008), and Ziefle (2010) point out the lack of design considerations when developing products for older adults as a major factor that could influence non-adoption. These observations highlight the need to develop specific guidelines that aid designers during the process of creation of products and services aimed at this specific audience.

A few resources addressing interface design for seniors are currently available, such as the Web Accessibility Initiative (W3C, 2008) guidelines for senior internet users, Pak and McLaughlin's "Designing Displays for Older Adults" (2010), Fisk, Rogers, Charness et al.,'s "Designing for Older Adults" (2009), "Interface design guidelines for users of all ages" (Spiezle, 2001),"Usability for Senior Citizens" (Nielsen, 2002), and "Making your Website Senior Friendly" (National Institute on Aging and the National Library of Medicine, 2002).

Several studies have also been conducted to investigate issues such as font type and sizes (Bernard, Liao, & Mills, 2001; Darroch, Goodman, Brewster, & Gray, 2005); (Ellis & Kurniawan, 2000)), colours and contrasts (Ellis & Kurniawan, 2000), target sizes and spacings (Jin, Plocher, & Kiff, 2007; Kobayashi et al., 2011), navigational structures (Ziefle, 2010; Ziefle & Bay, 2004) icons (Leung, McGrenere, & Graf, 2011; Linberg, Nasanen, & Muller, 2006; Salman, Kim, & Cheng, 2010) and multimodal interaction (Akamatsu, MacKenzie, & Hasbroucq, 1995; Emery et al., 2003; Jacko et al., 2002) on desktop and/or mobile displays for older adults. The information outcome from these studies is useful, however it is not very easily accessible. An interface design team would need to sort through a large amount of scientific papers before finding relevant guidelines (Zajicek, 2004), which points out the need for more readily accessible resources providing guidance to designers developing for the elderly.

Despite the lack of readily available design guidelines, many applications and services have been developed to address the needs of an ageing population. These efforts mainly concentrate themselves within a few domains such as health, wellness, home care, safety, security and mobility (Plaza et al., 2011).

Mobile devices have received an increasing amount of attention as platforms to develop specialised applications for the needs of seniors (Center for Tecnology and Aging, 2011; Kang et al., 2010; Liu, Zhu, Holroyd, & Seng, 2011). These applications have mainly been dedicated to chronic disease management, medication adherence, safety monitoring, access to health information, and wellness (Center for Tecnology and Aging, 2011).

Given recent modifications to healthcare systems in several countries, and an increasing old-age-dependency-ratio (European Commission, 2011; The World Bank, 2012), it is believed that services like the ones mentioned above will be most beneficial as they allow older adults to maintain social relationships and monitor their health while maintaining independence and living in their own homes (Plaza et al., 2011).

In order to fully take advantage of the benefits offered by these applications, and given the recent proliferation of smartphones, the investigation of mobile touchscreen interaction for older adults becomes of urgent importance. The following chapter further discusses touchscreen interaction, as well as its potential benefits and/or disadvantages for older adults.

3 TOUCH-BASED INTERACTION AND OLDER ADULTS

In this chapter, we present a historical review of the evolution of touch-display technology. Furthermore, it elicits the ways in which it shaped the gestures that we use nowadays to interact with touch-enabled devices, such as smartphones.

Throughout this work, gesture-based interaction is understood as the performance of meaningful touch motions, on a touch-sensitive display, with the objective of interacting with a system. These gestures can range from simple single point touches, to more complex multiple point touches (Khandkar & Maurer, 2010) or even to those involving continuous contact and movement.

3.1 THE EVOLUTION OF TOUCHSCREENS AND HAND GESTURE INTERACTION

For a historical review of touch-based interaction, we will be considering systems that obey three types of criteria: (1) they must respond to touch, either by finger or by the use of a stylus, (2) the system must include a touch-sensitive display, and not a touch tablet or touch pad, and (3) systems based on light-pens or free-form gestures are beyond the scope of this work. We chose these criteria in accordance with the nature of this work, as interaction with smartphones is accomplished by means of direct touch, either with a finger or stylus on a touch-sensitive display, where the user directly manipulates content. Touch pads or tablets provide a similar means of interaction to that of a mouse, or other indirect input devices. Indirect input devices ultimately require high levels of hand-eye coordination and spacial readjustment to compensate for differences in distance and size between the touch surface and the actual display, and therefore are not directly relevant to this study.

Firstly we will consider the advent of direct manipulation interfaces, as they are an important step in the evolution of user interfaces and constitute one of the main facilitators for the emergence of touch-based interaction interfaces.

Direct manipulation interfaces are defined by Shneiderman (1982) (quoted in: (Hutchins, Hollan, & Norman, 1985)) as systems that comprise the following properties:

1. Continuous representation of the object of interest.
2. Physical actions or labelled button presses instead of complex syntax.
3. Rapid incremental reversible operations whose impact on the object of interest is immediately visible (Ben Shneiderman, 1984).

These systems are defined by Hutchins, Hollan and Norman (1985) as those comprising a model-world metaphor. In this type of system, the interface is in itself a world where users can act and immediately see the consequences of their actions. It opposes the conversation metaphor (e.g., command-line interfaces) in which a conversation is constructed between the user and the computer about an “assumed, but not explicitly represented world”.

The first considerable contribution towards direct manipulation interfaces was the *Sketchpad* (Sutherland, 1964), where the author’s intention was to create a means for humans and computers to converse through the use of line drawings. The use of line drawings is explained as a possible means to speed up communication by allowing interaction that goes beyond communication through written statements. Conversation by the use of written statements was the paradigm of command-line interfaces, while direct manipulation characterises the Graphical User Interface (GUI). Sketchpad is a GUI and was designed to be a drawing program, where the user could draw objects on screen, delete, copy or move them by using a light pen and pointing it at the system’s display.

Many of these direct manipulation interfaces where mainly acted upon through the use of peripheral devices such as the light pen, mouse, keyboard or trackball; and touch-displays originally appear with the purpose of replacing such peripheral devices. This replacement is intended on the one hand because physical buttons require large amounts of space and restrict a particular device to a small set of restricted functions (e.g., an alphanumerical keyboard could not be a music keyboard) (Knowlton, 1977), and on the other because peripheral devices only provide a sort of indirect manipulation, that results in a less than optimal interaction performance and experience. Nakatani and Rohrlich (1983) argue that the ease of use of machines such as calculators or ovens, derives from the fact that all buttons are mapped to one unique function. This makes discoverability, memorability and efficiency of a system much easier for the user. The problem is that computers are not modular, unlike traditional machines where you have one appliance for each task, or set of small tasks. Computers perform a wide range of operations and would therefore need a large amount of space to accommodate all the hard buttons needed for each individual function (Nakatani & Rohrlich, 1983).

Although a formal discussion and analysis of touchscreen properties appeared only in 1983 (Nakatani & Rohrlich, 1983), the first touchscreen was developed in 1967 at The Royal Radar Establishment in Malvern (B. Buxton, 2007). This touchscreen was developed to make interaction, with an “Air Traffic Control Data-processing System”, easier and faster by proposing the substitution of “slow and clumsy” input devices such as a keyboard or trackball (Johnson, 1967). In order to overcome limitations of their use, the system was equipped with “a transparent screen responsive to touch suitable for fixing in front of the means for displaying data”, creating the first touch display by overlaying a transparent touch responsive surface over a common CRT display (Johnson, 1969).

A few years later in 1972, a terminal of a computer-based teaching system called PLATO IV included an innovative plasma display panel that was also responsive to touch events (W. Buxton, Billinghurst, Guiard, Sellen, & Zhai, 2011). This system differed from its predecessor by making use of a more recent technology to substitute the CRT monitor with a plasma display. PLATO’s developers claimed that the system allowed for every student to have access to an “infinitely patient” teacher (Meer, 2003).

In 1980, XEROX launches the first commercially available touchscreen. Their “XEROX 5700 Electronic Printing System” is shipped with a black and white video display where all its controls appear and are operable by simply touching the screen (Nakatani & Rohrlich, 1983).

During the 1980s, touchscreen devices entered the public domain through various commercial and industrial uses (B. Shneiderman, 1991). One particular example is the adoption of point-of-sale (POS) devices in restaurants, bars, and other retail surfaces. Another instance is the Hewlett-Packard 150 which was the first commercially available computer to be shipped with a touchscreen (Saffer, 2008). Although these devices were then commercially available, it is important to notice that they were still only capable of supporting single touch interaction (Computer Chronicles, 1983), unlike their counterparts that were being developed, at the same time, in research institutes and universities, such as the aforementioned systems made by Bob Boie and Paul McAvinney (B. Buxton, 2007).

In 1999, the Portfolio Wall is developed (B. Buxton, 2007; W. Buxton, Fitzmaurice, Balakrishnan, & Kurtenbach, 2000) and incorporated many gestures that are still recognisable today, such as a *flick* of the finger to the left in order to view the previous image or a *flick* to the right to view the next. Still, Bill Buxton (2007) describes a few other options that were available according to the direction of a finger *swipe/flick*: a downward gesture over a video made it stop playing; an upward and right diagonal gesture enabled annotations; and downward and right diagonal opened an application related to the image (B. Buxton, 2007).

However, the systems mentioned above were able to detect only one touch event at a time, therefore limiting interaction to a single finger. This meant that a user could only interact with the computer by using one touch-point, leaving room for issues related to undesired touches that ultimately confused the system. These issues could, for example, be the result of a user accidentally resting his hand on the touch surface for extra support or even to reduce arm fatigue. Unintentional touches would confuse the system, rendering it unable to detect any of the users' interventions and thus hindering further interaction (Sears, Plaisant, & Shneiderman, 1990).

3.1.1 MULTI-TOUCH

In order to overcome single finger interaction, various technological approaches to multi-touch displays were developed during the following years, ranging from the use of sensors — capacitive, resistive or acoustic — to various computer vision techniques — purely vision based, Frustrated Total Internal Reflection (FTIR) and Diffused Illumination (DI) (Chang, Wang, & You, 2010).

These multi-touch displays allowed for new types of interaction involving multiple fingers, hands or other tangible objects, that could now be used to communicate with a system (Khandkar & Maurer, 2010). Accordingly, such systems allowed events to be triggered by strokes, whole hand interactions, or even multiple interventions from one or various users at a time, in contrast to their predecessors that were capable of detecting only a single finger *tap* gesture at a time.

The following sections further discuss multi-touch systems according to the technology used to implement them — computer vision-based, and sensor-based systems.

3.1.1.1 COMPUTER VISION-BASED SYSTEMS

Looking to enhance interaction beyond a single finger, in 1983 the first surface capable of detecting multi-touch events and sending them as input to a computer, is developed by Nimish Mehta for his Master's thesis, at the University of Toronto (B. Buxton, 2007; Saffer, 2008). This system was called "Flexible Machine Interface" and although it was not a touchscreen but rather a touch-surface, it was revolutionary in the sense that users were then able to make use of more than only one contact point, and ultimately offered a whole new set of possibilities for designing future touch-based interaction displays and gestures.

Still in 1983, another non-touchscreen system was developed and had a huge impact on our current touch-enabled mobile devices (B. Buxton, 2007; Saffer, 2008). This system, called "VIDEOPLACE" and developed by Myron Krueger and colleagues, made use of human body movement to control computer generated graphics, in what was designated as a "Responsive Environment" (Krueger, Gionfriddo, & Hinrichsen, 1985). The library of gestures that was used in this project was later widely adopted by touch-display designers, and we can still recognise some of its gestures on smartphones today. Such examples may be the *pinch* and *spread* gestures used to resize digital objects (Museum of Natural History, 1988).

Later, in 1991, Pierre Wellner adopted an augmented-reality approach to touch-displays (B. Buxton, 2007) and proposes a Ubicomp (Ubiquitous Computing) project that transforms an ordinary workstation desk into a 'touch-sensitive' desk display — the "DigitalDesk". In a paper submitted to CHI'92 describing the system, Newman and Wellner state that *"instead of using the 'desktop metaphor' and electronic documents, we use the real desktop and real paper documents"* (Newman & Wellner, 1992). They do this by projecting the digital work environment onto a desk, and then receive input by tracking the users' fingers, hand positions, and gestures with a camera mounted above the workstation (Wellner, 1991). The library of gestures used in this project include some that are still very familiar to us, such as the *drag, pinch* and *spread* gestures which we use on a daily basis to operate our smartphones.

Around the same time, a similar project was developed by Ishii and Miyake (1991) in Japan, but their aim was to create a CSCW (Computer Supported Collaborative Work) project that included a digital shared workspace for supporting "dynamic collaboration in a work group or over space and time constraints" (Ishii & Miyake, 1991) instead of an individual workstation such as the one proposed by Newman and Wellner (1992).

Still in the domains of CSCW and Ubicomp, Matsushita and Rekimoto (1997) present the *Halowall*. The *Halowall* explored the potential of using a workspace's walls as interactive displays that could be operated without the use of any special pointing devices. The system was composed by a glass wall with a rear-projection sheet behind it, a projector behind the wall to display images on it, a series of infrared lights (LEDs) and a camera with an infrared filter. The *Halowall* was capable of detecting multiple finger, whole hand or body touches as well as other physical objects (Matsushita & Rekimoto, 1997).

Later, in 2005, Jef Han presents the first low cost multi-touch technique and is based on a technique called Frustrated Total Internal Reflection (FTIR). The interface is rear-projected upon the touch-surface. The main advantage of this system is its scalability, allowing the construction of very large touch displays at a relatively low cost. While a disadvantage could be that sensing depends on the optical properties of the object in contact with the surface, meaning that objects or styli might not be detected. Furthermore the author refers issues related to dry skin that provokes a deterioration in the system's ability to sense touch events; as well as the system's inability to distinguish between one or more users (Han, 2005).

In 2007, Microsoft unveils the Microsoft Surface 1.0. This large scale table is capable of supporting multi-touch and multi-user events and can also detect physical objects with identification tags placed on its surface (Microsoft News Center, 2007). The Microsoft Surface makes use of computer-vision techniques with a camera and rear-projection (B. Buxton, 2007) and is mainly targeted at hotels, retail establishments, restaurants and public spaces (Microsoft News Center, 2007).

In 2011 Microsoft in conjunction with Samsung released the Microsoft Surface 2.0 which substitutes the cameras used in the first version (B. Buxton, 2007) with PixelSense technology (Microsoft Surface, 2011a), in 10.16 cm thick display. PixelSense consists of adding an infra-red sensor to every set of RGB pixels in an LED display (Microsoft Surface, 2011b), "enabling vision-based interaction without the use of cameras" (Microsoft Surface, 2011a) and a significantly more compact setup than the first version that made use of a camera and rear-projector.

3.1.1.2 SENSOR-BASED SYSTEMS

The first true multi-touch display was created by Bob Boie at Bell Labs in 1984, and was a sensor-based system. The system consisted of a transparent array of capacitive touch sensors that were placed over a CRT monitor (B. Buxton, 2007). It was much like the touch-display developed in 1967 by Eric Johnson (Johnson, 1969), except this system was now capable of working with more than one touch event at a time.

In 1985 at the Carnegie Mellon University, Paul McAvinney developed a touchscreen called the "Sensor Frames" which consisted of a box, containing four optical sensors, that was then fixed onto a common computer screen. This system was capable of detecting up to three fingers at a time (B. Buxton, 2007), although some issues arise when fingers blocked each other from some of the sensors' points of view (NASA, 1990).

At this point, Ben Shneiderman was exploring applications for high precision touchscreens, and found that this mode of interaction was often experienced as "fun" and appealing to users, while still being as efficient as the GUI (B. Shneiderman, 1991). In parallel, many experiments were being made to compare traditional forms of input, such as the keyboard or mouse versus the touchscreen (Sears et al., 1990). Most studies found that tasks involving target acquisition were faster with touchscreens than with other devices, but also more prone to errors (Sears et al., 1990). Still, studies showed that users preferred touchscreens when text entry tasks were not involved, finding these tasks easier to accomplish with a traditional keyboard than on a soft keyboard (Karat, McDonald, & Anderson, 1986). The difficulties of typing rapidly and efficiently on a soft-keyboard, as well as the high costs involved in manufacturing such systems, may explain why touchscreens took a long time to become widely adopted by the general public, and may also justify the poor market success of the first smartphone.

In 1993, IBM and Bell released what is considered to be the world's first smartphone –– *Simon* (B. Buxton, 2007; Microsoft Research, 2009). As noted in the 1993 press release titled *'Bellsouth, IBM unveil personal communicator phone'* (Access Intelligence, 1993), Simon was the first mobile phone equipped with a touchscreen and capable of many functions that are currently available on our own smartphones, such as wireless and email capabilities. Although it was a single input device and not very successful in commercial terms, Simon was ahead of its time and set the ground for all future smartphones (B. Buxton, 2007), such as the Apple iPhone.

The Diamond Touch (2001) is a multi-user touch table with a front-projected display. This table makes use of capacitive sensors to detect touch and can distinguish between different users. In addition it is unaffected by other objects placed on the surface (Dietz & Leigh, 2001). The Diamond Touch is able to recognise gestures such as *swipe, drag, pinch* and *spread* (Mitsubishi Electric Research Laboratories).

In 2002, a new capacitive sensing architecture called *SmartSkin* is proposed by Rekimoto (2002). The display is projected onto the touch surface, and unlike its predecessors, this technology allows the touch-sensitive surface to be flexible. "The surface does not need to be flat — i.e., virtually any physical surface can interactive" (Rekimoto, 2002). Additionally, this system supports multiple finger and hand gestures, and can also make use of hand postures to determine interaction (Rekimoto, 2002).

Although the RoomPlanner (2003) makes use of the previously mentioned Diamond Touch surface, it is included in this literature review because the authors present a detailed discussion and description of the hand and finger gestures adopted in the system (Wu & Balakrishnan, 2003). These range from single finger, multiple fingers, one hand and two hands gestures. Single finger gestures include *tap, drag, double-tap* and *flick*; multiple finger gestures are *pinch, spread* and *two-finger rotation* while whole hand gestures are dependent on hand postures such as a "flat hand", "vertical hand", "horizontal hand", "tilted horizontal hand", "two vertical hands" and "two corner-shaped hands" (Wu & Balakrishnan, 2003). As is understandable, whole hand gestures are not possible on small mobile touchscreens, but many of the single and multiple finger gestures are the same as those implemented on current smartphones.

The Apple iPhone appeared in 2007, and much like Simon it is a mobile phone with a touch-sensitive display (B. Buxton, 2007). The iPhone makes use of gestures such as the *pinch* and *spread*, *tap, flick, swipe, pan* and *drag* (Apple, 2012); and since 2007 many other mobile phone manufactures have adopted touchscreens, such as HTC, Samsung and LG. In 2007 and 2010 Apple launched another two touchscreen devices — the iPod Touch (Apple, 2007) and the iPad (Apple, 2010).

In the following sections we discuss several efforts regarding creation of user-defined gestures for interaction with touchscreens, as well as the potential benefits and disadvantages of this interaction paradigm for older adults.

3.2 INVESTIGATION OF USER-DEFINED GESTURES

As discussed, most of the touch-surfaces described above made use of a set of gestures that are still those being implemented on current touchscreen devices. Our review of the literature suggests that these gestures were defined and developed by the designers of such systems without any feedback from users (Rico & Brewster, 2010; Wobbrock, Morris, & Wilson, 2009). Meaning that when developing these gestures, systems' designers may have been more concerned with the systems' recognition of such gestures, rather than in the end-usability of gestures. This indicates that further investigation into multi-touch gestures is needed.

Likewise, several efforts have been conducted into investigating gesture performance and users. In 2002, Beringer performed an investigation with 38 subjects with the goal of discovering which gestures and voice commands are performed by users interacting with the *SmartKom* interface. The results showed that the most broadly performed gestures were those of pointing, although some circling or free gestures were also performed (Beringer, 2002).

Voida, Podlaseck, Kjeldsen et al., (2005) compared typical gestures used in Augmented Reality (AR) environments with the manipulation of digital artefacts on a 2D touch-surface. Much like Beringer (2002), they found that pointing and direct-touch gestures were overall the most performed by the participants (Voida, Podlaseck, Kjeldsen, & Pinhanez, 2005).

In 2006, Lui, Pinelle, Sallam et al., conducted a study to evaluate rotation and translation techniques on touch-surfaces. In order to better design a gesture or set of gestures for this procedure they observe users interacting with sheets of paper on a real-world desktop. The authors found that most users performed the rotation and translation tasks simultaneously, unlike most touch interfaces which only allow for one task at a time (Liu, Pinelle, Sallam, Subramanian, & Gutwin, 2006).

In 2009, Wobbrock, Morris and Wilson conducted a study to investigate a set of user-defined gestures. The study was conducted with 20 non-technical persons using the Microsoft Surface. In order to elicit gestures from the participants a "guessability study methodology" was employed, and consists of firstly showing the effect/outcome of a gesture to the participants and then asking them to perform its cause. As a result, the authors propose a gesture-set for surface computing based in their findings (Wobbrock et al., 2009).

As stated by Mauney, Howarth, Wirtanen and Capra (2010), the International Usability Partners conducted a study to evaluate cultural differences and similarities in the definition of gestures for small, handheld touchscreen devices. In a similar form to Wobbrock, Morris and Wilson (2009), the participants were shown the effect/outcome of a gesture and asked to perform its cause, although in this study low-fidelity paper prototypes were used instead of a touchscreen. Participants were asked to perform gestures for 28 common tasks such as *zoom, copy and multi-select*. Their main findings were the following: (1) overall there is a high level of agreement in gesture definition across cultures; (2) previous touchscreen experience influenced the gestures that were performed for the *back, forward, scroll up* and *scroll down* actions; (3) when a gesture for an action was not immediately identifiable, participants would perform a *tap* on the screen to show a menu; (4) lastly, agreement scores were higher for direct manipulation gestures rather than symbolic gestures (Mauney, Howarth, Wirtanen, & Capra, 2010).

More recently, Ruiz, Li and Lank (2011) investigated user-defined motion gestures for smartphones. Unlike the research previously discussed which focusses on gestures performed on 2D surfaces, the gestures elicited from users in this study involve the manipulation of a smartphone within the users' 3D environment. The authors found that consensus exists between users in mapping gestures to certain commands and therefore propose a user-defined gesture set for motion gestures on smartphones. This gesture set defines gestures for actions such as *Voice Search, Home Screen, Next, Previous, Zoom-in, Zoom-out, Pan Up, Pan Left, Pan Down* and *Pan Right* (Ruiz, Li, & Lank, 2011).

However, to our knowledge, research concerning older adults and the definition of gestures is yet to be conducted. Since currently adopted gestures were defined by system designers without end-user input there is no way of accurately assuming that these gestures will be adequate for older adults and we therefore consider that further investigation is needed.

The following section further discusses research specifically regarding older adults and touch-based interaction.

3.3 POTENTIAL BENEFITS AND DISADVANTAGES OF TOUCHSCREEN INTERACTION FOR OLDER ADULTS

Given the proliferation of previously mentioned touchscreen devices such as smartphones, it is important to understand how this technology is adopted and used by older adults. Touchscreen interfaces are believed to provide an easy to learn, and quick to use form of interaction (Loureiro & Rodrigues, 2011; Sears et al., 1990; Wigdor & Wixon, 2011; Wolf, 1986) even for populations such as older adults (Hollinworth, 2009; Loureiro & Rodrigues, 2011; Stößel, Wandke, & Blessing, 2010) who might not be technologically proficient (Broady, Chan, & Caputi, 2010).

On the other hand, several authors argue that touchscreen interaction might not be as intuitive, or natural as has been believed until this point (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010). Norman (2010) points out that one of the main advantages of the GUI was the visibility of menus and icons, and therefore all possible actions. This made the system easily explorable and learnability was enhanced, in other words the users' ability to browse all available options made the system discoverable, easier to use, and learn. However, with touchscreen interfaces users do not know what gestures a system potentially supports, nor the options that are available to them (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010).

In order to assess the adequacy of touch-based interaction for older adults, several studies have been conducted to investigate interaction differences between traditional indirect input devices (e.g., mouse and trackball) versus direct input devices (e.g., touchscreen and light pen). Rogers, Fisk, McLaughlin et al., (2005) compared a rotary encoder input device (indirect) and a touchscreen (direct) with both a younger and an older group of users. They found that the touchscreen was better for discrete pointing and selection, or ballistic movement tasks while the indirect device was preferable for more repetitive tasks. Furthermore, the individual variability between older adults' performance in the touchscreen condition was high, meaning that in a large population more users might have difficulty using the touchscreen device rather than the rotary encoder (Rogers, Fisk, McLaughlin, & Pak, 2005). Contrastingly, Charness et al. (2004) found that the use of a light pen (direct) significantly reduced age-related differences in a target acquisition task and provided better results for novel use situations. Similarly, Murata (2005) found no age-related difference in target acquisition times on a touch surface, but also observed that in the case of the indirect input device (mouse) older adults were significantly slower (Murata & Iwase, 2005). Additionally, a study conducted with 32 japanese seniors showed that attitudes toward computers improved significantly for the group in the touchscreen condition rather than the group using a traditional keyboard setup (Umemuro, 2004).

In addition, specific research efforts have explored the performance of gestures on touchscreens (Stößel, Wandke, & Blessing, 2009; Stößel et al., 2010), as well as, touch target sizes and spacing sizes between targets for older adults. Stößel, Wandke and Blessing (2009; 2010) performed two studies in which participants where asked to perform a gesture by retracing the arrow displayed on the screen with their finger. They found that older adults are slower at performing gestures but are not less accurate than their younger counterparts and therefore are capable of interacting with both mobile (Stößel et al., 2009) and fixed touchscreen devices (Stößel et al., 2010). Although these studies do not answer the gesture discoverability issues pointed out by (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010), they reveal that older adults are physically capable of performing gestures independently of cognitive and psychomotor age-related changes. Regarding target and spacing sizes, Kobayashi, Hiyama, Miura, et al., (2011) investigated target sizes for *tap* gestures on mobile touchscreen devices but considered only three different targets sizes for individual targets with no neighbours (Kobayashi et al., 2011). Jin, Plocher and Kiff (2007) also conducted a study to evaluate touch target sizes for older adults, considering six different target sizes for both adjacent and non-adjacent targets, as well as five spacing sizes for adjacent targets. Although their study investigated *tap* gestures and target dimensions for older adults, it was conducted using a 17-inch touchscreen tablet fixed on a stand and presented at a 45º angle to the participants (Jin, Plocher, & Kiff, 2007), therefore, these results are not directly applicable to mobile devices such as smartphones which are the focus of this work. Generally, large touch surfaces have been considered as the most appropriate for older adults (Loureiro & Rodrigues, 2011) and could explain why mobile devices have received few attention up until this point.

In 2010, an exploratory study of a touch-based interface for older adults revealed that gestures such as *tap* and *flick* were easily understood and performed, while the *drag* gesture was more confusing and harder to perform. Some additional findings were: (1) *tapping* on the background (instead of on an object) to perform an action was generally not understood and should be avoided, (2) the same object should not respond to both *tap* and drag gestures as a slight error in gesture performance might confuse the system and the user; (3) for drag gestures a "natural version" is proposed, were if an object is released it should stay in the same position and not return to its initial state; (4) iconic gestures were very engaging; and (5) time setting for gestures is of paramount importance (e.g., time constraints for *tap* versus a *tap and hold*).

Moreover, touchscreens have been receiving increasing attention for the development of applications related to health and wellness (Annett et al., 2009; Buiza et al., 2009; Gamberini et al., 2006; Paggetti & Tamburini, 2005), safety and security (Calvo-Palomino, de las Heras-Quirós, Santos-Cadenas, Román-López, & Izquierdo-Cortázar, 2009; Hansen, Eklund, Sprinkle, Bajcsy, & Sastry, 2005; Maged et al., 2007; Scanaill, Ahearne, & Lyons, 2006; Frank Sposaro, Danielson, & Tyson, 2010; F. Sposaro & Tyson, 2009), as well as, social interaction and entertainment for older adults (Apted, Kay, & Quigley, 2006; Plaza, Martín, Martin, & Medrano, 2011; Tsai, Chang, Chang, & Huang, 2012).

Given the number of application being developed specifically for mobile devices or for these devices in interaction with larger systems, it is clear that further research is needed regarding the usability of mobile touchscreens for older adults. As these applications will not be of use if their users are not able to easily operate them. Additionally, to our knowledge the usability of mobile touchscreen devices has not been greatly explored for this specific target audience.

In sum, older adults performance of mobile touchscreen gestures when such gestures are explicitly shown seems to be acceptable (Stößel et al., 2009, 2010). However as (Bau & Mackay, 2008; Bragdon et al., 2010; Norman, 2010) refer, gesture discoverability might still be an issue and to our knowledge no research has been conducted to investigate the mapping between performed gestures and actions for older adults as has been done for other user populations (see Section 3.2).

4 DESIGN PATTERNS AND OLDER ADULTS

4.1 HISTORY OF DESIGN PATTERNS

A design pattern is a form of documenting validated, and in-context, knowledge regarding a certain area of expertise, and a design pattern language is a form of organising those patterns in a purposeful way. They can be compared to other approaches such as guidelines, heuristics, and claims.

The idea of a pattern language is born with Christopher Alexander and his colleagues when they decide to create one for architecture, (Alexander, Ishikawa, & Silverstein, 1977) with the intention of improving the design and construction of architectural spaces for their future inhabitants. Primarily, the authors were unhappy with the course that modern architecture was taking at the time, stating that is was growing further away from the final users' characteristics and needs. So they decided to observe architectural spaces where people seemed "comfortable" or "alive". They stated that these places all had "a quality without a name", and that they were unable to name this quality accurately but could sense it, and observe it, when it existed. Alexander compared this quality with several adjectives such as "alive", "whole", "free", "exact", "comfortable" in an attempt to fully characterise it, but felt that none of these words could entirely define the "quality without a name" (Alexander, 1979).

From observing the places thought to possess such a quality, they compiled a language of 253 patterns in an attempt to capture the invariant characteristics that make these places good examples (Alexander et al., 1977).

"Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice" (Alexander et al., 1977, x).

Furthermore, the authors' intention was that these patterns not only be used by other architects, but also, and above all by laymen to construct their own towns, neighbourhoods and homes (Alexander et al., 1977, x). In order to achieve this, they state that patterns and pattern languages should be written in clear and non-technical language with the objective of making them understandable to all, and thus empowering the end-user.

Every pattern is written in clear and simple language, and every pattern follows the same structure which is outlined by the authors as: each pattern begins with (1) a photograph of a real-world example of that pattern, then (2) an introductory paragraph sets context and explains how a particular pattern is related to the ones above it in the language, after which the central part of the pattern is marked by three diamonds and is followed by (3) a short headline that states the problem, after the headline comes (4) a more detailed discussion of the problem, its empirical background and competing forces, then (5) the solution is presented and stated in the form of an instruction and followed by (6) a diagram of the solution which is in turn separated by another three diamonds from (7) a final paragraph pointing to other smaller but related patterns (Alexander et al., 1977, x).

This structure allows for a networked organisation of the pattern language, where each pattern is connected to other related and larger patterns within the language, as well as other smaller patterns. Essentially, each pattern helps complete the ones above it (larger patterns) and is completed by the ones below it (smaller patterns) (Alexander et al., 1977, xii). This interconnectedness provides the pattern language with generativity, meaning that it steers readers throughout the patterns by leading them step-by-step from larger and more generalised problems to more specific details and issues. Thus, generating the readers' path as they work along the design process (Alexander, 1999). For example, if the pattern "THE DISTRIBUTION OF TOWNS" is chosen as a starting point, then "COUNTRY TOWNS", followed by "COMMUNITY OF 7000", other patterns that were linked to the initial one, but are not directly relevant to the design problem, will be excluded from the readers' path, such as "AGRICULTURAL VALLEYS" or "COUNTRY SIDE" (Alexander et al., 1977).

4.1.1 DESIGN PATTERNS IN SOFTWARE ENGINEERING

The concept of a pattern language was later adopted in object-oriented software (Beck & Cunningham, 1987, Gamma et al. 1995). At the OOPSLA'87 (Object-Oriented Programming, Systems, Languages & Applications), based on Alexander's idea of patterns, K.Beck & W.Cunningham (1987) describe an experiment in which they present a set of five patterns, for designing Smalltalk windows, to a group of application specialists without prior knowledge of Smalltalk. Their results demonstrated that the group of inexperienced participants were successfully able to design their own interfaces within a short period of time, proving the usefulness of patterns as a form of documenting and disseminating domain-specific knowledge. Moreover, the authors present a definition of pattern languages as a tool that *"guides a designer by providing workable solutions to all of the problems known to arise in the course of design. It is a sequence of bits of knowledge written in a style and arranged in an order which leads a designer to ask (and answer) the right questions at the right time"* (Beck & Cunningham, 1987), which is in accordance with the concept of generativity outlined in the work of Alexander et al. (1977, xii)

In 1995, Eric Gamma and colleagues publish a book that is considered to be the most influential work regarding pattern languages in software engineering — "Design Patterns: Elements of Reusable Object-Oriented Software". The authors state that their *"goal is to capture design experience in a form that people can use effectively. To this end we have documented some of the most important design patterns and present them as a catalog"* (Gamma, Helm, Johnson, & Vlissides, 1995, 2), stating that none of these patterns are new knowledge but rather proven solutions to specific problems. In addition, the patterns presented in this book follow a different structure than that proposed by Alexander et al., (1977), where each one is composed by (1) a name that describes the design problem in a few words; (2) a statement of the problem and its context which describes when the pattern should be applied; (3) the solution that presents a set of "relationships, responsibilities, and collaborations" that make up the design; and (4) the consequences that are the costs and benefits of applying a specific pattern (Gamma et al., 1995, 3).

However, in Alexander's keynote presentation at the OOPSLA'96 he points out that pattern languages in software engineering had neglected the moral component of pattern languages. He means this in the sense that in architecture, the intention was to provide better, more "alive" or "comfortable" environments and consequently improve peoples' lives; however, in software engineering patterns seem to have been used with the sole purpose of making programs more efficient, without regarding how this would impact the end-users (Alexander, 1999). Moreover, a few other authors have criticised the form in which patterns were adopted by the software engineering community. Jennifer Tidwell (1999) states that although the book published by Gamma and colleagues was useful for software developers, it alienated Alexander's original concept of bringing users closer to the construction of the products that they will ultimately use (Tidwell, 1999b); while, Jan Borchers (2000) states that these patterns could not be considered patterns because they were not written in a language that could be readily understood by experts and non-experts alike (J. Borchers, 2000).

4.1.2 DESIGN PATTERNS IN HUMAN-COMPUTER INTERACTION

Reflecting on Alexander's ideal of bringing architecture and construction closer to the inhabitants, reminds us of the principles of User-Centred Design (D. A. Norman & Draper, 1986) and Participatory design (Muller & Kuhn, 1993) within Human-Computer Interaction (HCI).

Mentions of Alexander's design patterns in HCI appear as early as 1986, in Norman and Draper's *"User Centered System Design: New Perspectives on Human-computer Interaction"* (D. A. Norman & Draper, 1986), Norman's "The Psychology of Everyday Things" (D. Norman, 1988), and even the "Macintosh Human Interface Guidelines" (Apple Computer, 1992), although they do not discuss how the idea of patterns could be applied to the domain of HCI.

The first true effort in adopting design patterns into HCI practice occurs in 1994, when the Utrecht School of Arts presents design patterns as part of their interaction design curriculum (Barfield et al., 1994), referring that *"Alexander's patterns may even be more applicable to interactive systems than they are to buildings, since interactive systems literally have behaviours inside them (manifest system behaviours as well as evoked user behaviours)"*.

Three years later, at the CHI'97 (Computer-Human Interaction) conference — one of the biggest world-wide HCI conferences — a workshop is held with the stated purposes of (Bayle et al., 1998): (1) finding out if design patterns were in effect being created and used within the HCI community, (2) sharing design pattern knowledge between participants in order to further each others' knowledge of design patterns, and (3) finding out how design patterns could adapt and continue to be developed within HCI practice. Here, one of the main findings were that design patterns could be divided into two categories, the first would be called "Activity patterns" which describe events, behaviours or actions that occur repeatedly in a certain context — they describe activities but do not provide explanations for them; and the second category would be that of "Design patterns" that delineate a proven solution for a given recurring design problem (Bayle et al., 1998). These two definitions are in many ways parallel to those presented by Alexander as "patterns of events" and "patterns of space" (Alexander, 1979), although within HCI only the "Design patterns" seem to have gained wide acceptance.

Moreover, during the CHI'97 workshop, it was discovered that patterns were used and understood in different ways within the HCI community (Bayle et al., 1998): (1) the first was the use of patterns a tool to capture and describe the main characteristics of a place, situation, or event in a context-sensitive way; (2) the second to generalise across various situations but maintain a certain level of concreteness; next, (3) to prescribe or provide guidance for HCI practitioners, much in the same way as guidelines; (4) to constitute a rhetoric that can provide a common language for the community to discuss a certain domain of expertise, since they capture knowledge from everyday situations and are written in non-expert language; and lastly, (5) to predict the consequences of changing certain characteristics of an interface, since the user can follow different pattern ramifications and overview the changes caused by opting for one pattern over another (Bayle et al., 1998).

A year later, the first comprehensive pattern language for interface design was published by Jennifer Tidwell (1998) – *"Common Ground: A Pattern Language for Human-Computer Interface Design",* even though the author considered the language to be a work-in-progress, since some patterns were still missing and others still required further revision. In this document, besides presenting an extensive set of patterns for general interface design, Tidwell describes the benefits she sees in constructing a pattern language for interface design. Those benefits are described as their ability to: (1) capture collective interface design knowledge that can be readily used by domain experts or novices; (2) provide a common language to discuss interface design with fellow colleagues, with experts from other knowledge domains, with customers, and with participatory design teams; (3) supply space to "think outside the toolkit" by adapting existing patterns to new problems; (4) help designers keep focus on essential interface values; and (5) express design invariants that can be encoded into the software (Tidwell, 1999a).

This first pattern language for interface design was a predecessor for the book "Designing Interfaces: Patterns for Effective Interaction Design" (Tidwell, 2005), published seven years later. The patterns included in the book cover the design of desktop applications, Web applications, interactive websites, software for mobile devices or other consumer electronics, turnkey systems, and operating systems (Tidwell, 2005). Since then, a second edition has been published with a series of additional chapters more focused on interface design for the Web, for social media, and for mobile devices (Tidwell, 2010).

A few years after Tidwell's first pattern language, Jan Borchers (2001) published a set of three pattern languages for interactive music exhibits, as well as a comprehensive review and discussion of design pattern languages. The author derives his patterns from previous experience in developing interactive systems and divides the three languages as follows: the first is an application domain pattern language for blues music capturing "important aspects of the musical knowledge of an experienced blues player", the second and largest of the three languages describes successful interface design solutions for interactive exhibits, and the third concerns itself with the software design of such systems (Jan Borchers, 2001). These patterns demonstrate the usefulness of design patterns as a *lingua franca* for HCI (Erickson, 2000), which facilitates communication between experts from different knowledge domains working on the same project.

In 2002, Duyne, Landay and Hong publish a pattern language for the design of websites. The authors decided to develop this language after observing people solving the same design problem over and over, and state that their patterns analyse the solutions to such recurring issues (Van Duyne, Landay, & Hong, 2003). In 2011, the second edition was published (Van Duyne, Landay, & Hong, 2007).

A year later, Laakso (2003) developed an interface design pattern language for teaching various design courses at the University of Helsinki. The authors state that this pattern language is not limited to concepts related to the design of traditional GUIs but rather to the issues related to developing a good design (Laakso, 2003). The patterns presented in their document do not follow Alexander's structure, but rather try to *"emphasise the most interesting findings of each pattern"* (Laakso, 2003). Unlike the previously referred languages, this one is relatively small, encompassing around 20 individual design patterns. Additionally, a few other authors have found patterns to be a useful tool in pedagogical settings (Jan Borchers, 2002; Carvalhais, 2008; Koukouletsos, Khazaei, Dearden, & Ozcan, 2009).

Still regarding Web interfaces, Ian Graham (2003) published a pattern language focussed on Web usability — "A pattern language for Web usability" (Graham, 2003). It contains 79 patterns woven into a pattern language and cover topics such as: usability, content, navigation and aesthetics. Unlike Alexandrian patterns, this book includes both good examples and bad examples (called anti-patterns (Long, 2001)) in each pattern.

A number of patterns aimed at Web interfaces have also been published online. Such as the "Yahoo! Design Pattern Library" (Yahoo!, 2012) and Patterns in Interaction Design (Van Welie, 2008).

More recently, patterns have started to be developed exclusively for mobile devices, such as smartphones and tablets. This could be due to the fact that smartphone market share in Europe grew from 31% (2010) to 44% (2011) in Europe, and in the US from 27% (2010) to 41.8% (2011) (comScore, 2012). Examples of this recent trend are the books *"Designing Mobile Interfaces"* (Hoober & Berkman, 2011) and *"Mobile Design Pattern Gallery"* (Neil, 2012), both of which present collections of design patterns for mobile interfaces. The first is a more complete language while the second is more accurately considered as a collection or gallery.

Additionally, Dan Saffer developed a pattern language for gestural interfaces (Saffer, 2008). Although not specifically directed at smartphones, this patterns language documents gestures employed in a wide variety of touch-surfaces.

Finally, although platform specific guidelines continue to be published, such as the iOS Human Interface Guidelines (Apple, 2010), the Android User Interface Guidelines (Android), Android Design (Android, 2012), or the User Experience Guidelines for Windows (Microsoft, 2012), third-party developers and designers have started to publish online pattern languages for mobile platforms. Despite some of these languages[1] still being immature or incomplete when compared to the official guidelines, they are a starting point in adopting patterns and pattern languages for mobile interface design.

4.2 DESIGN PATTERN FORMAT

Most of the pattern languages presented above follow their own structure, but still maintain elements in common with Alexander et al. (1977). We will now present a more detailed explanation of the components present in the original pattern format, which was later also reused by Borchers (2001).

All of the patterns found in "A Pattern Language: Towns, Buildings, Construction" (Alexander et al., 1977) follow the same structure, where each has (1) a name which is an essential element to identify the pattern, and should be short, and easy to remember (Jan Borchers, 2001), (2) the pattern ranking which can go from zero to three asterisks, and represents the level of confidence the author deposits in a particular pattern (Jan Borchers, 2001), (3) a picture which is intended to show ideal example of that pattern (Alexander et al., 1977), (4) an introductory paragraph that sets context for the current pattern, by linking it to other larger patterns, (5) a problem statement which addresses the issue that needs to be resolved, (6) the problem description that provides the problem's empirical background,

1 http://www.lovelyui.com/

http://www.androiduipatterns.com/p/android-ui-pattern-collection.html

http://pttrns.com

http://mobile-patterns.com/

http://androidpatterns.com/

examines the validity of a pattern, and discusses why one particular solution was chosen over another, (7) the solution statement, which presents a general solution to the problem at hand (Alexander et al., 1977; Jan Borchers, 2001), (8) a simple diagram of the solution, and lastly (9) references to other smaller patterns that help complete the current pattern (Alexander et al., 1977; Jan Borchers, 2001).

In the next section, we will discuss the strengths of design patterns, and then compare them to other forms of domain-specific knowledge documentation, such as guidelines, heuristics and claims.

4.3 ADVANTAGES OF DESIGN PATTERNS OVER OTHER FORMS OF HCI KNOWLEDGE DOCUMENTATION

A full understanding of interaction design pattern languages should be put into context with other approaches for the reuse of HCI knowledge, such as Guidelines, Claims and Heuristics. The following sections will present the main advantages of design patterns, and then compare them to other forms of domain-specific knowledge documentation.

4.3.1 ADVANTAGES OF DESIGN PATTERNS

Patterns as *lingua francas*. As Alexander and colleagues refer, patterns should be written in a clear and non-technical language. This is especially relevant when considering interface design where many persons from distinct knowledge domains — users, engineers, visual designers, marketing and administration personnel, etc — are involved in the design and development process. In this context, the non-technical nature of design patterns greatly facilitates communication between all involved parties in the design and development processes (Erickson, 2000). Most importantly, they provide a common language for which to discuss a project with all involved parties.

Various levels of abstraction. A pattern language usually organises its patterns in a hierarchical form, beginning with the broader patterns toward the most specific ones. The different scope of the patterns results in several levels of abstraction within the same language, where the large-scale ones are generally more abstract in nature and the small-scale ones are more detailed and concrete. Patterns can therefore be used to describe problems of several dimensions (Nilsson, 2009, 5).

Context and generative nature. A pattern provides a solution within a certain context. It is part of a broader pattern language where it supports larger patterns than itself and is supported by smaller ones, and therefore provides the reader with necessary contextual information as to its position in the design process. When browsing a pattern language, there will be many patterns that do not apply to the problem at hand, however if designers follow the sequential and interconnected nature of the language they will be led from pattern-to-pattern in a meaningful and relevant way (Alexander et al., 1977, xii).

Design rationale. A pattern includes not only problem and solution statements but also the underlying rationale of the choices made to arrive at a given solution. This allows readers to access further understanding of the applicability of the pattern to problem at hand, as well as the trade-offs associated with implementing the solution. Furthermore, patterns tend to include references to other relevant literature within the context of each pattern, allowing the reader to pursue a more detailed perception of its underlying issues (Abraham & Atwood, 2009).

Examples. Patterns are generally complemented with real-world examples of their successful implementation. Most of these examples are of visual nature — drawings, photographs, diagrams, etc., — and contribute to further reinforce the validity of a pattern (Welie, Veer, & Eliëns, 2000).

Teaching and learning. Given the contextual nature of patterns, their provision of an empirical background and design rationale, many authors have considered them to be a powerful teaching and learning tool. Borchers (2002) found that the use of design patterns in two different university courses (1) lead students to retain an above average amount of design principles, and (2) that students found them useful to document their own design experience (Jan Borchers, 2002). In a more recent study, comparing the use of guidelines and claims in teaching Web interaction design, it was found that patterns generally lead to better performance for novice designers (Koukouletsos et al., 2009).

4.3.2 GUIDELINES VS. PATTERNS

Guidelines are a traditional approach for capturing and summarising effective HCI practice in constructing good human-computer interfaces (Cowley & Wesson, 2005; Koukouletsos et al., 2009; Molich & Nielsen, 1990). Although, throughout time, many inadequacies have been found in using guidelines to effectively design interfaces:

- The length and structure of these documents where "the work of locating relevant guidelines is not considered worth the effort" (Mahemoff & Johnston, 1998; Molich & Nielsen, 1990). As opposed to the networked and sequential organisation of pattern languages, where readers are navigated through a path of relevant patterns.
- Guidelines tend to be too generalist in an attempt to be applicable to a wide range of situations (A. G. Sutcliffe & Carroll, 1999). This makes them ill-suited for specific design problems but useful to ensure consistency within a brand, company or user group (Griffiths & Pemberton, 2000; Mahemoff & Johnston, 1998).
- Given their effort towards universal applicability, guidelines are very open to misinterpretation, especially when concerning inexperienced designers (Cowley & Wesson, 2005; Mahemoff & Johnston, 1998; A. G. Sutcliffe & Carroll, 1999).
- The technical jargon often included in guidelines excludes potential users from actively participating in the design of a product (Griffiths & Pemberton, 2000).

4.3.3 HEURISTICS VS. PATTERNS

Heuristics are more general principles that are not intended to be strictly accurate or reliable in every situation (Nielsen, 2005). They are rather broad guides, that lead the evaluator's judgment through a set of important factors to be considered, and are consequently broader and more abstract than design patterns. Heuristics provide a kind of quick checklist, where design advice is summarised and easily assimilated by practitioners (Dix, 2004). Contrary to design patterns, heuristics do not provide a contextualization of the problem, nor the rationale behind a chosen solution, they are instead broad guides that help practitioners take into account a set of fundamental rules. Consequently, given their unspecific nature, lack of contextualization and rationale, heuristics may be more open to misinterpretation than design patterns.

4.3.4 CLAIMS VS. PATTERNS

Claims are arguably very similar to patterns, in the sense that both patterns and claims can address larger scale issues than guidelines, they both include examples of specific implemented systems and both rely on cross-referencing between patterns or claims (Dearden & Finlay, 2006). Although, they ultimately differ in many core components (Abraham & Atwood, 2009):

Claims are solution-driven while patterns, besides providing a solution, also present the problems' empirical background, competing forces and overall context (Chung et al., 2004) making them more problem-driven. As a matter of fact, claims do not include a clear statement of the problem (Abraham & Atwood, 2009; Dearden & Finlay, 2006) but are rather the result of a specific artefact's usage scenario from which the problem can be inferred (Abraham & Atwood, 2009; A. G. Sutcliffe & Carroll, 1999).

Claims define context based on a particular usage scenario, while patterns describe various characteristics that can be included in a diverse range of possible contexts (Abraham & Atwood, 2009; Jan Borchers, 2001; A. G. Sutcliffe & Carroll, 1999). Typically, patterns are a solution to a problem within a broader context or set of situations (Abraham & Atwood, 2009; A. G. Sutcliffe & Carroll, 1999), while claims tend to present one solution tied into a single usage scenario (Dearden & Finlay, 2006; A. G. Sutcliffe & Carroll, 1999).

Both forms of knowledge documentation further differ in the form in which they present the rational behind a certain design solution. Where claims focus on both the negative and positives aspects of a given solution, patterns tend to reinforce the positive outcomes both in the rationale and through provided examples (Abraham & Atwood, 2009).

Finally, a few shortcomings have also been identified in the use of design patterns. According to Seffah (2010), the main disadvantages of design patterns are the following: (1) no universally accepted taxonomy exists for HCI patterns, (2) relationships between patterns in existing languages are often incomplete, or not "context-oriented", (3) the lack of tools to support designers and developers involved in UI design, as well as lack of tools that document how patterns are "discovered, validated, used and perceived", and lastly the existing need for automated tools to support the "usage of patterns as prototyping artefacts and building blocks" (Seffah, 2010).

Considering the literature review, and the stated advantages of design patterns over guidelines, claims, and heuristics, we believe that design patterns are the best choice for our work. Design patterns are more comprehensive than guidelines and heuristics, while also being applicable to a wider set of contexts than claims. In our opinion they combine the best aspects of both ends of the spectrum by providing examples, context and a clear explanation of the problem and respective solution. They provide the reader with more information, which in turn provides better design guidance than guidelines or heuristics, while not being overly specific to a certain artefact or situation.

4.4 THE POTENTIAL OF DESIGN PATTERNS WHEN DEVELOPING FOR SENIORS

Given the characteristics of design patterns, guidelines, heuristics and claims discussed in the previous section, we now refer to the perceived advantages of using design patterns when developing interfaces for older adults, as discussed by Mary Zajicek (2004).

Firstly, although a large amount of research has been conducted regarding older adults and interface design, and findings have been documented in scientific publications, sorting through this information will potentially be extensively time consuming. As a result the compact but explanatory characteristics of design patterns could provide better guidance for both experienced and novice designers working with older adults, provided that they are based on previous knowledge of observation and experimentation with older adults (Zajicek, 2004).

Secondly, it is especially hard to include specific user-groups, such as older adults, in a user-centred design process (Zajicek, 2004), and it is therefore essential for designers to have access to detailed information regarding interface design solutions. Consequently, the ability to share this information with the HCI community is of paramount importance, and patterns have proven to be a successful means for doing so (Jan Borchers, 2001; Fincher, 1999; A. Sutcliffe, 2000).

Finally, given the nature of design patterns which include not only a solution but a detailed discussion of the problem and its context, it is generally believed that they constitute a powerful teaching and learning tool (Jan Borchers, 2002; Carvalhais, 2008; Koukouletsos et al., 2009) and are therefore more useful to inexperienced designers or designers who have never worked with older adults, than other forms of knowledge documentation, such as guidelines or heuristics.

In sum, adequate design guidance is especially important when developing interfaces for older adults. Not only because this user-group is harder to access and include in a typical user-centred design process, but also because their needs and expectations are less homogenous, when compared to a younger group of users (Zajicek, 2006). Furthermore, due to the age-related dynamic diversity (Gregor, Newell, & Zajicek, 2000) of cognitive, motor and sensory capabilities (Zajicek, 2004), it is harder for the designer, whom is generally not an older adult, to understand their specific needs. For all these reasons, design patterns can constitute an invaluable aid when designing for certain user-groups.

5 METHODOLOGY

In the previous three chapters, the literature review enhanced our understanding of (1) age-related phsychomotor, sensory and cognitive declines and their impact on interface design, (2) older adults main characteristics and their relationship with technology, of (3) the evolution of touchscreens, gesture based interaction, as well as the potential advantages and disadvantages of this interaction paradigm for older adults, and lastly of (4) design patterns, and their potential when developing interfaces for older adults.

We will now review the research questions and objectives outlined in Section 1.3, and detail the research methodology used to answer such questions. Regarding methodology, our work was divided into five distinct phases of research, where each phase was designed to answer a set of, or a single research question. The phases of our research and their respective mapping to the research questions was outlined in the following manner:

Phase one provides answers to the following questions:

> RQ1: Are current smartphone gestures easily discoverable for older adults?
>
> RQ2: Do older adults, without prior touchscreen experience perform the same gestures as those currently implemented by systems' designers? If not, which gestures do they perform?
>
> RQ3: What are the main characteristics of performed gestures, such as number of fingers and hands used?

Phase two aims to answer:

> RQ4: If current smartphone gestures prove to be problematic, and if older adults do not propose a set of user-defined gestures, can we effectively teach them how to use the current ones?

Phase three has the objective of answering:

> RQ5: Are recommended touch-target sizes, found in official guidelines, adequate for older adults performing *tap* and *swipe* gestures?
>
> RQ6: Are current recommendations regarding spacing sizes between touch-targets adequate for older adults performing *tap* and *swipe* gestures?

Phase four aims to provide answers for:

> RQ7: Are activity zones on smartphones the same for younger and older adults?

RQ8: In the particular case of *swipe*, does gesture orientation influence such activity zones?

And lastly, phase five intends to provide an answer to:

RQ9: Which is the best form of documenting the knowledge outcome of this research, in order to share it and make it readily available to practitioners involved in creating smartphone interfaces for older adults?

The following sections discuss the research and data analysis methods used in each of the above-mentioned five phases, in order to provide an overview of the methodology used in our work, and an understanding of how each phase relates to the following one.

PHASE ONE: EXPLORING USER DEFINED GESTURES FOR SMARTPHONES WITH OLDER ADULTS

Phase one aimed to explore the discoverability of current smartphone gestures, as well as the possibility of creating a novel user-defined gesture set with older adults. Accordingly, a review of the literature revealed that several authors have conducted research into user-defined gestures for a variety of situations (Beringer, 2002; Liu, Pinelle, Sallam, Subramanian, & Gutwin, 2006; Mauney, Howarth, Wirtanen, & Capra, 2010b; Ruiz, Li, & Lank, 2011; Voida, Podlaseck, Kjeldsen, & Pinhanez, 2005; Wobbrock, Morris, & Wilson, 2009)(see section 3.2 of this document for further detail).

For the purpose of our research, the method described in (Wobbrock et al., 2009) was adapted to be used on smartphones instead of the large Microsoft Surface. In this way, participants would view the animation on the smartphone itself, and then perform a gesture on that same device. Contrary to (Wobbrock et al., 2009), we did not employ auditory explanations of the tasks on the smartphone itself. Instead, the facilitator would explain tasks verbally. We opted for this solution as we could not account in advance for issues related to background noise in the retirement homes and day-care centres where the tests took place. Nor could we assess in advance any auditory complications that participants might have. In this context, a script was developed to ensure consistency across all sessions (Appendix A.1).

All sessions were video recorded for posterior analysis. Once the data was collected, we proceeded to analyse these recordings. In order to facilitate the process, we used The Observer XT[1] software. This software allowed us to view the videos and assign codes to the segments we found relevant. The codes were structured in the following manner:

1. Each code describes a gesture performed by a participant.
2. The name of the code is a literal description of the performed gesture.
3. Modifiers are associated to each code name in order to provide more specific details regarding each gesture. These modifiers were the following:
    - Participant ID;
    - Hand used to hold the device;
    - Fingers used to perform the gesture;
    - Area of the screen where the gesture was performed (e.g., on displayed item, on neutral space).

1 http://www.noldus.com/human-behavior-research/products/the-observer-xt/

4. Finally, a set of descriptive variables was assigned to each participant:
   - Age;
   - Gender;
   - Mobile phone ownership (e.g., owns or does not own a mobile phone);
   - Frequency of computer usage;
   - Touchscreen device ownership (e.g., owns or does not own a touchscreen device);
   - Observation of touchscreen being used (e.g., has or has not seen a touchscreen being used before).

All sessions were analysed and all performed gestures were documented according to the coding structure outlined above. The detailed results of all gestures performed, including the modifiers associated to each gesture can be found in Section 6.2.4.

Finally, once all gestures were classified, we proceeded to evaluate the consensus in gesture selection among participants for each task. The consensus was calculated according to the formula presented in (Wobbrock, Aung, Rothrock, & Myers, 2005), and the results can be found in Section 6.2.4.

PHASE TWO: TEACHING GESTURES TO USERS

The objective of phase two was to assess if we could effectively teach older adults how to use current smartphone gestures. A review of the literature revealed that when the correct teaching strategies are employed, that older adults are in fact able and interested in learning how to use new technologies (Broady, Chan, & Caputi, 2010; Czaja & Sharit, 1998)(see Section 2.4). Accordingly, we decided to try to teach older adults how to apply current smartphone gesture to the right tasks. In order to do so, we created a set on animated tutorials to show to participants. The need to introduce contextual tutorials to explain gestural interaction has been identified by several authors (Bau & Mackay, 2008; Bragdon et al., 2010; Kurtenbach, Moran, & Buxton, 1994). In this context, a tutorial was developed for each task, and can all be seen in Section 7.3. All tutorials were shown on the smartphone where participants would then solve the tasks. We chose to conduct all steps on the same device in order to better simulate the existence of contextual help mechanisms.

Similarly to phase one, a script was created (Appendix A.2) to ensure consistency among all sessions. In this script we would explain the test procedure to participants. Again, all sessions were video recorded for posterior analysis.

Once the data was collected, we reviewed all the videos of the sessions and classified them according to correct or incorrect gestures, that is: a gesture is correct if it matches the current smartphone one, or incorrect if it does not. In order to classify the gestures we used The Observer XT software, where we could code the segments of the videos where participants were performing either correct or incorrect gestures, for each of the tasks. All recordings were analysed and all performed gestures were coded according to the boolean criteria we defined. Detailed results according to each task can be found in Section 7.4.

Next, in order to compare the data gathered in this phase with that of the first phase we proceeded to recode the data from the first phase. Accordingly, we recoded the data in agreement with the criteria defined for this phase of testing — correct or incorrect gestures. This was done in order to allow us to compare the performance of correct or incorrect gestures without aid from tutorials (phase one), versus the performance of gestures with the aid of tutorials (phase two). A detailed comparison of the results is included in Section 7.4.

PHASE THREE: EVALUATING TOUCH-TARGET SIZES AND SPACING SIZES BETWEEN TARGETS

As previously stated, phase three aimed to answer research questions five and six, by investigating touch-target sizes and spacing sizes between targets. A review of the literature showed us that this subject has been extensively investigated for younger adults (see Section 8) (Colle & Hiszem, 2004; Henze, Rukzio, & Boll, 2011; Parhi, Karlson, & Bederson, 2006; Perry & Hourcade, 2008; Sun, Plocher, & Qu, 2007), but not for older adults. Furthermore, studies found regarding older adults were either not carried out on small touchscreen devices such as smartphones, but rather on larger, stationary surfaces (Jin, Plocher, & Kiff, 2007), or investigated only a small number of target sizes and no spacing sizes between targets (Kobayashi et al., 2011).

Accordingly, we found that further investigation was needed into target sizes and spacings on mobile touchscreen devices for older adults. Our first step was to define the range of target sizes to be tested, which we based on the average size of a human fingerpad (Dandekar, Raju, & Srinivasan, 2003) and defined five target sizes, and four spacing sizes between adjacent-targets + single-target condition as described in Section 8.3. In this way, our independent variables were target sizes and spacing sizes between targets. Each target size would be tested for all adjacent-target and single targets conditions, and all conditions were repeated three times per participant.

A within-subjects design was used, in which all participants would be exposed to all independent variables. Accordingly, as each target size and spacing sizes were tested three times, each participant would perform 5 (target sizes) x 5 (4 spacing sizes + single-target) = 75 *taps* and 75 *swipes*. The tests were designed in the form of two games — one for *tap* and one for *swipe* — which we thought would better motivate participants (see Section 8.3 for further detail on why we opted for using games in these tests). Finally, both games were run on an Android device (see Section 8.2 for further detail regarding the apparatus used).

In addition, a post-session questionnaire was completed by all users (the questionnaire is available in Appendix B.1), where our aim was to assess subjective preferences regarding target sizes, gesture preference, and levels of fatigue associated to each gesture (detailed responses can be seen in Section 8.4.3).

Finally, all data (with the exception of the questionnaire) was collected on the smartphone itself during the tests, thus avoiding the need to video record sessions. The data was then automatically imported into Microsoft Office Excel, by the use of a program developed at Fraunhofer Portugal AICOS running on Ruby on Rails. Finally, all data was analysed for statistical purposes with repeated measures ANOVAs (details of the results can be found in Section 8.4).

PHASE FOUR: EVALUATING ACTIVITY ZONES AND GESTURE ORIENTATION

A review of literature showed that activity zones on mobile touchscreen devices have indeed been evaluated with young adult users (Henze et al., 2011; Parhi et al., 2006; Perry & Hourcade, 2008; Saffer, 2011) (see Section 9 for further detail). However, to our knowledge activity zones on smartphones have not yet been assessed for older adult users.

Accordingly, we identified the need to evaluate this issue with older adults. In order to do so, our first step was to define grids on the smartphones display to test different onscreen locations for these targets. These grids were defined for both the *tap* and *swipe* targets and can be seen in Section 9.3. For *tap* we defined 28 grid locations, and for *swipe* 11 grid locations + 4 gesture orientations (e.g., left-to-right, right-to-left, top-to-bottom, and bottom-to-top) per participant. A within-subjects design was used, where all participants would test each grid position three times. Again, and given the high number of gesture repetitions per participant we decided to design tests in the form of two games that we thought would better motivate participants (see section 9.3 for further detail regarding the number of gesture repetitions and rationale behind the choice of games).

Similarly to the previous phase, all of the data (except for the questionnaire) was logged on the smartphone itself and later imported into Microsoft Office Excel. Later, all data was analysed for statistical purposes with repeated measures ANOVAs (details of the results can be found in Section 9.4).

PHASE FIVE: CREATING INTERACTION DESIGN PATTERNS FOR *TAP* AND S*WIPE* GESTURES FOR OLDER ADULTS

A review of the literature allowed us to choose the form of HCI knowledge documentation we felt would be more adequate for compiling the results of our work. Given the identified advantages of design patterns over guidelines, claims and heuristics (see Section 4.3 for further detail), we opted to document the recommendations resulting from our research in the form of interaction design patterns. These patterns can be found in Section 10.

As a result of the literature reviews we decided to adopt a pattern structure similar to that of (Alexander, Ishikawa, & Silverstein, 1977) and (Borchers, 2001) (see Section 4 for an overview of design patterns and authors in historical context). Next, we documented the main findings of our research according to this structure, and published them on a website (Section 10) with the purpose of making these patterns available to the community. Our main objective was that the outcome of this research would be readily available to the community, and could therefore be employed by practitioners when designing interfaces for older adults.

Having outlined the research methodology for this work, the following chapters will individually present the four phases of testing with users, with detailed descriptions regarding participants, apparatus used, procedure, and results.

6 PHASE ONE: EXPLORING USER DEFINED GESTURES FOR SMARTPHONES WITH OLDER ADULTS

Previous research regarding gestures has focused primarily on issues related to gesture recognition and systems' technological characteristics, while overlooking the end-usability of such gestures (Rico & Brewster, 2010; Wobbrock, Morris, & Wilson, 2009). Additionally, while some authors state that gesture-based interaction is natural, or easy and requires a very short learning-curve (Loureiro & Rodrigues, 2011; Sears, Plaisant, & Shneiderman, 1990; Wigdor & Wixon, 2011; Wolf, 1986), several authors refer to the lack of clues or affordances (D. Norman, 1990) available on theses systems and consequent discoverability issues, associated with gesture-based interaction (Bau & Mackay, 2008; Bragdon et al., 2010; D. A. Norman, 2010).

The aim of the work stage reported in this chapter was to understand which gestures older adults, without prior touchscreen experience, would perform. We believe that these gestures would be less constrained than those designed by systems' developers, as end-users are typically not concerned with technological issues. In addition, we hope to better understand what makes some gestures more discoverable, or intuitive, than others by examining the characteristics of these user-defined gestures.

Accordingly, this first phase of our work seeks to answer RQ1, RQ2, and RQ3:

> RQ1: Are current smartphone gestures easily discoverable for older adults?
>
> RQ2: Do older adults, without prior touchscreen experience perform the same gestures as those currently implemented by systems' designers? If not, which gestures do they perform?
>
> RQ3: What are the main characteristics of performed gestures, such as number of fingers and hands used?

In order to answer these questions, we applied the method described by (Mauney, Howarth, Wirtanen, & Capra, 2010), where the authors intend to discover cultural differences and similarities in gestures executed by participants on mobile touchscreen devices. It consisted of a low-fidelity approach, where participants were presented with paper-prototypes of a "before" and an "after" screen. Faced with both screens, participants were then asked to perform a gesture over the "before" screen that would cause the effect seen in the "after" screen. The outcome of this study would be a set of user-defined gestures for mobile touchscreen devices (a more extensive review of several authors' work regarding user-defined gesture sets can be found in section 3.2).

However, after a set of tests with older adults we found that they did not react well to paper-prototypes simulating a gestural interface. They frequently stated that they did not understand what to do because it was a sheet of paper, and nothing would happen if they performed a gesture over it. This finding is consistent with Hawthorn (2007) were the author states that “It was found that low-fidelity prototypes did not work. Older people generally did not make the imaginative leap to seeing low-fidelity prototypes as representing an actual application”.

As a result, we decided to adopt a higher-fidelity approach by asking the participants to perform a gesture on a smartphone, instead of on paper, with the hope of making the tasks more realistic and easier for the participants to understand. Thus, eliminating the “imaginative leap” described by Hawthorn (2007). The need to eliminate paper-prototypes lead us to a similar method presented in (Wobbrock et al., 2009). The authors describe a method to investigate user-defined gestures for a large touch-surface. During this procedure, participants are first presented with an animation that demonstrate the consequence of a gesture, and are then asked to perform a gesture they feel could result in that consequence.

Finally, the outcome of this phase of research was intended to be a set of user-defined gestures for common actions on smartphones, such as scroll, pan, select, zoom-in, zoom-out, etc. The following sections detail the results of this research phase.

6.1 IDENTIFICATION OF COMMERCIALLY AVAILABLE GESTURE SETS

In order to investigate user-defined gestures, we first identified the main pairings of gestures and consequent actions on currently available smartphones. It was our understanding that the tasks included in the experiments should be based on the actions available on smartphones and not on hypothetical ones. We opted for this approach as what was being evaluated were not smartphone functionalities, but rather the gestures used to elicit such existing functionalities.

The gestures and possible functions were considered according to current smartphone OS manufacturers and official gesture descriptions, namely Apple’s iOS[1], Windows Phone 7[2], and Google’s Android[3]. Accordingly, the Table 6.1 summarises pairings of gestures and consequent actions as presented in official guidelines.

From these specifications, ten tasks that match the consequent actions listed in the Table 6.1, were derived for testing with users. These tasks were defined as (1) *scroll content*, (2) *pan content,* (3) *drag an item,* (4) *select an item,* (5) *stop moving content,* (6) *zoom-in,* (7) *zoom-out,* (8) *reveal contextual menu,* (9) *show magnified view of cursor*, and (10) *rotate content*.

1 https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

2 http://www.microsoft.com/windowsphone/en-us/howto/wp7/start/gestures-flick-pan-and-stretch.aspx

3 The gesture patterns on this website have since been updated by Android http://developer.android.com/design/patterns/gestures.html

Table 6.1 Gesture and actions pairings according to smartphone OS guidelines

Gesture	Consequent action	iOS	WP7	Android
Tap	Select an item/ stop moving content	To press or select a control or item (analogous to a single mouse click)	Opens or launches whatever you *tap*	To select or activate something
double-tap	Zoom in / Zoom out	To zoom in and centre a block of content or an image. To zoom out (if already zoomed in)	Zooms in or out in stages	*Tap* quickly twice on a Webpage, map, or other screen to zoom, and double-*tap* again to zoom out.
Tap and Hold	Place cursor / Show contextual menu	In editable or selectable text, to display a magnified view for cursor positioning	Opens a context-specific menu (like right-clicking with a mouse)	Display a context menu or options page for an item
Pinch / Spread	Zoom in / Zoom out	Pinch open to zoom in. Pinch close to zoom out	Zooms gradually in or out of a website, map, or picture.	Pinch open to zoom in. Pinch close to zoom out
Swipe / Drag	Scroll / Pan / Drag item	To scroll or pan (that is, move side to side) To drag an element	Moves through screens or menus at a controlled rate.	To scroll or pan (that is, move side to side); To drag an element.
Flick	Scroll / Pan	To scroll or pan quickly	Scrolls rapidly through menus or pages, or moves sideways in hubs	To scroll or pan quickly.
Rotate device	Rotate	(No platform description provided) Alternate between portrait and landscape orientation	(No platform description provided) Alternate between portrait and landscape orientation	The orientation of the screen rotates with your device as you turn it
Shake device	Show contextual menu	To initiate an undo or redo action	-	-

6.2 ELICITING USER-DEFINED GESTURES

When designing the tasks for this phase of testing, we opted to use geometric figures instead of common GUI elements, such as buttons or menus. This was done in order to avoid biases related to common desktop interaction models (Wobbrock et al., 2009). In addition, when conducting the previously mentioned tests with paper-prototypes, we found that when participants did not know what to do, they often drew the geometric figure depicted on the actual prototype (Figure 6.1). In order to avoid this, we made the figures more complex (Figure 6.2) and consequently harder to mimic.

Figure 6.1 Paper-prototype for the *move an item* task

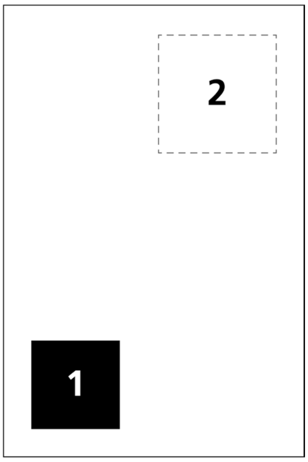
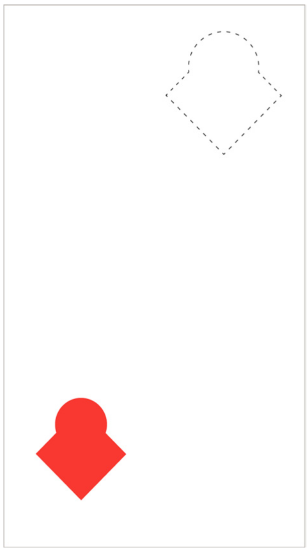


Figure 6.2 Medium-fidelity prototype for the *move an item* task



The following sections will provide further detail regarding (1) participants, (2) the apparatus used, (3) procedure and task scenarios, (4) the results, and finally (5) a discussion of the results and their implications.

6.2.1 PARTICIPANTS

Twenty older adults (14 female and 6 male) aged from 62 to 89 years (Mean = 74.2) voluntarily participated in this study, and agreed to be recorded while doing so. Participants were recruited from several retirement homes and adult day-care centres within the city of Porto, and all had normal or corrected to normal vision. We did not collect any data that allows for the identification of participants. The following Table presents a summary of participants' characteristics.

Table 6.2 Summary of participants' characteristics

Participant Nº	Age	Gender	Frequency of computer usage	Mobile phone ownership	Touchscreen device ownership	Observed a touchscreen being used
1	68	female	never	yes	no	no
2	81	female	never	yes	no	no
3	73	female	never	no	no	yes
4	81	male	never	yes	no	no
5	80	male	never	yes	no	no
6	90	female	never	no	no	no
7	71	male	never	yes	no	no
8	89	female	never	no	no	no
9	74	female	never	yes	no	no
10	75	female	less than once a week	yes	no	yes
11	62	female	never	yes	no	yes

12	77	male	daily	yes	no	yes
13	68	female	less than once a week	yes	no	yes
14	73	male	at least once a week	yes	no	yes
15	73	male	daily	yes	no	yes
16	72	female	at least once a week	yes	no	yes
17	72	female	less than once a week	yes	no	no
18	80	female	at least once a week	yes	no	no
19	65	female	at least once a week	yes	no	no
20	60	female	daily	yes	no	yes

All subjects were asked to rate the frequency with which they used a computer on of the following scale: (1) never used a computer, (2) used to use a computer but do not use one anymore, (3) use one less than once a week, (4) use one at least once a week, or (5) use a computer daily. Seven participants claimed to use a computer on a daily basis or at least once a week, while another three participants used a computer less than once a week, and the remaining ten stated to have never used a computer.

While computer usage was not very widespread among the group, most of the participants owned a mobile phone and used it on a daily basis. None of those devices had a touchscreen, but nine participants claimed to have seen family members or friends using a touchscreen device.

6.2.2 APPARATUS

The study was conducted with a Samsung Galaxy Nexus measuring 135.5 x 67.94 mm, with a 1280×720 px display at 316 ppi. In order to video record the sessions, a Noldus Mobile Device Camera[4] was attached to the smartphone. The whole setup was light and easy to hold in one hand. This particular smartphone was chosen because it is slightly larger than most commercially available smartphones. Due to the device's size and its large multi-touch screen we believed it would be easier for older adults effectively perceive onscreen contents, while still being comfortable to hold.

The animations shown to participants as the consequence of a gesture were animated gifs running on a gif viewer application.

Lastly, participants sat on a chair in front of a table while performing the tasks. They were invited to hold the device in the same way they would do with their own mobile phones.

4 http://www.noldus.com/human-behavior-research/accessories/mobile-device-camera-mdc

6.2.3 PROCEDURE

An individual task was created for every function associated with a gesture (see Table 6.1). As previously discussed, ten individual tasks were defined: (1) *scroll content*, (2) *pan content*, (3) *move an item*, (4) *select an item*, (5) *stop scrolling content*, (6) *zoom-in*, (7) *zoom-out*, (8) *reveal contextual menu*, (9) *show magnified view of cursor*, and (10) *rotate content*. Accordingly, the following table lists our ten tasks and their corresponding gesture, as currently implemented on smartphones.

Table 6.3 Tasks for tests with users and corresponding smartphone gestures

Task	Current smartphone gesture
Scroll content	Swipe
Pan content	Swipe
Move an item	Swipe/Drag
Select an item	Tap
Stop scrolling content	Tap
zoom-in	Spread; Double-tap
zoom-out	Pinch; Double-tap
Reveal contextual menu	Tap and Hold
Show magnified view of cursor	Tap and Hold
Rotate content	Rotate entire device

Before beginning the tasks, it was explained to each participant that the mobile phone being used did not have hard buttons but that you could operate the device by touching or moving your fingers on the screen, or by manipulating the entire device in whatever way seemed more adequate to solve a task (see script in Appendix A.1 for further detail).

No gestures were exemplified or explained during the pre-session debriefing. We chose not to demonstrate any gestures since we intended to find those that would be more “natural” to inexperienced users, and felt that a demonstration might influence their performance.

All participants were asked to complete the same ten tasks. These tasks were presented one at a time to each participant, in a random order. For each task, the participant would first watch an animation demonstrating the consequence of a gesture. Then the test facilitator would verbally explain what was intended, for example: “In this movie, the list of numbers was partially hidden to the top of the screen. In order to see the remaining numbers, the list was moved in a downward fashion”. Finally, the facilitator would prompt participants to perform a gesture they felt could result in the consequence seen in the animation.

Each animation was repeated twice, in order to compensate for distractions or interruptions. Once completed, the animation would return to its initial frame and remain static while participants carried out a gesture. Overall, the average duration of each session was around 30 to 45 minutes per participant.

Since the intention of this experiment was to explore gestures performed by older adults without prior touchscreen experience, the system did not respond to any of the users actions. Without prior knowledge of the gestures that were going to be performed, we could not construct a system that would adequately respond to the participants’ actions. For this reason, it was explained to each participant that they would be interacting with a low-fidelity prototype that would not react to their gestures.

Finally, all participants performed the tasks while sitting on a chair in front of a table and where asked to hold the device as they would normally do with their own mobile phones.

The following sections will explain each of the ten tasks in further detail.

TASK 1: SCROLL CONTENT

Task one was designed to elicit gestures from participants for the *scroll content* action (see Table 6.3). In accordance, an animation was developed in which the list of numbers shown in Figure 6.3, would appear at the bottom of the screen and remain stationary for a few seconds. Then, the list would start moving upwards, as if being scrolled. After playing twice, the animation would return to an initial stationary position, where the list was again partially hidden to the bottom of the screen (Figure 6.4). At this point, the facilitator would explain the task and ask participants to execute a gesture:

"In this movie, the list of numbers was partially hidden to the bottom of the screen. In order to see the remaining numbers, the list was moved in an upward fashion. Now I would like you to perform a gesture that you think could make the list move up, in order to reveal the hidden numbers, much like what you saw in the previous animation" (see test script in Appendix A.1 for further detail).

Figure 6.3 Screenshots of animation for *scroll content* task

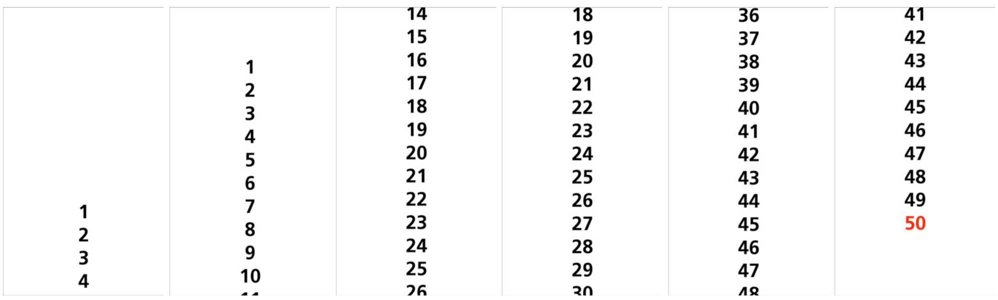
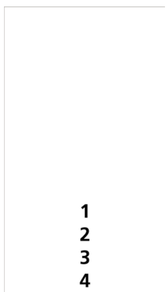


Figure 6.4 Screen appearance during gesture input for the *scroll content* task



TASK 2: PAN CONTENT

Task two was designed to elicit user-defined gesture for the *pan content* action (see Table 6.3). Participants were presented with a short animation showing a list of numbers moving from the right to the left of the display, as Figure 6.5 demonstrates. Once the animation played twice, the screen would return to an initial state as in Figure 6.6, where the list of numbers would again be partially hidden to the right of the screen. At this point, the facilitator would explain the task and prompt participants to perform a gesture:

"In this movie, the list of numbers was partially hidden. In order to see the remaining numbers, the list was moved toward the left of the screen. Now I would like you to perform a gesture that you think could provoke the action seen in the animation, in order to reveal the hidden numbers" (for further detail regarding the test script, see Appendix A.1).

Figure 6.5 Screenshots of animation for *pan content* task

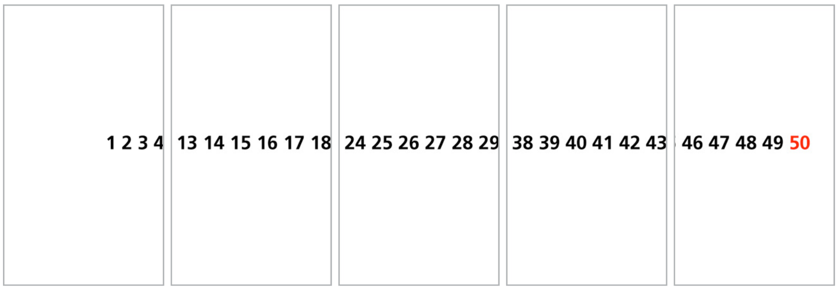


Figure 6.6 Screen appearance during gesture input for the *pan content* task

TASK 3: MOVE AN ITEM

The purpose of task three was to elicit gestures for the *move an item* action (see Table 6.3). Accordingly, as can be seen in Figure 6.7 the participants were presented with an animation in which the red item was moved into another item present at the top-right-corner of the smartphone's display. Once the animation was played twice, the screen reverted to an initial status (Figure 6.8). Then the facilitator explained the task at hand and prompted participants to execute a gesture:

"What happened in this movie, was that the item in the bottom-left-corner was moved into the item present at the top-right-corner. I would now like you to perform a gesture that would move the item, just like what happened in the animation you just watched" (for further detail regarding the test script, see Appendix A.1).

Figure 6.7 Screenshots of animation for *move an item* task

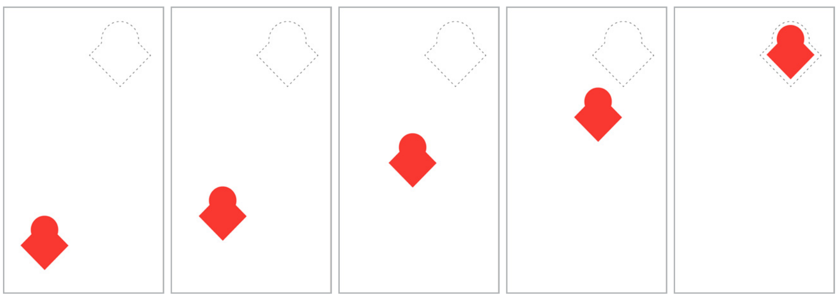
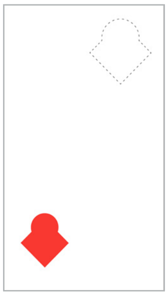


Figure 6.8 Screen appearance during gesture input for the *move an item* task



TASK 4: SELECT ITEM

Task four was meant to evoke gestures for the *select an item* action (see Table 6.3). For this purpose, an animation was presented to participants, in which four items were displayed. After a few seconds, three of these items would fade away, leaving only the top-right one (Figure 6.9). After being played twice, the animation would return to an initial fixed state, where all four items were present once again (Figure 6.10). Now, the facilitator explained the task and asked participants to perform a gesture:

"What happened in this movie is that the red item, the top-right one, was selected. As a result of being chosen, the other items disappeared. Now I would like you to make a gesture, that you think would choose the red item. The red item is the one in the upper-right-corner" (see Appendix A.1 for further detail).

Figure 6.9 Screenshots of animation for the *select an item* task

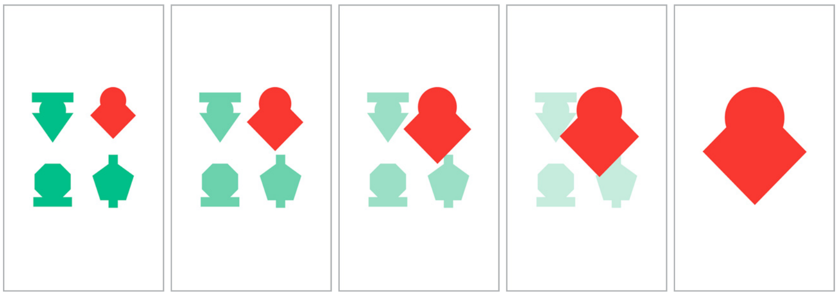
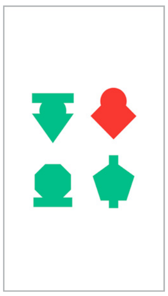


Figure 6.10 Screen appearance during gesture input for the *select an item* task

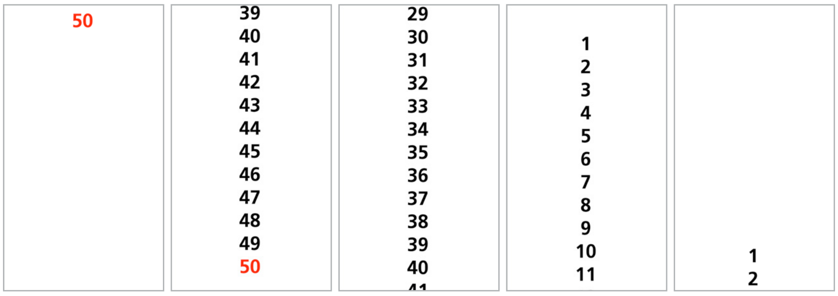


TASK 5: STOP SCROLLING CONTENT

Task five was meant to gather user-defined gestures for the *stop scrolling content* action (see Table 6.3). In order to do so, a short animation was shown to participants. In this animation, a moving list of numbers would appear at the top of the screen and then progressively continue moving toward the bottom of the screen, until disappearing completely (Figure 6.11). Contrary to the remaining tasks, the animation would not return to its initial state and pause, but rather play again. We found that in the case of eliciting gestures for stopping an item, it would make better sense for that item to remain in motion while participants solved the task. As an additional imaginative leap would be required of participants if we asked them to imagine that the list was moving. However, the animation did pause for a few seconds before repeating so the facilitator could explain the task and prompt users for input:

"In this movie, a list of numbers moved from the top and toward the bottom of the screen, until it eventually disappeared. The list will start moving again in a few seconds, and I would like you to perform a gesture you think could stop that list from disappearing again" (see script in Appendix A.1 for further detail).

Figure 6.11 Screenshots of animation for the *stop scrolling content* task



TASK 6: ZOOM-IN

This particular task was designed to evoke gestures for the *zoom-in* action (see Table 6.3). As a result, an animation in which an item becomes progressively larger was shown to the participants (Figure 6.12). This animation was repeated twice, after which it would return to an initial fixed state, as seen in Figure 6.13. Then, the facilitator would explain the task and prompt participants to perform a gesture:

"In this movie, the image got bigger so that we were able to see it better. Now I would like you to make a gesture that you think would make the image bigger again, similarly to what you saw in the previous animation" (see script in Appendix A.1 for further detail).

Figure 6.12 Screenshots of animation for the *zoom-in* task

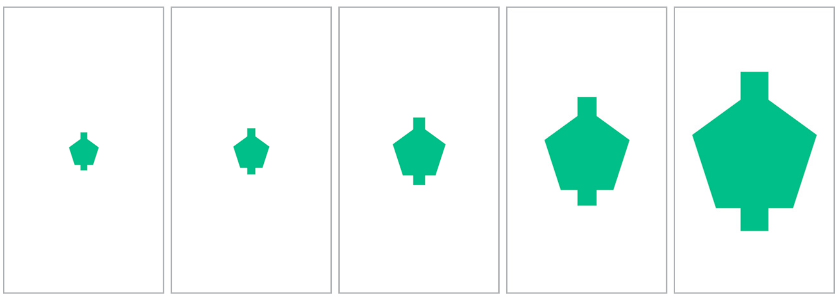
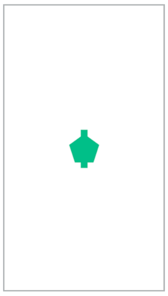


Figure 6.13 Screen appearance during gesture input for the *zoom-in* task



TASK 7: ZOOM-OUT

Opposite to the previous task, this one was meant to evoke gestures for the *zoom-out* task (see Table 6.3). An animation was presented to the participants in which an item became progressively smaller (Figure 6.14). After playing twice, the animation would return to its initial state, as Figure 6.15 demonstrates. At this point, the task would be explained to the participants and they would be asked to perform a gesture:

"In this movie, the image became progressively smaller. Now I would like you to make a gesture on the screen, that you think would make the image smaller, like what happened in the animation" (for further details on the script see Appendix A.1).

Figure 6.14 Screenshots of animation for the *zoom-out* task

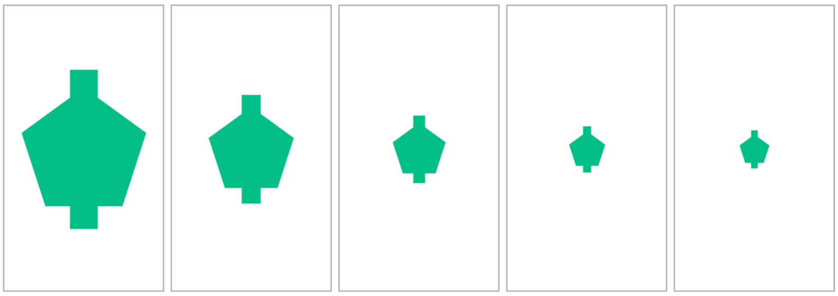
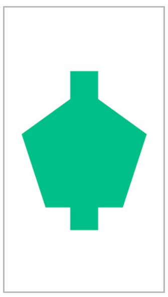


Figure 6.15 Screen appearance during gesture input for the *zoom-out* task



TASK 8: REVEAL CONTEXTUAL MENU

This task was meant to elicit gestures from users for the *reveal contextual menu* action (see Table 6.3). As can be seen in Figure 6.16, during the animation a menu appeared associated to the green geometric figure. After a few seconds, it would disappear again and the animation would return to an initial status (Figure 6.17). At this point, the facilitator would explain the task and ask participants to perform a gesture they thought would be most adequate:

"In this movie, a grey rectangle that is related to the object was opened. Now I would like you to make a gesture on the screen, that you think would make that same grey rectangle re-open, like you saw in the animation" (for further detail regarding the test script, see Appendix A.1).

Figure 6.16 Screenshots of animation for the *reveal contextual menu task*

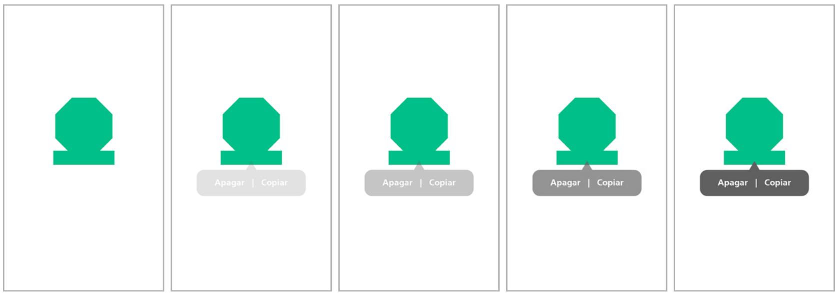
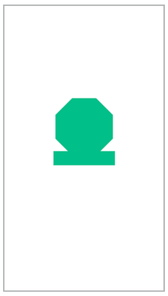


Figure 6.17 Screen appearance during gesture input for the *reveal contextual menu task*



TASK 9: MAGNIFIED VIEW OF CURSOR POSITION

Task number nine was meant to elicit gestures from participants, for the action of displaying a *magnified view of the cursor's position* (see Table 6.3). In order to do so, an animation was presented were the magnified view shown in Figure 6.18 would appear for a few seconds and then disappear. When the animation stopped the screen looked like Figure 6.19, with the cursor between the letters "A" and "m". The facilitator would then explain the task, and participants were asked to carry out a gesture:

"In this movie, a magnified view of the position of the red rectangle (cursor) appeared, between the letters "A" and "m", and then disappeared after a few seconds. I would now like you to perform a gesture that you think could provide a magnified view of red rectangle's position, much like what happened in the animation" (for further detail regarding the test script, see Appendix A.1).

The cursor was referred to as the "red rectangle", since many users had little or no experience with computers and could therefore be unfamiliar with this concept.

Figure 6.18 Screenshots of animation for the *magnified view of cursor position* task

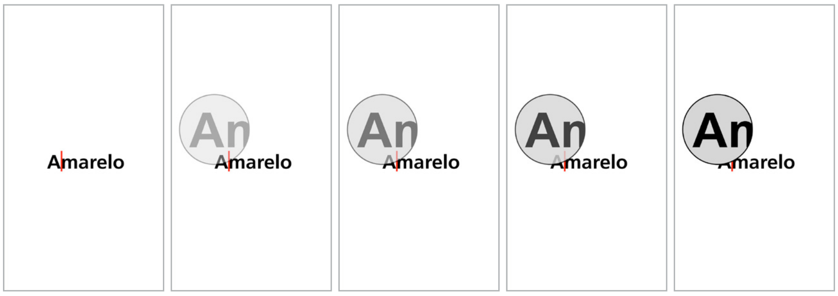


Figure 6.19 Screen appearance during gesture input for the *magnified view of cursor position* task

TASK 10: ROTATE CONTENT

Task number ten intended to retrieve gestures from participants for the *rotate content* action (see Table 6.3). It is slightly different from the remaining nine tasks, as on existing smartphones it typically requires manipulating the entire device, rather than performing a finger gesture on the display.

Like in previous tasks, an animation was presented to the participants in which an item was rotated in a clockwise fashion (Figure 6.20). Once the animation played twice, it would return to its initial state, as Figure 6.21 demonstrates. At this point, the facilitator explained the task and prompted participants to perform a gesture:

"What happened in this movie was that the item was rotated 90º to the right. I would now like you to perform a gesture that you think could rotate that item, much like you saw in the previous animation" (for further detail regarding the test script, see Appendix A.1).

Figure 6.20 Screenshots of animation for the *rotate content* task

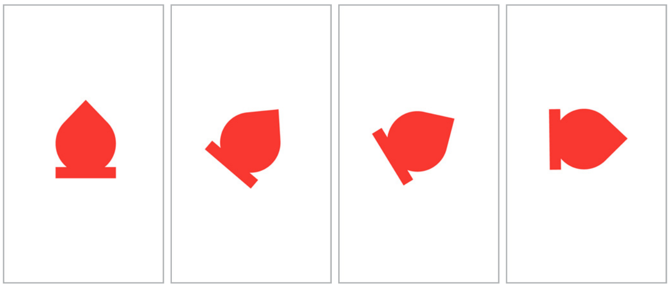
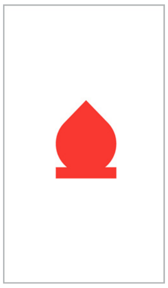


Figure 6.21 Screen appearance during gesture input for the *rotate content* task



6.2.4 RESULTS

The following sections detail the test results for each task — (1) Scroll content, (2) Pan content, (3) Move an item, (4) Select item, (5) Stop scrolling content, (6) Zoom-in, (7) Zoom-out, (8) Reveal contextual menu, (9) Magnified view of cursor, and (10) Rotate content. For all tasks, we present a table showing an overview of the gestures performed by each participant, a graph presenting the percentage of unique gestures performed, as well as a calculation of the level of agreement in gesture selection among participants. The level of agreement in gesture selection among participants (*A*) was calculated according to the formula presented in (Wobbrock, Aung, Rothrock, & Myers, 2005):

Figure 6.22 Formula presented in (Wobbrock, Aung, Rothrock, & Myers, 2005).

$$A = \frac{\sum_{r \in R} \sum_{P_i \subseteq P_r} \left(\frac{|P_i|}{|P_r|} \right)^2}{|R|}$$

In this formula, and as defined by the authors, “r is a referent in the set of all referents R, P_r is the set of proposed gestures for referent r, and P_i is a subset of identical gestures from P_r”. In addition, the authors consider agreement scores over 10% to show sufficient agreement in gesture selection among participants.

Before progressing to the results analysis, it is important to clarify the meaning of what we have defined as random gestures. These are considered as those performed on neutral screen space, with no apparent or stated relation to the displayed item or task. In fact, in many cases participants would state that they did not know what to do and then perform a *tap* or *swipe* at a random onscreen location. Besides performing these actions randomly, many *taps* on the item being displayed were also stated as being a way to avoid performing no gesture at all when participants did not know how to solve a task.

Finally, we present detailed results regarding certain gesture characteristics, such as participants posture — whether they held the smartphone in their left or right hands or placed it on a table; as well as general preferences for the number of fingers, and hands used to perform gestures.

The following sections will detail the study’s results according to each of the ten tasks.

TASK 1: SCROLL CONTENT

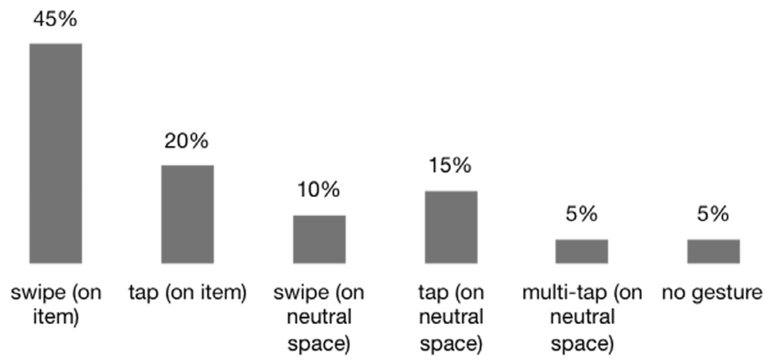
Firstly, Table 6.4 presents our results for the *scroll content* task. Regarding this table, we can see that no novel user-defined gestures were performed for the *scroll content* task (see Table 6.4). Overall, the agreement score among participants in gesture selection was 31%, which reveals a good level of agreement in gesture selection among participants (Wobbrock, Aung, Rothrock, & Myers, 2005), where the most performed gesture was *swipe*. This gesture matched the current one used to scroll content on existing smartphones (see Table 6.1).

Table 6.4 Gestures performed by each participant for the *scroll content* task

Subject Nº	Gesture	Fingers	Hand
17	*swipe* (on item)	Index	Left
5	*swipe* (on item)	Index	Right
11	*swipe* (on item)	Index	Right
12	*swipe* (on item)	Index	Right
13	*swipe* (on item)	Index	Right
14	*swipe* (on item)	Index	Right
16	*swipe* (on item)	Index	Right
18	*swipe* (on item)	Index	Right
2	*swipe* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
19	*tap* (on item)	Index	Right
3	*tap* (on neutral space)	Index	Right
7	*tap* (on neutral space)	Middle; Index	Right
1	*tap* (on neutral space)	Index	Left
20	*swipe* (on neutral space)	Index	Right
15	*swipe* (on neutral space)	Index	Right
6	multi-*tap* (on neutral space)	Index	Right
4	no gesture	-	-

Additionally, Graph 6.1 provides a more immediate overview of the results. Here we can see that *swipe* was performed by a total of 45% of participants. While other remaining gestures were either *taps* or *swipes* on neutral space (25%), a *tap* on the item being displayed (20%), or even no gesture at all (5%). In a few cases, participants did not perform any gesture at all, they would say that they did not know how to solve a task, and then ask to proceed to the following one. Furthermore, those considered as random gestures — *tap* and *swipe* on neutral space — amounted to 30% of all gestures. Given the lack of new proposed gestures and the level of consensus among participants in gesture selection, the specification of user-defined gestures for this task does not seem neither necessary, nor possible. Besides, results indicate that the current smartphone gesture for scrolling might be adequate for older adults.

Graph 6.1 Percentage of unique gestures performed for the *scroll content* task



Finally, all participants used a single hand for interaction, and all but one used only their index fingers. In sum, the most widely performed gesture for the *scroll content* task was *swipe,* and no novel user-defined gesture can be proposed for this task.

TASK 2: PAN CONTENT

Much like in the previous task and regarding the following table, no novel gestures were performed by a satisfactory number of participants. Where, the only new gesture was a variation of *swipe* performed with two fingers spread apart. Accordingly, the most widely performed gesture was *swipe*, and the agreement score in gesture selection among participants was 34%. These findings are consistent with the gesture used to perform a *pan content* action on existing smartphones (see Table 6.1).

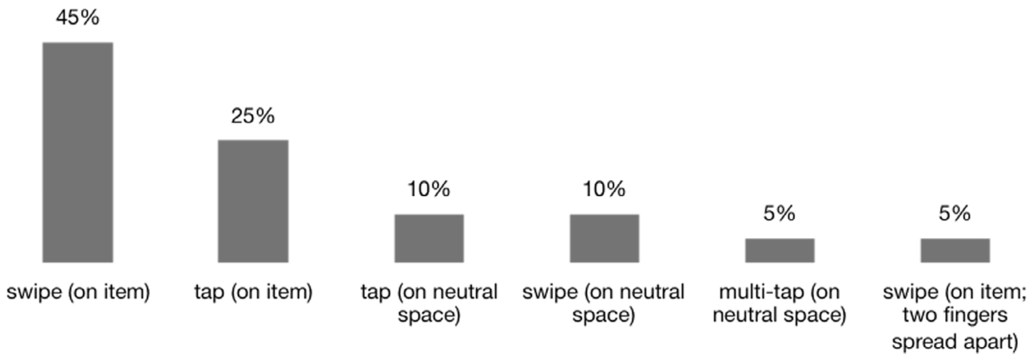
Table 6.5 Gestures performed by each participant for the *pan content* task

Subject Nº	Gesture	Fingers	Hand
4	*swipe* (on item)	Index	Right
5	*swipe* (on item)	Index	Right
11	*swipe* (on item)	Index	Right
12	*swipe* (on item)	Index	Right
13	*swipe* (on item)	Index	Right
14	*swipe* (on item)	Index	Right
16	*swipe* (on item)	Index	Right
17	*swipe* (on item)	Index	Left
18	*swipe* (on item)	Index	Right
3	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
19	*tap* (on item)	Index	Right
6	*tap* (on item)	Index	Right
7	*tap* (on neutral space)	Middle	Right
9	*tap* (on neutral space)	Index	Right
15	*swipe* (on neutral space)	Index	Right

20	*swipe* (on neutral space)	Index	Right
1	multi-*tap* (on neutral space)	Ring; Middle	Left & Right
2	*swipe* (on item; two fingers spread apart)	Index;Thumb	Right

Next, Graph 6.2 provides an overview of the data presented in the above table. Furthermore, the Graph shows that *swipe* was carried out by a total of 45% of participants, while the only other gesture used for this task was *tap*. 25% performed what was considered as a random *tap* or *swipe*, and another 25% simply *tapped* the item that was presented on the device's display. Still, 5% performed multiple *taps*, but when asked about the gesture they replied that the system did not do anything so they *tap*ped it again. This particular gesture can be attributed to the lack of feedback of the system, which is consistent with the findings of (Stößel, Wandke, & Blessing, 2009), where confusion among older adults is attributed to the lack of system feedback.

Graph 6.2 Percentage of unique gestures performed for the *pan content* task



Lastly, all but one participant used a single hand for interaction. Considering number of fingers used, 80% used their index or middle fingers, and the remaining 20% used two fingers in conjunction.

In sum, given that *swipe* was the most widely performed gesture, and the level of consensus among participants, it seems that the current smartphone gesture might be adequate for older adults.

TASK 3: MOVE AN ITEM

Firstly, Table 6.6 provides details regarding participants and the gestures performed for moving an item. Much like in the previous tasks, no novel gestures were suggested by the participants. Overall, the most performed gesture for moving an item from one location to another was *swipe* with an agreement level of 45% among participants, which is consistent with the current smartphone gesture for moving an item (see Table 6.1).

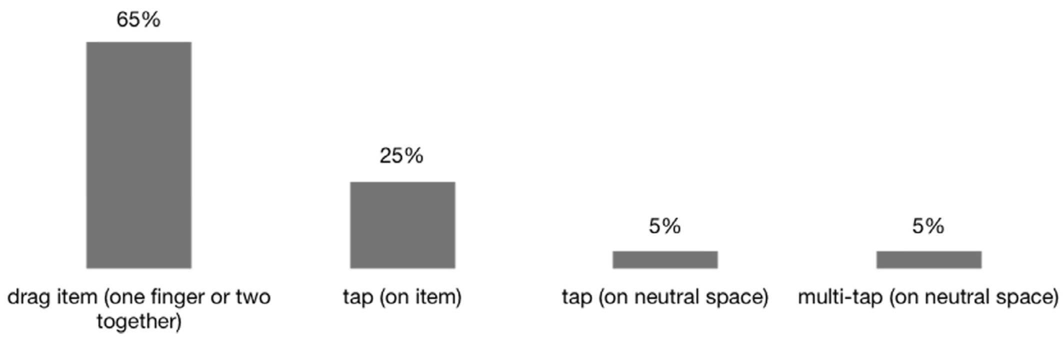
Table 6.6 Gestures performed by each participant for the *move an item* task

Subject Nº	Gesture	Fingers	Hand
2	drag item (one finger or two together)	Index	Right
5	drag item (one finger or two together)	Index	Right
6	drag item (one finger or two together)	Index	Right

11	drag item (one finger or two together)	Index	Right
12	drag item (one finger or two together)	Index	Right
13	drag item (one finger or two together)	Index	Right
14	drag item (one finger or two together)	Index	Right
15	drag item (one finger or two together)	Index	Right
16	drag item (one finger or two together)	Index	Right
17	drag item (one finger or two together)	Index	Left
18	drag item (one finger or two together)	Index	Right
19	drag item (one finger or two together)	Index	Right
20	drag item (one finger or two together)	Index	Right
3	*tap* (on item)	Index	Right
4	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
7	*tap* (on neutral space)	Index	Right
1	multi-*tap* (on neutral space)	Index	Left & right

In addition, considering the overview of the data provided in Graph 6.3, we can see that *swipe* was performed by 65% of the participants, while other remaining gestures were either *tap* (on item) (25%), or *taps* at random onscreen location (10%). Still, similarly to the previous task, 5% performed *multiple taps* and stated that the gesture repetition was not intentional, but rather due to the lack of system feedback. This finding is consistent with (Stößel et al., 2009), where the authors attribute confusion among older adults to the lack of feedback. Consequently, the lack of novel gestures and the level of consensus among participants in gesture choice for this task, does not justify the documentation of any user-defined gestures for moving an item.

Graph 6.3 Percentage of unique gestures performed for the *move an item* task



Lastly, 95% of participants used only one hand for interaction while 5% used both, and all used their index finger. In sum, it seems that the current smartphone gesture for moving an item — *swipe* — might be satisfactory for older adults.

TASK 4: SELECT ITEM

As seen in Table 6.7, two novel gestures were performed for the *select an item* task — *lasso* and *tap and rub*. However, both gestures were only executed by one participant each, and therefore cannot be generalised into a proposal for a set of user-defined gestures. Besides, the performance of *tap and rub* could again be explained by the system's lack of feedback. In this case, even though it was explained that the prototype would not provide any feedback for the gestures performed, participants could feel that the first *tap* did not work and try to *rub* the item. This is consistent with the findings of (Stößel et al., 2009), where the authors attribute lack of system feedback to confusion among older adult participants.

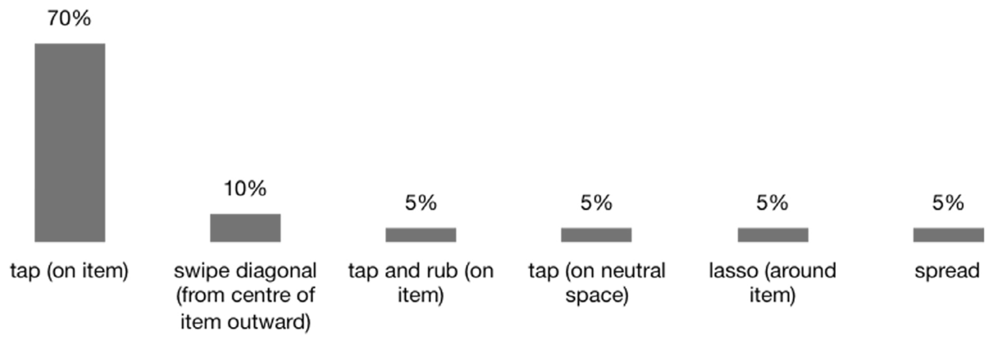
Next, for selecting an item, the overall agreement score among participants was 51% and the most widely performed gesture was *tap (on item)*. This is consistent with the gesture currently implemented in smartphones for this action (see Table 6.1), which leads us to conclude that *tap* for selecting an item could be adequate for older adults.

Table 6.7 Gestures performed by each participant for the select item task

Subject Nº	Gesture	Fingers	Hand
2	*tap* (on item)	Index	Right
3	*tap* (on item)	Index	Right
4	*tap* (on item)	Index	Right
6	*tap* (on item)	Index	Right
8	*tap* (on item)	Middle	Right
9	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
11	*tap* (on item)	Index	Right
12	*tap* (on item)	Middle	Right
14	*tap* (on item)	Index	Right
15	*tap* (on item)	Index	Right
16	*tap* (on item)	Index	Right
19	*tap* (on item)	Index	Right
20	*tap* (on item)	Index	Right
13	*swipe* diagonal (from centre of item outward)	Index	Right
18	*swipe* diagonal (from centre of item outward)	Index	Right
5	*tap* and rub (on item)	Index	Right
7	*tap* (on neutral space)	Middle	Right
1	lasso (around item)	Index	Left
17	spread	Index	Left

In addition, Graph 6.4 provides an overview of the data, and shows that *tap (on item)* was performed by 70% of participants. Next, the number of random gestures performed for this task was much lower than the previous ones, at 5% compared to 35% for *scroll content*, and 30% for *pan content*. However, these findings could be influenced by the fact that participants would, in many cases, *tap* the displayed item to avoid not performing any gesture at all. Nonetheless, *tap* is consistent with the current smartphone gesture for *selecting an item* (see Table 6.1), meaning that 70% of participants would have been capable of selecting an item on existing Android, iOS or Windows Phone devices.

Graph 6.4 Percentage of unique gestures performed for the *select an item* task



Lastly, all of the participants used one hand and a single finger to solve this task, where 85% used their index finger and the remaining 15% their middle finger.

TASK 5: STOP SCROLLING CONTENT

Considering Table 6.8 which presents an overview of the results for task 5, we can see that the most widely used gesture for stopping scrolling content was *tap (on item)*. This gesture matches the current smartphone gesture used to stop scrolling content (see Table 6.1). In addition, the consensus level among participants for this task reached 54%. In this way, we conclude that *tap* to stop scrolling content might indeed be satisfactory for older adults interacting with smartphones.

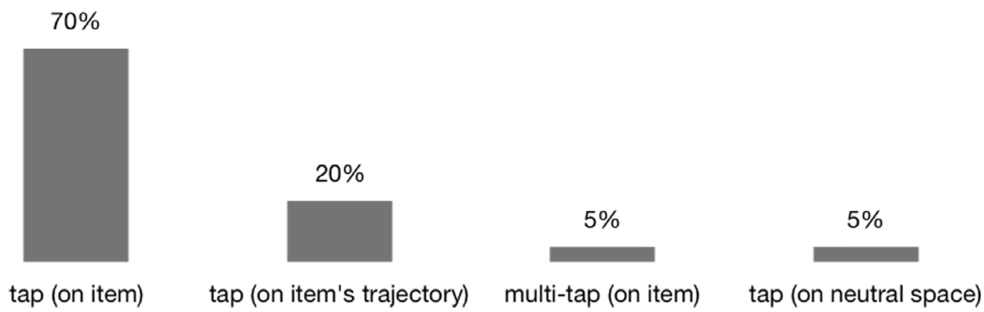
Table 6.8 Gestures performed for the *stop scrolling content* task

Subject Nº	Gesture	Fingers	Hand
3	*tap* (on item)	Index	Right
4	*tap* (on item)	Index	Right
5	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
12	*tap* (on item)	Middle	Right
13	*tap* (on item)	Index	Right
14	*tap* (on item)	Index	Right
15	*tap* (on item)	Index	Right
16	*tap* (on item)	Index	Right
17	*tap* (on item)	Index	Left
18	*tap* (on item)	Index	Right
19	*tap* (on item)	Index	Right
1	*tap* (on item's trajectory)	Index	Left
2	*tap* (on item's trajectory)	Index	Right

6	*tap* (on item's trajectory)	Index	Right
20	*tap* (on item's trajectory)	Index	Right
11	multi-*tap* (on item)	Index	Right
7	*tap* (on neutral space)	Index	Right

Additionally, considering the overview of the data provided in Graph 6.5, *tap (on item)* was carried out by a total of 70% of participants. While, all other performed gestures were variations of *tap*, either on a neutral screen location (5%), or *multi-taps* on an item (5%), or even *tapping* the projected trajectory of the scrolling list (20%). However, it could be argued that for most smartphones it would not be possible to *tap* on a scrolling list's projected trajectory as they generally occupy the entire display. What remains to be understood is if in these cases, users would *tap* the list or try to avoid it entirely as in 25% of the gestures carried-out for this task.

Graph 6.5 Percentage of unique gestures performed for the *stop scrolling content* task



Finally, all participants used only one hand and a single finger for interaction, where 95% used their index finger and the remaining 5% their middle finger.

TASK 6: ZOOM-IN

Unlike previous tasks, consensus among participants was slightly lower for the zoom-in action, at 27% compared to 31% for *scroll content,* and 34% for *pan content*. Still, the most executed gesture was *tap (on item)* which does not match the current smartphone gestures for this action (see Table 6.1). Current gesture sets define *double-tap* and *spread,* of which the first was not performed by any participants in this study, and the second was executed by only 20%. The low level of agreement and the mismatch between user-defined and currently implemented gestures, lead us to believe that *spread* for zooming-in might not be adequate for older adults.

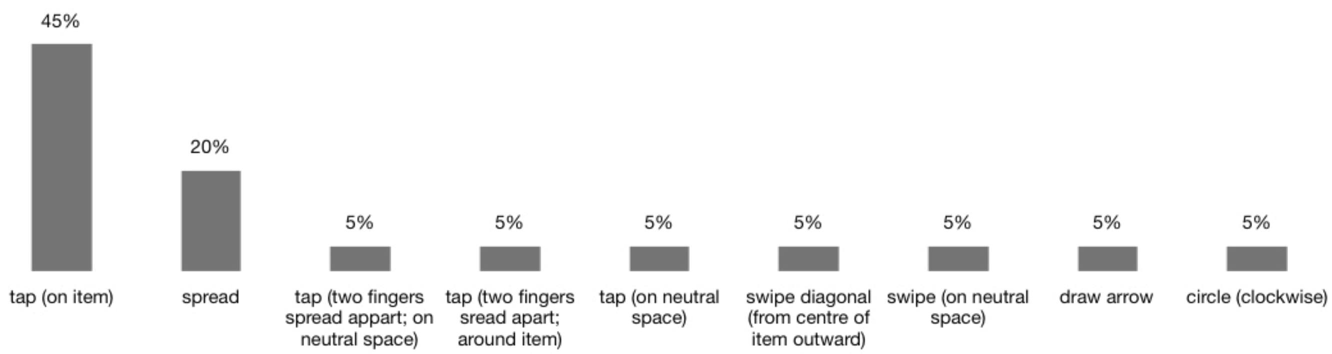
Table 6.9 Gestures performed for the *zoom-in* task

Subject Nº	Gesture	Fingers	Hand
3	*tap* (on item)	Index	Right
4	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right

10	*tap* (on item)	Index	Right
11	*tap* (on item)	Index	Right
12	*tap* (on item)	Index	Right
15	*tap* (on item)	Index	Right
19	*tap* (on item)	Index	Right
17	spread	All	Left
13	spread	All	Right
14	spread	Index; Thumb	Right
16	spread	Middle; Thumb	Right
1	*tap* (two fingers spread apart; on neutral space)	Middle; Index	Left
2	*tap* (two fingers spread apart; around item)	Index; Thumb	Right
7	*tap* (on neutral space)	Index	Right
6	*swipe* diagonal (from centre of item outward)	Index	Right
20	*swipe* (on neutral space)	Index	Right
5	draw arrow	Thumb	Right
18	circle (clockwise)	Index	Right

Considering Graph 6.6 which provides a summary of the data found in the previous table, we can see that a few novel gestures were executed for this task — *tap with two finger spread apart*, *diagonal swipe from centre of item outward*, *draw circle* and *draw arrow*. However, none of them were performed by more than 10% of participants and can therefore not be generalised as user-defined gestures for this task.

Graph 6.6 Percentage of unique gestures performed for the *zoom-in* task



Lastly, 60% of participants used a single finger to perform this task, where 55% used their index finger and the remaining 5% used their thumb. In addition, 10% used all five fingers to perform a *spread* gesture, while 30% used either their middle finger and thumb, or their index finger and thumb. Finally, all participants used only one hand for gesture performance.

TASK 7: ZOOM-OUT

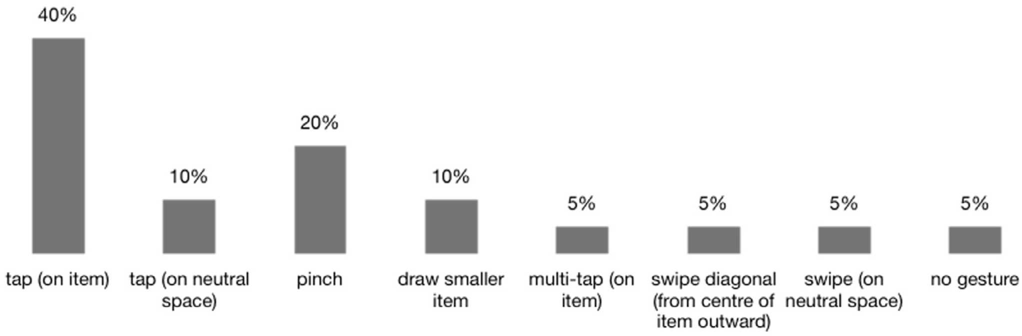
In a similar way as the previous task, gesture selection for *zoom-out* reached a lower level of consensus than the first five tasks, at 25%. Still, the most performed gesture was *tap (on item),* which does not concur with the current smartphone gesture for this action (see Table 6.1). Existing gesture sets define *double-tap* and *pinch* for zooming-out. However, a mere 5% of the participants performed the first gesture, and only 20% executed the second one. Consequently, we believe that currently adopted gestures for zoom-out, might not be adequate for older adults. The following table and graph provide details regarding participants and gesture performance.

Table 6.10 Gestures performed for the *zoom-out* task

Subject Nº	Gesture	Fingers	Hand
2	*tap* (on item)	Index	Right
3	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
12	*tap* (on item)	Middle	Right
15	*tap* (on item)	Index	Right
19	*tap* (on item)	Index	Right
1	*tap* (on neutral space)	Index	Left
7	*tap* (on neutral space)	Index	Right
13	pinch	All	Right
14	pinch	Index; Thumb	Right
16	pinch	Middle; Thumb	Right
17	pinch	All	Left
5	draw smaller item	Index	Right
18	draw smaller item	Index	Right
11	multi-*tap* (on item)	Index	Right
6	*swipe* diagonal (from centre of item outward)	Index	Right
20	*swipe* (on neutral space)	Index	Right
4	no gesture	-	-

Next, in Graph 6.7 we can see that 40% of participants performed a *tap (on item)*. Additionally, 10% solved this task by *drawing a smaller item*,while none drew a bigger item for *zoom-in*, revealing that in some cases these tasks were not perceived as opposites. Other remaining gestures were *pinch,* which corresponds to the current smartphone gesture and was only performed by 20% of participants, a diagonal *swipe* (5%), *multi-tap* (5%) and other gestures considered as random ones (15%). As previously discussed the *multi-tap* gesture was mainly attributed to the lack of system feedback and is consistent with (Stößel et al., 2009). Additionally, considering the variety of gesture performed for this task, it seems that participants found this task to be more difficult than other previous tasks.

Graph 6.7 Percentage of unique gestures performed for the *zoom-out* task



Finally, a single finger for interaction was used by 79% of participants, where 73.7% used their index finger and 5.3% used their middle finger. Another 10.5% used all fingers to carry out a pinch gesture, while a further 10.5% used only their index or middle fingers in conjunction with their thumb. In addition, all participants used only one hand for interaction.

TASK 8: REVEAL A CONTEXTUAL MENU

Similarly to other more complex actions such as zoom-in and zoom-out, consensus among participants in gesture selection for revealing a contextual menu was 27%. Furthermore, the complexity of this action is revealed by the most executed gesture being *tap (on neutral space)*. As has been mentioned, participants often stated to not know how to solve a task and then would proceed to *tapping* the screen at any random position. It seems that opening a contextual menu by resorting to a particular gesture is hard to understand by older adults. This finding is consistent with Mauney (2009), where the most performed gesture was "*tap* (anywhere)" for the contextual menu task. Details regarding gesture performance and participants can be found in the following table.

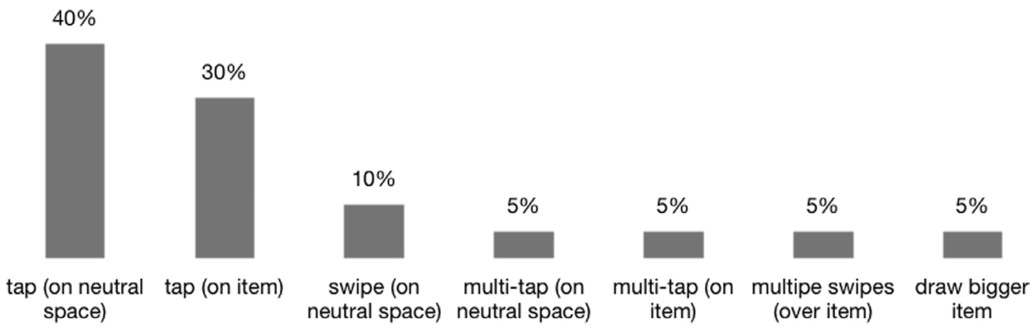
Table 6.11 Gestures performed for the *reveal contextual menu task*

Subject Nº	Gesture	Fingers	Hand
4	*tap* (on neutral space)	Index	Right
6	*tap* (on neutral space)	Index	Right
7	*tap* (on neutral space)	Index	Right
15	*tap* (on neutral space)	Index	Right
16	*tap* (on neutral space)	Index	Right
17	*tap* (on neutral space)	Index	Left
19	*tap* (on neutral space)	Index	Right
20	*tap* (on neutral space)	Index	Right
2	*tap* (on item)	Index	Right
3	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right

10	*tap* (on item)	Index	Right
12	*tap* (on item)	Index	Right
5	*swipe* (on neutral space)	Thumb	Right
14	*swipe* (on neutral space)	Index	Right
1	multi-*tap* (on neutral space)	Middle; Index	Left & right
11	multi-*tap* (on item)	Index	Right
13	multiple *swipes* (over item)	Index	Right
18	draw bigger item	Index	Right

Next, Graph 6.8 provides an overview of the data presented in the previous table. Here we can seen that *tap (on neutral space)*, which is considered a random gesture was performed by 40% of participants. Followed by *tap (on item)* by 30%, and then another random gesture — *swipe (on neutral space)* by a further 10%. Regarding novel gestures, *multiple swipes, multi-tap,* and *draw bigger item* were performed by a few participants, but did not reach a sufficiently high number to justify the replacement of the current with one of them. Furthermore, given the variety of proposed gestures, it seems that this task might have been more difficult to solve than some of the previous ones.

Graph 6.8 Percentage of unique gestures performed for the *reveal contextual menu task*



Lastly, only 5% of participants used both hands to solve this task and 95% made use of a single finger for interaction, 90% used their index finger and 5% their thumb. The remaining 5% used their index finger and thumb in conjunction.

TASK 9: MAGNIFIED VIEW OF CURSOR POSITION

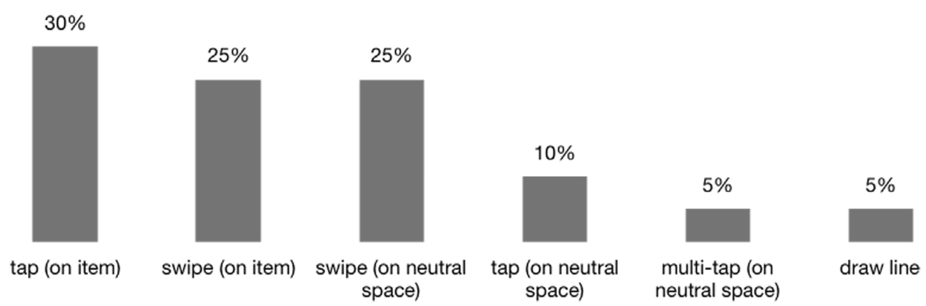
Overall, the magnified view of cursor task was the one with the lowest consensus among participants in gesture selection, reaching only 23%. The most executed gesture was *tap (on item)*, followed by *swipe (on item),* and *swipe (on neutral space)*. None of the above gestures match the current *tap and hold* implemented in most smartphones (see Table 6.1), which leads us to believe that current smartphone gestures might not be adequate for older adults. The following table provides details regarding participants, and respective gestures executed for this task.

Table 6.12 Gestures performed for the *magnified view of cursor position* task

Subject Nº	Gesture	Fingers	Hand
2	*tap* (on item)	Index	Right
3	*tap* (on item)	Index	Right
4	*tap* (on item)	Index	Right
6	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Left
12	*swipe* (on item)	Index	Right
15	*swipe* (on item)	Index	Right
18	*swipe* (on item)	Index	Right
19	*swipe* (on item)	Index	Right
20	*swipe* (on item)	Index	Right
11	*swipe* (on neutral space)	Index	Right
13	*swipe* (on neutral space)	Index	Right
14	*swipe* (on neutral space)	Index	Right
16	*swipe* (on neutral space)	Index	Right
17	*swipe* (on neutral space)	Middle; Thumb	Left
7	*tap* (on neutral space)	Middle	Right
9	*tap* (on neutral space)	Index	Right
1	multi-*tap* (on neutral space)	Middle; Index	Left & Right
5	draw line	Index	Right

Next, Graph 6.9 provides an overview of the data presented in the above table. As we can see, *tap (on item)* was performed by 30% of participants, followed by *swipe (on item)* by another 25%. In addition, gestures considered as random — *swipe (on neutral space), tap (on neutral space) and multi-tap (on neutral space)* — amounted to 40% of all gestures. Interestingly, the only novel gesture performed for this task was drawing a line over the cursor. However, only one participant performed this gesture and therefore it cannot be generalised as a substitute for the current *tap and hold* used on smartphones.

Graph 6.9 Percentage of unique gestures performed for the *magnified view of cursor position* task



Lastly, 90% of participants used a single finger for interaction, of which 85% used their index finger and 5% their middle finger. Only 10% used more than one finger, where 5% account for the middle finger and thumb, and another 5% for the middle and index fingers.

TASK 10: ROTATE CONTENT

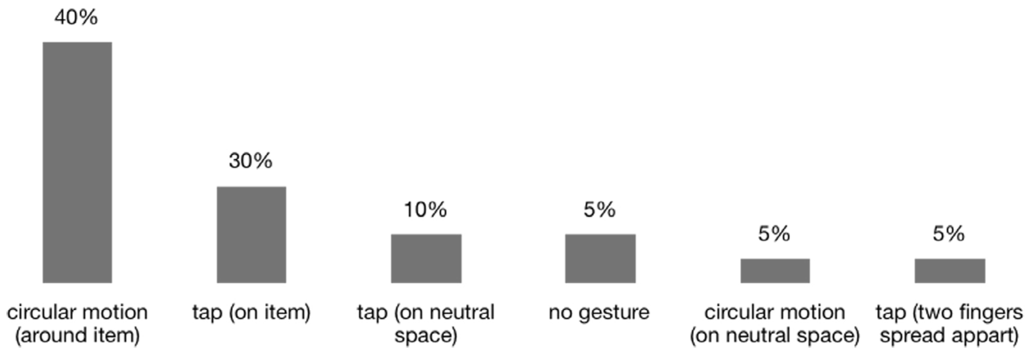
The consensus on gesture selection for the rotate content task was 28%. Where the most performed gesture was a novel one, which consisted of drawing a circle, in a clockwise direction around the item as if to rotate it which is consistent with the findings of (Mauney et al., 2010). The following table presents details regarding participants and gesture performance.

Table 6.13 Gestures performed for the *rotate content* task

Subject Nº	Gesture	Fingers	Hand
17	circular motion (around item)	Index	Left
4	circular motion (around item)	Index	Right
5	circular motion (around item)	Index	Right
6	circular motion (around item)	Index	Right
11	circular motion (around item)	Index	Right
15	circular motion (around item)	Index	Right
18	circular motion (around item)	Index	Right
12	circular motion (around item)	Middle	Right
13	circular motion (around item)	Index;Thumb	Right
14	circular motion (around item)	Index;Thumb	Right
3	*tap* (on item)	Index	Right
8	*tap* (on item)	Index	Right
9	*tap* (on item)	Index	Right
10	*tap* (on item)	Index	Right
19	*tap* (on neutral space)	Index	Right
20	*tap* (on neutral space)	Index	Right
1	circular motion (on neutral space)	Middle;Index	Left
7	*tap* (two fingers spread appart)	Middle;Index	Right
2	no gesture	-	-
16	no gesture	-	-

Next, Graph 6.10 presents an overview of the data from the previous table. In this graph we can see that 55% of participants performed the previously discussed circular gesture, either around the displayed item (50%) or on unrelated neutral space (5%). In addition, this gesture was performed using one or two fingers depending on the participant. Other remaining gestures, consisted of *tap (on item)* at 30%, or *tap (on neutral space)* at 5%, or no gesture at all (5%).

Graph 6.10 Percentage of unique gestures performed for the *rotate content* task



Lastly, only 10% of participants interacted with their right hand. Regarding the number of fingers used, 65% used their index finger, while 5% used their middle finger, and 40% used either their index and thumb, or their middle and index fingers in conjunction.

GESTURE CHARACTERISTICS

We will now discuss specific gesture characteristics regarding posture and number of fingers used for interaction. Overall, as shown in Table 6.14, 60% of participants opted for placing the smartphone on a table instead of holding it. However, this could be explained by the apparatus used in these tests, where a small camera and frame where attached to the smartphone (see Section 6.2.2). Although the frame and the camera were very light and the whole structure, including the smartphone, could be easily held in one hand — much like holding only the smartphone itself, it might have nonetheless influenced participants' posture. This is consistent with the findings of (Stößel et al., 2009) where 50% of the elderly participants preferred to place the device on a table.

Table 6.14 How participants placed or held the smartphone while performing tasks

On table	In left hand	In right hand
60%	35%	5%

When participants adopted more than one posture during the test session (e.g., first held the smartphone and then placed it on the table to perform most of the tasks), then the most used posture was considered for analysis.

Additionally, as was discussed for each individual task and is now summarised in Table 6.15, 83% of participants used only their index finger for interaction. Furthermore, only 1% of participants used their thumbs, which is contrary to what is generally accepted for younger adults who prefer to use their thumbs to perform most tasks, except those requiring text entry. (Karlson, Bederson, & L., 2006).

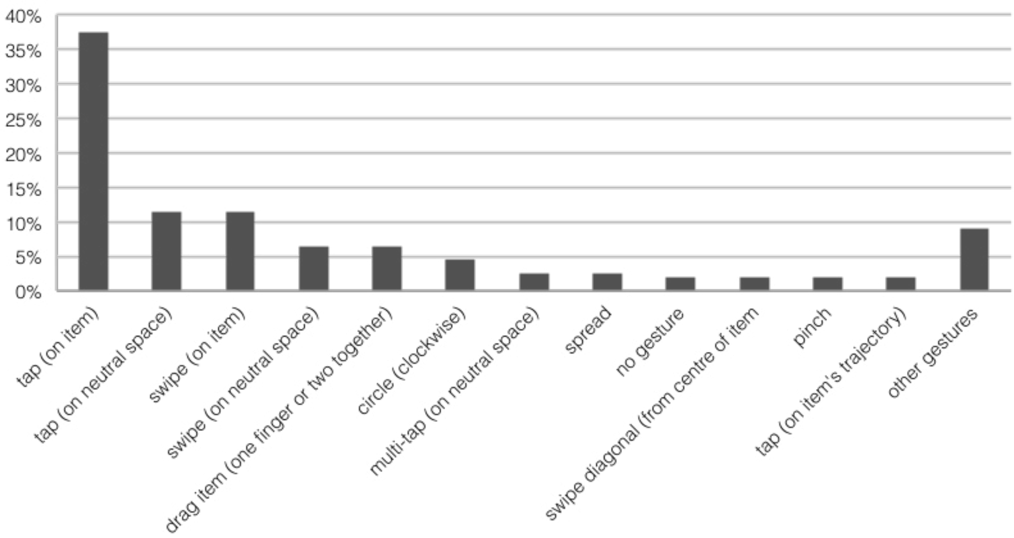
Table 6.15 Fingers used for interaction while performing test tasks

All fingers	Index	Index and Thumb	Middle	Middle and Index	Middle and Ring	Middle and Thumb	Thumb	No gesture	Grand Total
2%	83%	3%	4%	3%	0.5%	1.5%	1%	1%	100%

6.2.5 DISCUSSION

The purpose of this study was to assess the discoverability of current smartphone gestures, and to elicit a set of user-defined gestures for older adults operating smartphones. We found that in general, older adults tend to use the same gestures as those that are currently implemented on smartphones. Moreover, as Graph 6.11 demonstrates the most commonly used gestures were *tap* and *swipe*. Although a few new gestures were performed, none of them reached a satisfactory level of agreement between users. In other words, a single new gesture was never performed by more than 10% of the participants, while common gestures such as *tap* and *swipe* were performed by as many 70% and 45% of participants, on the *select an item* and on the *scroll content* tasks. In addition, we found that more complex gestures such as *double-tap, touch and hold, pinch* and *spread* were not understood, or discovered by our participants, where the *double-tap* and *touch and hold* were not performed at all. While *pinch* ,and *spread* were only performed by 20% of participants for the *zoom-in* and *zoom-out* tasks respectively.

Graph 6.11 Overview of all gestures performed by participants for the ten tasks



Furthermore, when considering current smartphone gestures and comparing these with the gestures performed by participants, we find that:

- Only 52% of participants would have correctly solved tasks requiring a *swipe* gesture;
- 70% would have correctly solved tasks requiring *tap* gestures;
- 20% would have solved those requiring *pinch* or *spread;*
- And none would have correctly performed tasks requiring *touch and hold*.

However, when analysing these results it is important to keep in mind that in many cases, participants stated to not know what gesture to perform or how to solve the task and would then proceed to simply *tap* or *swipe* the screen. This could mean that the high percentages of correct gestures seen for *tap* and *swipe* tasks could indeed be biased. Nonetheless, it seems that these two gestures were simple enough to act as stand-ins for cases when no other gesture was immediately obvious, which is consistent with the findings of (Beringer, 2002) and (Voida, Podlaseck, Kjeldsen, & Pinhanez, 2005). Therefore, when designing smartphone interfaces for older adults, keep in mind that they will often tap or swipe your interface when they do not know what to do next. In this way, the users will often open new menus or pages unintentionally and further loose themselves within the flow of your application.

Furthermore, gestures such as *tap and hold* or *double-tap* were not performed by any of the users, while others such as *pinch and spread* were carried-out by very few. This could in turn mean that soft UI buttons are still needed for the actions that are activated by these particular gestures.

In conclusion, the initial goal of creating a user-defined gesture set was not accomplished. Contrary to what was expected, participants without prior touchscreen experience did not perform a novel set of gestures. This could be due to the fact that many participants referred not to know what to do, because they did not understand how they could act on 'images hidden behind a glass plate'. Overall, participants did not have much experience with ICT devices and had difficulty in engaging with the experiment, or in understanding the purpose of performing such tasks. In addition, as each session took on average 30 to 45 minutes, older adults started to get anxious or preoccupied, which could have also influenced their performance. During the following phases of our research we decreased the time for each session, in order to avoid causing discomfort to the participants.

However, these findings did enable us to get a better understanding of the gestures older adults perform, as well as they way in which they perform these gestures. These findings are documented the following design pattern, which can be viewed in Section 10:

- SELECTING SMARTPHONE GESTURES FOR OLDER ADULTS

The fact that older adults did not perform new gestures could be explained by the lack of previous experience with gestural interaction systems (Table 6.2), where participants did not have the necessary knowledge that would allow them to more freely explore the performance of gestures for the tasks presented to them. In this context, we decided to further our investigation regarding the usability of smartphone interfaces for older adults by seeing if we could effectively teach current smartphone gestures to our target-users. Accordingly, the following section will detail the study designed to do so.

7 PHASE TWO: TEACHING SMARTPHONE GESTURES TO OLDER ADULTS

The previous phase of research revealed that smartphone gestures were not easily discoverable by older adults. However, we did see that those that were overall better understood were *tap* and *swipe* (Graph 6.11). Furthermore, to our knowledge several research efforts have been made to compare the usage of direct (e.g., touchscreen) versus indirect input (e.g., trackball) devices by older adults (see section 3.3), as well as participants ability to physically perform touchscreen gestures (see section 3.3). However, research regarding older adults and the immediate discoverability of touchscreen gestures has still not been extensively explored.

Given the results from the first phase of our study, where in many cases participants would not have correctly solved tasks on existing smartphones, nor was it possible to define a new set of gestures that would be more adequate for them. We found that further investigation was needed, and in order to do so, we conducted a second phase of research were our aim was to answer to following question:

- RQ4: If current smartphone gestures prove to be problematic, and if older adults do not propose a set of user-defined gestures, can we effectively teach them how to use the current ones?

In this context, the use of tutorials to teach gestures to users has been explored by several authors (Bau & Mackay, 2008; Bragdon et al., 2010; Kurtenbach, Moran, & Buxton, 1994). For this purpose, we developed a set of five tutorials to explain each of the tasks, and corresponding gestures. Only five tasks were considered as they were the ones that made use of *tap* and *swipe* gestures. Both these gestures revealed to be the easiest for older adults in the first phase of our study, while also being the most essential to operate a smartphone. Moreover, all other gestures, such as *tap and hold, double-tap, pinch* and *spread*, generally have UI buttons that substitute them, allowing users to accomplish the task without being aware of the correct gesture. Therefore, we decided to concentrate only on the tasks requiring *tap* and *swipe*. Besides focussing only on the most essential gestures, we also aimed to maintain each test session limited to 30 min. We found in our previous set of tests, that participants began feeling anxious, uneasy or even bored when sessions became too long. Therefore, we considered it best to limit our study to a small, but essential, set of gestures to be studied.

For each of the five tasks an individual tutorial was developed, in the form of an animation. These tutorials demonstrate the physical performance of a gesture, and also the tasks in which each gesture should be applied. In this way, firstly participants are shown how to solve tasks with gestures, and are then asked to solve those same tasks with the knowledge they gained.

The following sections will provide further detail regarding (1) participants, (2) apparatus used, (3) the test procedure, (4) the results from our study, and finally (5) a discussion of our main findings.

7.1 PARTICIPANTS

A new set of twenty Portuguese older adults, with ages between 60 and 90 years (Mean = 74.3 years old) voluntarily participated in this study. Participants were recruited from several retirement centres and adult day-care centres within the city of Porto, and all had normal or corrected to normal vision. We did not collect any data that allows for the identification of these participants, and all of them agreed to take part in this study (see session script in Appendix A.2).

Regarding participants' computer experience see Table 7.1, only 2 participants reported using a computer on a daily basis, while another three stated using a computer at least once a week. However, most of the participants had never used a computer. While computer use was fairly low, eighteen participants owned a mobile phone while only two did not. None of the users had ever used a touchscreen device but seven of them said they had observed friends or family using these devices. Participants' characteristics are summarised in the following table.

Table 7.1 Participant data

Participant Nº	Age	Gender	Frequency of computer usage	Owns a mobile phone	Owns a touchscreen device	Observed a touchscreen device being used
1	69	f	none	yes	no	no
2	90	f	none	no	no	no
3	86	f	none	no	no	no
4	60	f	none	yes	no	no
5	67	m	daily	yes	no	yes
6	69	f	none	yes	no	yes
7	80	m	none	yes	no	no
8	67	m	less than once a week	yes	no	no
9	73	m	at least once a week	yes	no	yes
10	80	f	none	yes	no	yes
11	88	f	none	yes	no	no
12	83	f	none	yes	no	no
13	77	f	none	yes	no	no
14	71	m	none	yes	no	no
15	68	f	none	yes	no	no
16	68	f	none	yes	no	yes
17	67	f	daily	yes	no	yes
18	76	f	less than once a week	yes	no	yes
19	83	f	none	yes	no	no
20	64	f	none	yes	no	no

7.2 APPARATUS

The study was conducted with a Samsung Galaxy Nexus measuring 135.5 x 67.94 mm, with a 1280×720 px display at 316 ppi. In order to video record the sessions, a Noldus Mobile Device Camera1 was attached to the smartphone. The whole setup was light and easily held in one hand. This particular smartphone was chosen because it is slightly larger than most commercially available smartphones. Due to the device's size we believed it would be easier for older adults to comfortably hold, and given its large multi-touch screen we also believe it would be easier for older adults to effectively perceive the onscreen contents.

The applications used to collect the data generated for this phase of testing were developed using Processing for Android2, then deployed and run on the smartphone itself.

During the test sessions, participants would sit on a chair in front of a table while performing the tasks. They were asked to hold the device in the same way they would do with their own mobile phones.

7.3 PROCEDURE

Each participant performed five tasks that required commonly used touchscreen gestures (see Table 6.1). Only tasks that required the use of *tap* and *swipe* gestures were considered in this second phase of testing. These tasks were defined as (1) *scroll content*, (2) *pan content,* (3) *move an item,* (4) *select an item*, and (5) *stop scrolling content.* In addition, all five tasks were solved by each participant in a randomised order.

For all of the above-mentioned tasks, a short animated tutorial was shown. The tutorials had the objective of teaching participants how, and in what cases, a particular gesture should be carried out. In other words, they do not just demonstrate the physical and motor execution of a gesture, but also which specific tasks it resolves.

In addition, all tasks followed the same general structure. This structure was enforced by the screen-flow of the applications developed for this phase. Participants would first be presented with a screen containing a single button labelled as "View example" (see Figure 7.1). After pressing this button, the tutorial would start playing (Figure 7.2). Once the tutorial stopped, another screen was presented with a further two labelled buttons: (1) "Try", and (2) "View Tutorial" (Figure 7.3). Participants could at this stage attempt to solve the task (Figure 7.4) or if needed, watch the tutorial again (tutorial views were limited to three per task). One tutorial was shown to participants before each task as these were meant to simulate contextual help mechanisms. These contextual help mechanisms would appear when a system detects that a user is either performing the wrong gesture, or does not know what to do, as opposed to a more common approach where a set of tutorials is shown on the device's first start-up.

Finally, contrary to the first set of user-testing, the prototypes for these tests were fully functional. We decided to adopt this approach because in the previous phase of our research participants were often confused by the lack of feedback, they did not understand why nothing would happen when they performed a gesture. Similarly (Stößel, 2009) reported that the lack of system feedback generated confusion among older adult participants. Naturally, it did not seem to make sense to show a tutorial

1 http://www.noldus.com/human-behavior-research/accessories/mobile-device-camera-mdc

2 http://wiki.processing.org/w/Android of a gesture, then ask participants to perform those gestures on a prototype that would not confirm, or deny, the intended knowledge acquisition.

The following sections provide further detail regarding each of the five tasks, and the animated tutorials that were designed for each one of them.

Figure 7.1

Figure 7.2

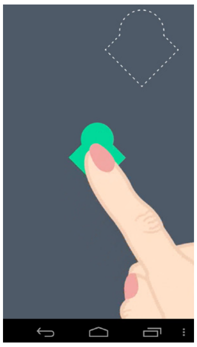
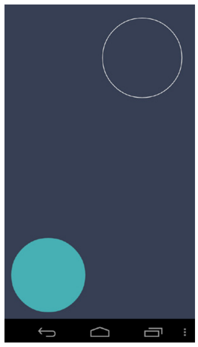


Figure 7.3

Figure 7.4



TASK 1: SCROLL CONTENT

For the *scroll content* task, an animated tutorial depicts a partially hidden geometric figure being scrolled into view. The animation starts by showing only part of the otherwise hidden figure, and after a few moments an illustrated finger appears and scrolls that same figure into view. Once the finger reaches the centre of the display, it leaves the figure in place, and moves out of the display's boundaries. An overview of the animation can be seen in Figure 7.5, and Figure 7.6 shows the application where participants would attempt to mimic the tutorial.

The intention of this task was that participants would scroll the geometric figure into view, by using a *swipe* gesture, as demonstrated in the tutorial.

Figure 7.5 Screenshots of animation for *scroll content* task

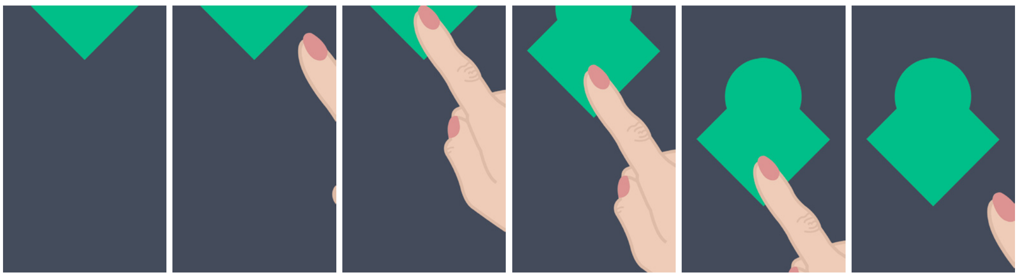


Figure 7.6 Screen appearance during gesture input for the *scroll content* task

TASK 2: PAN CONTENT

Similarly to the *scroll content* task, this tutorial first depicts a partially hidden geometric figure, and then shows that figure being moved into view. Initially, only half of the figure appears onscreen, as its left portion is hidden to the left edge of the display. After a few moments, an illustrated finger appears and *pans* the whole figure into view, leaving it at the centre of the display. An overview of the animation, that can be seen in Figure 7.7, and Figure 7.8, shows the application where participants would then attempt to mimic the tutorial.

Finally, the objective of this task was that participants would move the whole geometric figure toward the centre of the display. And in order to do so, our aim was to assess if they would correctly employ a *swipe* gesture.

Figure 7.7 Screenshots of animation for *pan content* task

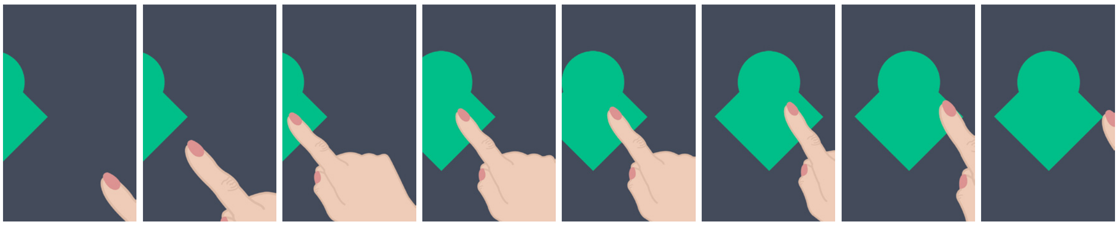
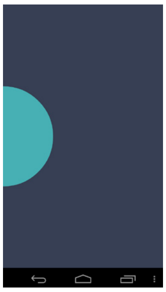


Figure 7.8 Screen appearance during gesture input for the *pan content* task



TASK 3: MOVE AN ITEM

For the *move an item* task, the tutorial shows a finger moving an item from the bottom-left-corner of the display, into another item at the opposite top-right-corner. Initially, the two geometric figures appear stationary on the smartphone's display. One of these figures is then moved into the other, by an illustrated finger. After placing one figure into the other, the finger moves away and disappears from view. Figure 7.9 provides an overview of this tutorial, and Figure 7.10 shows the application where participants would then attempt to mimic the gesture shown in the tutorial.

Lastly, the intent of this task was that participants would drag one figure into the other, by correctly making use of a *swipe* gesture.

Figure 7.9 Screenshots of animation for *move an item* task

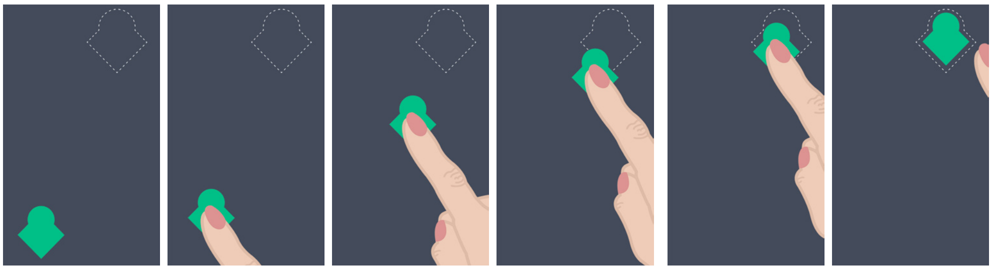
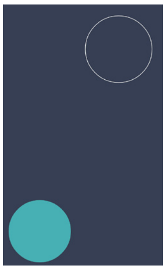


Figure 7.10 Screen appearance during gesture input for the *move an item* task



TASK 4: SELECT AN ITEM

For the *select an item* task, an animated tutorial demonstrates a single item being selected from a group of items, much like can be done on the applications screens on the iPhone and Android. The animation starts by showing a set of four stationary items onscreen. After a few moments, an illustrated finger appears and performs a *tap* on the top-right item. After selecting the item, the finger disappears from view. An overview of the animation can be seen in Figure 7.11, and Figure 7.12 shows the application where participants would then attempt to mimic the tutorial.

Finally, the aim of this task was that participants would correctly make use of a *tap* gesture to select an item.

Figure 7.11 Screenshots of animation for *select an item* task

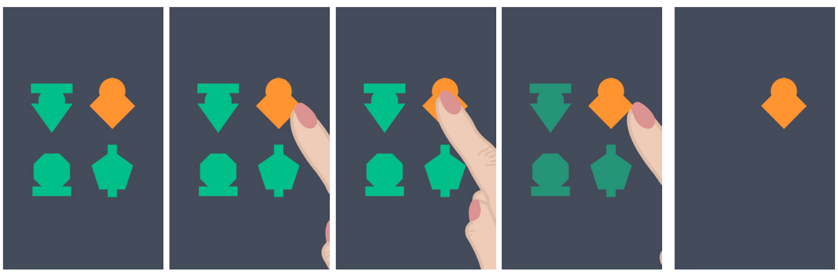


Figure 7.12 Screen appearance during gesture input for the *select an item* task

TASK 5: STOP SCROLLING CONTENT

In the case of the *stop scrolling content* task, the tutorial shows a list of fifty numbers moving from the top toward the bottom of the display. The tutorial begins by displaying a list of numbers partially hidden to the top of the screen. Then, the list starts moving downward until eventually disappearing entirely, leaving a blank screen. However, for this particular task, the list would begin moving again after a few seconds. We did this so that participants could perform a gesture to stop the moving list. An overview of the tutorial can be seen in figure 7.13, and figure 7.14 shows the application where participants would then attempt to mimic the gesture shown in the tutorial.

Further, our objective was that participants would stop the moving list, by adequately making use of a *tap* gesture.

Figure 7.13 Screenshots of animation for *stop scrolling content* task

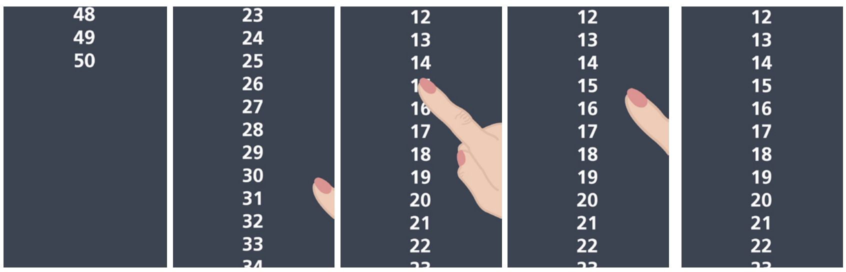
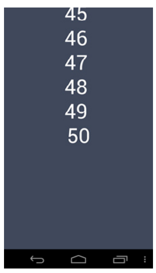


Figure 7.14 Screen appearance during gesture input for the *stop scrolling content* task



Finally, now that a description of each task has been provided, we will review the results for each task.

7.4 RESULTS

Considering the results analysis, we defined a set of criteria for distinguishing correct and incorrect gestures. In this way, correct gestures were those that match the current smartphone gesture (see Table 6.1). While incorrect gestures, were those that do not coincide with the existing smartphone gestures.

Our objective was to assess if the introduction of tutorials would help older adults performance of correct gestures. Consequently, the data from the first phase of tests was re-coded according to this criteria of correct or incorrect gestures, where our intention was to make the two phases of testing comparable. In this way, we could study the immediate discoverability of a particular gesture, versus the performance of correct gestures after viewing a tutorial. This allowed us to assess both the extent to which the lack of gesture discoverability affects usability, as well as the potential of contextual help for older adults using such systems. Accordingly, the following sections will compare the results from this second phase of tests, with those of phase one (see Section 6).

TASK 1: SCROLL CONTENT

The following table shows correct or incorrect gestures performed for the *scroll content task,* according to each participant. In addition, it details the number of times each participant viewed the tutorial before attempting to solve this task. A comparison of correct or incorrect gestures executed in the first set of tests (see Section 6) versus this second phase of tests, is shown in Graph 7.1.

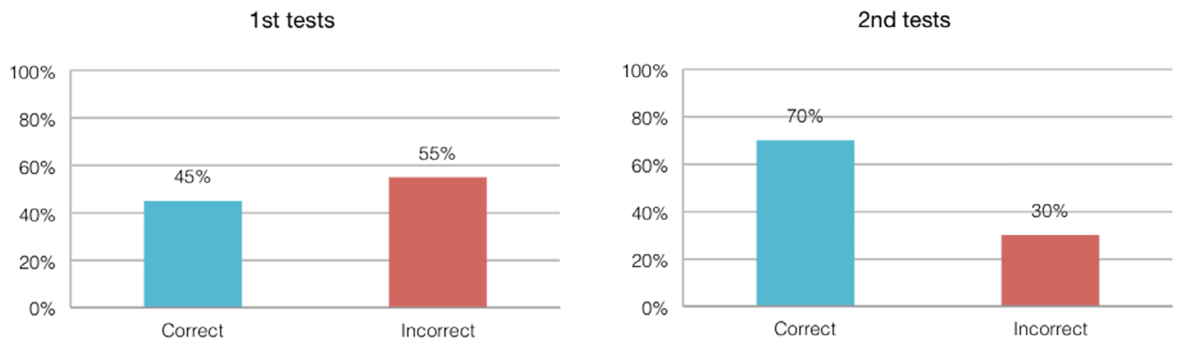
Table 7.2 Participant data for *scroll content* task

Subject Nº	Right or Wrong	Number of tutorial views
1	Right	1
2	Right	2
3	Right	1
4	Right	2
5	Right	1
6	Right	2
7	Right	2
8	Wrong	2
9	Right	3
10	Wrong	1
11	Wrong	3
12	Wrong	2
13	Right	1
14	Wrong	1
15	Wrong	1
16	Right	1
17	Right	1
18	Right	1
19	Right	1
20	Right	1

Table 7.2 shows that 60% of participants viewed the tutorial only once, while 30% asked to see the tutorial a second time, and 10% saw three repetitions.

In addition, regarding Graph 7.1 it seems that the introduction of a tutorial did in fact enhance participants' performance. Where the number of wrong gestures went down from more than half (55%) to only 30%, which means that more older adults were able to correctly employ a *swipe* gesture to scroll content. Consequently, it seems the introduction of a tutorial did indeed enhance performance in the *scroll content* task.

Graph 7.1 Correct and incorrect gestures performed in the first phase of tests, and in the second phase of tests



TASK 2: PAN CONTENT

Regarding the *pan content* task, the following table presents the number of correct or incorrect gestures for each participant. In addition, it also contains the number of tutorial views per participant. Then, Graph 7.2 presents a comparison of the results between the first phase of tests and this second phase, with the objective of assessing the influence of the tutorial on gesture performance.

Table 7.3 Participant data for *pan content* task

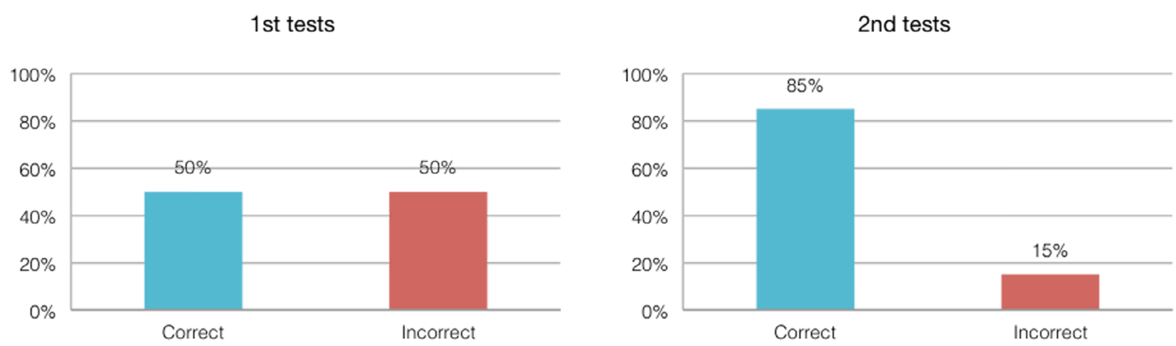
Subject Nº	Right or Wrong	Number of tutorial views
1	Right	1
2	Right	1
3	Right	1
4	Right	1
5	Right	1
6	Right	1
7	Right	1
8	Wrong	2
9	Right	1
10	Right	1
11	Right	1
12	Wrong	2

13	Right	1
14	Wrong	2
15	Right	1
16	Right	1
17	Right	1
18	Right	1
19	Right	2
20	Right	1

Regarding tutorial views, 60% of participants viewed the tutorial only once, while the remaining 40% asked to watch it a second time. Unlike in the previous task, none of the participants needed to view the tutorial a third time.

Next, looking at Graph 7.2, it seems that the introduction of the tutorial did in fact enhance the number of correct gestures performed. A total of 85% of participants executed the correct gesture in this test versus only 50% in the first phase. This shows that more participants correctly employed a *swipe* gesture to pan content. In this way, it seems that the introduction of the tutorial did in fact benefit older adults' performance. This improvement was registered also when considering the low number of tutorial views, for this task.

Graph 7.2 Correct and incorrect gestures performed in the first phase of tests, and in the second phase of tests



TASK 3: MOVE AN ITEM

Considering the *move an item* task, Table 7.4 presents an overview of correct, or incorrect, gestures performed by participants. As well as, the number of tutorial views per participant. Then, Graph 7.3 provides a comparison between the first phase of testing and this second phase, again according to correct or incorrect gestures.

Table 7.4 Participant data for the *move an item* task

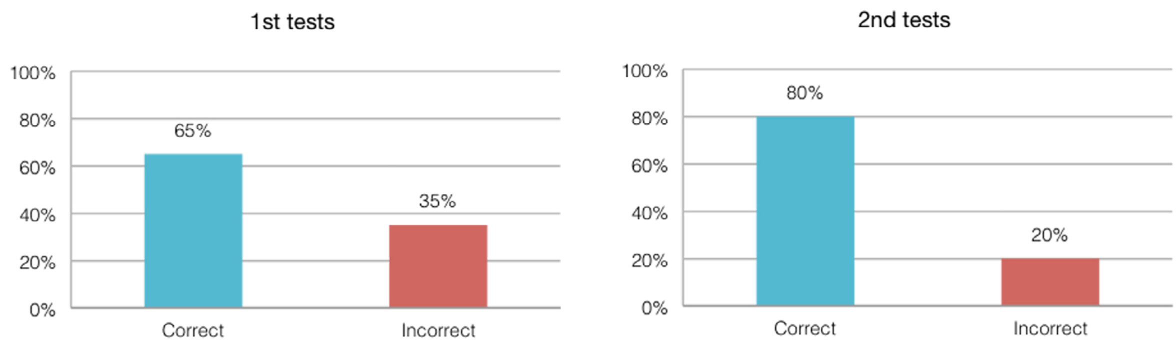
Subject Nº	Right or Wrong	Number of tutorial views
1	Right	1
2	Wrong	1
3	Right	1
4	Wrong	2

5	Right	1
6	Right	1
7	Right	2
8	Wrong	3
9	Right	1
10	Right	1
11	Right	1
12	Wrong	3
13	Right	1
14	Right	1
15	Right	1
16	Right	1
17	Right	1
18	Right	1
19	Right	1
20	Right	1

Regarding tutorial views, most participants did not ask to view the tutorial more then once (80%). Only 10% asked to view it a second time, and the remaining 10% watched the tutorial a total of three times.

Additionally, considering Graph 7.3 the number of correct gestures performed went up from 65% in the first phase, to 80% in the second phase. Although the level of improvement is slightly lower than in the previous tasks, it still increased a total of 15%. This means that more participants correctly employed a *swipe* gesture to drag content from one location to another. Likewise, these results lead us to believe that the introduction of a tutorial could in fact enhance older adults performance in dragging items on smartphones.

Graph 7.3 Correct and incorrect gestures performed in the first phase of tests, and in the second phase of tests



TASK 4: SELECT AN ITEM

The following table presents an overview of the results for the *select an item* task. It details the number of correct or incorrect gestures carried out by each participant, as well as the number of tutorial views per participant. Next, Graph 7.4 compares results from the first phase of tests with this second phase, with the intent of assessing the influence of the tutorial on gesture performance for this task.

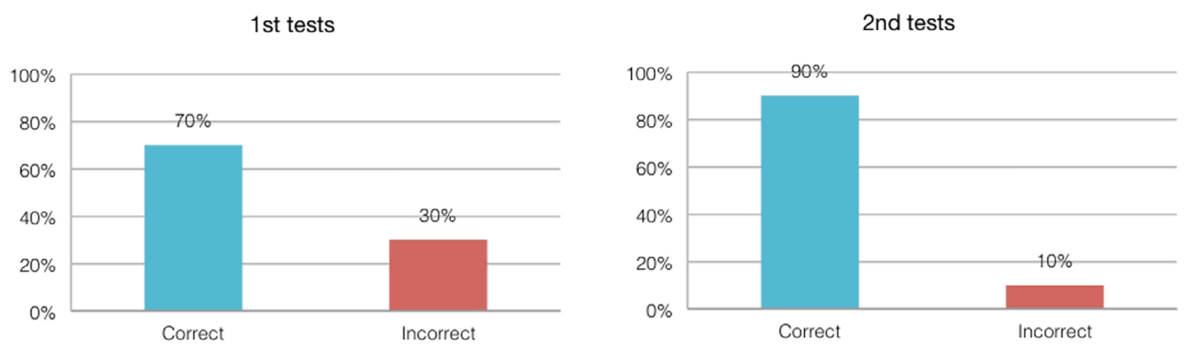
Table 7.5 Participant data for the *select an item* task

Subject Nº	Right or Wrong	Number of tutorial views
1	Right	1
2	Right	1
3	Right	1
4	Right	1
5	Right	1
6	Right	1
7	Wrong	1
8	Right	3
9	Right	1
10	Right	2
11	Right	3
12	Right	1
13	Right	2
14	Right	1
15	Right	1
16	Right	1
17	Right	1
18	Right	2
19	Right	1
20	Right	1

With respect to tutorial views, 75% of participants watched the tutorial once, while 15% asked to view the tutorial twice, and 10% viewed it three times. In addition, as illustrated by Graph 7.4, the percentage of correct gesture performance went up from 70% to 90%, from the first phase of tests to the second. However, it is noteworthy that during the first phase of user-testing, participants often *tapped* the screen as an escape to not performing any gesture at all (see Section 6), and could therefore negatively influence the level of improvement seen between phases. Nonetheless, more older adults were able to correctly make use of *tap* for selecting an item in the second phase, than in the first.

This shows that the introduction of a tutorial did seem to enhance participants' performance for the *select an item* task, even though the level of improvement was slightly lower than in previous tasks.

Graph 7.4 Correct and incorrect gestures performed in the first phase of tests, and in the second phase of tests



TASK 5: STOP SCROLLING CONTENT

Regarding the *stop scrolling content* task, the following table presents the number of correct or incorrect gestures according to all participants. In addition, it also shows the number of tutorial views per participant. Then, Graph 7.5 presents a comparison of the results between the first phase of tests and this second phase, with the objective of assessing the influence of the tutorial on gesture performance.

Table 7.6 Participant data for the *select an item* task

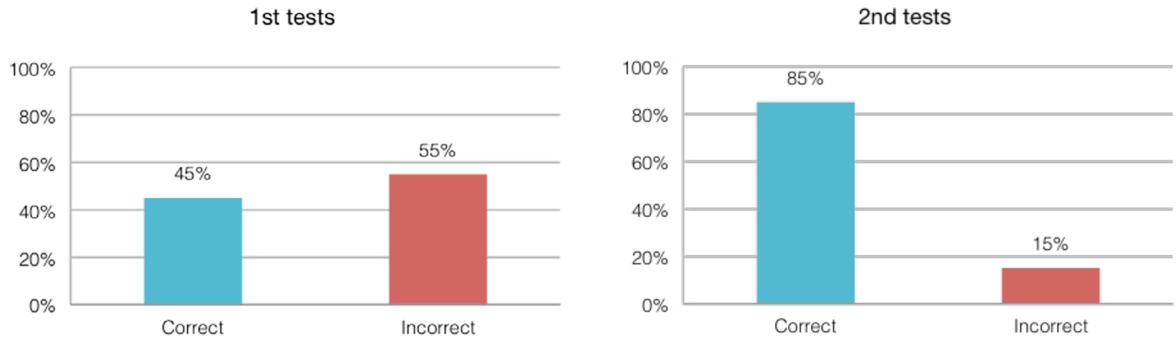
Subject Nº	Right or Wrong	Number of tutorial views
1	Right	1
2	Right	3
3	Right	2
4	Right	1
5	Right	2
6	Right	1
7	Right	1
8	Right	3
9	Right	1
10	Right	1
11	Right	1
12	Right	1
13	Wrong	1
14	Right	1
15	Right	1
16	Right	1
17	Right	1
18	Right	1
19	Right	1
20	Right	2

Focussing on tutorial views, 75% of participants viewed the tutorial only once, while the 15% asked to watch it a second time, and 10% required viewing it three times.

In addition, Graph 7.5 shows that the introduction of the tutorial did in fact enhance the number of correct gestures performed., where 85% of participants executed the correct gesture versus only 75% in the first phase. In other words, a higher number of participants correctly employed a *tap* gesture in order to stop scrolling content. Furthermore, as previously stated *tap* was often used as a stand-in, during the first phase of tests, for cases where participants did not know what else to do. Therefore, the lower level of improvement registered in this task versus the higher levels found in the *swipe* tasks, could in fact be negatively influenced by this stand-in function of *tap*.

Nonetheless, like in all other tasks, participants' performance did seem to improve with the introduction of a tutorial for this task.

Graph 7.5 Correct and incorrect gestures performed in the first phase of tests, and in the second phase of tests



7.5 DISCUSSION

The purpose of this study was to investigate if we could teach older adults to use current smartphone gestures, by introducing a set of visual tutorials that were available on the smartphone itself. Our objective was to answer RQ5:

- RQ5: *Can we effectively teach current smartphone gestures to older adults?*

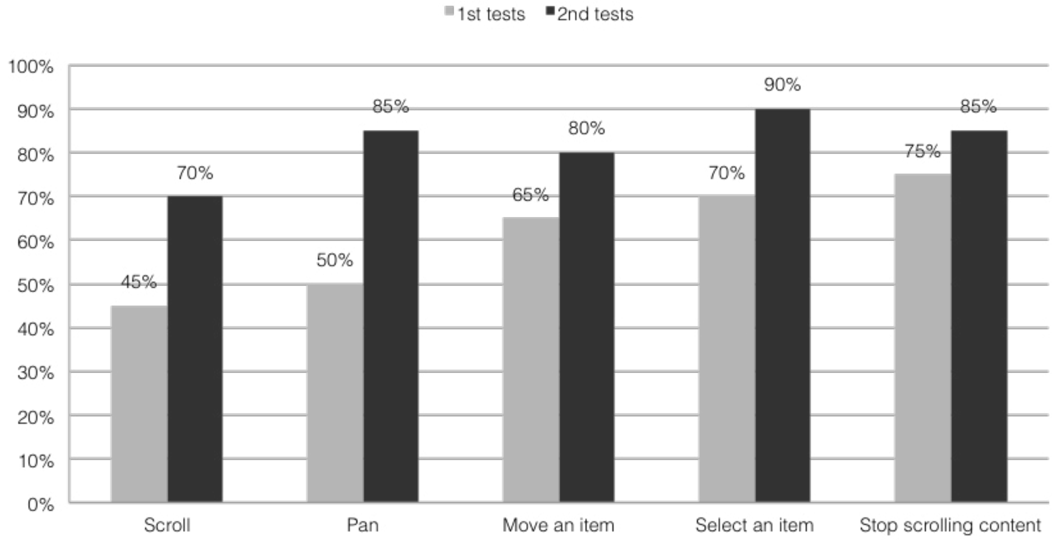
Our results indicate that there was in fact an improvement in correct gesture performance from the first phase of our study to the current phase. In addition, all five tasks registered some level of improvement, being that *swipe* tasks showed slightly higher levels than *tap* tasks. In sum, improvement levels for all tasks can be summarised as:

- 25% for *scroll content*;
- 35% for *pan content*;
- 15% for *move an item;*
- 20% for *select an item* and*;*
- 10% for *stop a scrolling list*.

As Graph 7.6 demonstrates, the introduction of tutorial might have indeed improved participants' overall performance of current smartphone gestures.

Furthermore, most participants only required viewing each tutorial once. This low number of tutorial views, associated with above mentioned improvement rates, lead us to believe that contextual help mechanisms can in fact be an important aid for older adults learning how to operate smartphones. The finding that contextual help, or other forms of explanation, can in fact improve older adults' performance is consistent with the findings of (Stößel, Wandke, & Blessing, 2009). In addition, we believe the use of such tutorials could be especially important for older adult users who are not familiar with technology. As these could provide the infrastructure needed to overcome initial lack of gesture discoverability, while allowing for progressive learning while interacting with these devices.

Graph 7.6 Comparison of correct gestures performed in the first and second phases of testing with users



However, it is noteworthy that the participants were different between the first and the second study. Consequently, it would be interesting to further investigate the potential of such tutorials in enhancing gesture performance for older adults, by use of a within-subjects experimental design.

Our findings are consistent with that of (Stößel et al., 2009; Stößel, Wandke, & Blessing, 2010), where participants were in fact physically able to perform gestures if these were previously explained, or demonstrated in some manner. However, in their study participants were asked to trace over several line shapes with their fingers, without knowing what a particular gesture was for. Our study aimed to teach participants how to physically perform gestures, but overall we aimed to teach them how to use gestures to resolve tasks. Furthermore, the performance improvement supported by the introduction of tutorials is also consistent with the findings of (Broady, Chan, & Caputi, 2010), where the authors believe that proper training can positively influence older adults performance and attitudes toward ICT devices.

The results from these findings were documented in the following design pattern, fully included in Section 10:

- FOR NOVICE USERS, PROVIDE DEMONSTRATIONS OF AVAILABLE GESTURES

8 PHASE THREE: EVALUATING TARGET SIZES AND SPACING BETWEEN TARGETS FOR OLDER ADULTS

Considering the results from the previous phase of testing with users (see Section 7), we found that we could effectively teach *tap* and *swipe* gestures to older adults. As a result, the aim of this current phase of research was to assess the influence of touch target sizes, and spacing sizes between targets on the performance of such gestures.

Accordingly, to our knowledge research regarding touch target sizes on smartphones for older adults has not yet been extensively explored. Kobayashi, Hiyama, Miura, et al., (2011) investigated target sizes for *tap* gestures on mobile touchscreen devices but considered only three different targets sizes for individual targets with no neighbours. In addition, Jin, Plocher and Kiff (2007) also conducted a study to evaluate touch target sizes for older adults using a 17-inch touchscreen tablet fixed on a stand and presented at a 45º angle to the participants. Therefore, their results are not directly applicable to mobile devices such as smartphones.

On the other hand, several research efforts have been conducted with younger subjects. Parhi, Karlson and Bederson (2006) carried-out a study with twenty younger adults with the objective of evaluating thumb-based interaction and the performance of both discrete and serial *tap gestures*[1], according to target dimensions and onscreen locations. The authors found that for serial *taps* targets should be at least 9.6 mm square, and for discrete *taps* this value should be 9.2 mm square. Later, Perry and Hourcade (2008), conducted a similar study and found that accuracy was only over 95% for the largest target size, which was 11.5 mm. Both of these studies were conducted using PDAs, and solely concentrated on one-handed thumb use. More recently, Henze, Rukzio and Boll (2011) aimed to evaluated the effect of target sizes, and targets' onscreen positions on participants' performance. They found error rates started to increase dramatically for targets below 15 mm square.

In addition, most currently available smartphone guidelines[2] do not aid designers in creating a smartphone

1 Discrete target selection involves acquiring a single target, while serial target selection involves acquiring a sequence of targets.

2 Android: http://developer.android.com/design/style/metrics-grids.html

iPhone: https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

Windows Phone: http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx

user-interfaces (UIs) that adequately responds to older adults' specific characteristics. These guidelines recommend 9 mm touch-targets as the ideal, or for cases when screen real-estate is limited they advise the usage of targets around 7 mm square. These target dimensions are considerably smaller than the recommendations found in the previously discussed literature regarding younger adult users.

Regarding spacing sizes between targets, (Colle & Hiszem, 2004) and (Sun, Plocher, & Qu, 2007) found that with younger adults the spacing between *tap* targets had no significant effect on participants' performance. Although (Sun et al., 2007) revealed that contrary to what was expected, performance did not improve as spacings became larger. Similarly, (Jin, Plocher, & Kiff, 2007) found that older adults had longer reaction times with larger spacing sizes between *tap* targets, and that spacing should be between 2.17 and 12.7 mm. However, to our knowledge the effect of spacing sizes between targets has not yet been investigated for older adults interacting with mobile touchscreens. Additionally, existing smartphone OS guidelines recommend spacing of 1.5 to 2 mm, which is lower than those found by (Jin et al., 2007) for older adults using a larger fixed touchscreen.

Therefore, given the psychomotor, sensory, and cognitive declines associated with ageing (as discussed in Section 2), as well as the lack of existing guidelines for designing for older adults, we consider it of paramount importance to further investigate the influence of touch-target sizes, and spacing sizes between touch-targets, on the performance of common smartphone gestures. Accordingly, our aim was to provide answers for the following questions:

- RQ5: Are recommended touch-target sizes, found in official guidelines, adequate for older adults performing *tap* and *swipe* gestures?
- RQ6: Are current recommendations regarding spacing sizes between touch-targets adequate for older adults performing *tap* and *swipe* gestures?

In order to answer these questions, we developed two games to be played by older adults. Each game will allow us to measure the dependent values defined for the phase of tests: (1) accuracy, (2) task completion times, and (3) number of attempts. Accordingly, each dependent variable will be assessed according to the four independent variables: (1) *tap* target sizes, (2) spacing sizes between *tap* targets, (3) *swipe* target sizes, and (4) spacing sizes between *swipe* targets. The following sections will provide detail regarding the study's participants, apparatus used, procedure, results, and finally a discussion of our main findings.

8.1 PARTICIPANTS

Forty older adults (30 female and 10 male), with ages between 65 and 95 (Mean = 76.88) agreed to participate in this study (Table 8.1). Participants were recruited from several retirement homes and day-care centres within the city of Porto. We did not collect any data that allows for identifying participants, and all agreed to take part in this study (see session script in Appendix A.3). The following table provides an overview the ages and gender of each participant.

Table 8.1 Participants ages and gender

Participant Nº	Age	Gender
1	78	F
2	83	F
3	70	M
4	78	M
5	71	F
6	65	M
7	68	F
8	67	F
9	67	F
10	69	F
11	95	F
12	65	F
13	77	F
14	86	F
15	92	M
16	65	F
17	82	M
18	70	F
19	68	F
20	74	M
21	81	F
22	87	F
23	81	F
24	78	F
25	77	F
26	76	M
27	82	F
28	85	F
29	84	F
30	79	F
31	82	M
32	77	F
33	68	F
34	79	F
35	72	F
36	89	F
37	73	F
38	79	F
39	79	M
40	77	M

8.2 APPARATUS

All tests were performed on a Samsung Nexus S measuring 123.9 x 63 mm, with a 800 x 400 px display at 233 PPI. All participant data was logged on the smartphone itself, consequently there was no need to collect any audio or video during any of the sessions.

Unlike the first and second set of tests, we did not conduct these sessions in a separate room but rather were participants where already sitting. We found that older adults were generally less willing to participate when they were asked to go to a separate room with the facilitator. Therefore, due to time constraints and the high number of participants required for this phase of testing, we opted to conduct the sessions in the leisure rooms were participants were usually sitting, watching television or playing card games.

8.3 PROCEDURE

A within-subject design was used, in which two within-subject variables were included — touch target size and spacing between targets, for both the *tap* and *swipe* gestures.

Based on the average size of a human fingerpad, which is about 10 mm to 14 mm (Dandekar, Raju, & Srinivasan, 2003), five levels of touch target size where used: 21 mm, 17.5 mm, 14 mm, 10.5 mm and 7 mm. That is, target sizes considered the higher bound of the average human finger, which is 14 mm and then added or subtracted 14/4 = 3.5 mm in order to obtain the remaining sizes, e.g., 14 + 3.5 = 17.5 mm, 17.5 + 3.5 = 21 mm, 14 – 3.5 = 10.5 mm, and 10.5 – 3.5 = 7 mm. The smaller target size considered in this study matches the minimum target sizes recommended by Android[3], Apple[4], and Windows Phone[5].

Spacing between targets obeyed the same criteria and included another 5 levels: 0 mm, 3.5 mm, 7 mm, and10.5 mm, plus an additional level for non-adjacent targets (a single target with no neighbours). In comparison, Windows Phone recommends 2 mm spacing between adjacent targets, Android recommends an average of 1.5 mm, and Apple does not provide advice regarding spacing sizes. All targets and spacings were defined in millimetres, and then converted to pixels by obtaining a mm to px ratio based on the dimensions and resolution of the screen used for the evaluation.

Each factor was measured three times per participant. Resulting in 5 (sizes) * 5 (spacing sizes) * 3 (repetitions) = 75 *taps* for the first task and 75 *swipes* for the second task, per participant. Overall, our data consists of a mean 3000 *taps* and 3000 *swipes*.

In addition, three dependent variables were considered: (1) accuracy, (2) task completion time, and (3) number of attempts per task. Accuracy was measured as the number of times a target was missed before correctly acquiring it, so if a participant tried to hit a target twice but only managed to do so on the third try, then accuracy would be 1 (accurate hit)/3 (attempts) = 33% (accuracy rate). Task completion time was considered as the average amount of time participants took to accurately complete a task, and finally,

3 http://developer.android.com/design/style/metrics-grids.html

4 https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

5 http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx the number of attempts was only accounted for in the *swipe* task, and represents the number of times a target was dragged and released before reaching its destination mark.

Furthermore, all participants answered a post-session questionnaire. This questionnaire intends to collect subjective ratings regarding target sizes, preferred gestures, and level of fatigue associated to each gesture.

In this way, all users completed both tasks and the post-session questionnaire. Each task consisted of a game which we thought would better motivate users to participate, given the high levels of gesture repetition that the tasks required. Games have been found to provide enjoyable experiences, while motivating players to achieve a defined goal even when certain actions need to be extensively repeated (Lazzaro, 2008). Likewise, games have been found to benefit older adults by contributing to the improvement of reaction times, visuo-motor coordination, and general quality of life (Torres, 2011). Additionally, both games were explained by the facilitator at the beginning of each session (see Appendix A.3 for the test script).

For each game, participants would first view a tutorial on how to play. Next, they would play a short trial where no data was collected. This was done in order to give participants an opportunity to learn how to play before we collected the actual data, thus avoiding biases related to learning issues. Lastly, participants would play the actual games.

Finally, the following sections will further detail the design and procedure inherent to both games, first for the *Tap* Game, and and then for the *Swipe* Game.

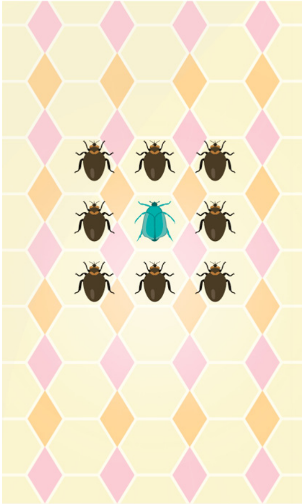
8.3.1 *TAP* GAME

The *Tap* Game or Insect Game required participants to smash a target insect, using a *tap* gesture, while avoiding the other insects that surrounded it. The target insect was deliberately distinct from its neighbours in both colour and shape. The difference between the actual target and its neighbours was made purposely evident in order to avoid high levels of cognitive demand and visual-search capabilities, that could be required if the target insect was not easily distinguishable.

The target insect appeared in a random order at any one of three defined locations. These locations were chosen to be near the centre of the screen, which has been found to be a comfort area for most users (Henze, Rukzio, & Boll, 2011; Parhi, Karlson, & Bederson, 2006). We opted for placing targets within a comfort area, in order to avoid results being affected by targets' onscreen locations and related reachability issues.

Lastly, only one target was presented at a time, and the following target only appeared if the participants accurately acquired the current one, or if they missed it more than three times.

Figure 8.1 Screenshot of the *Tap* Game



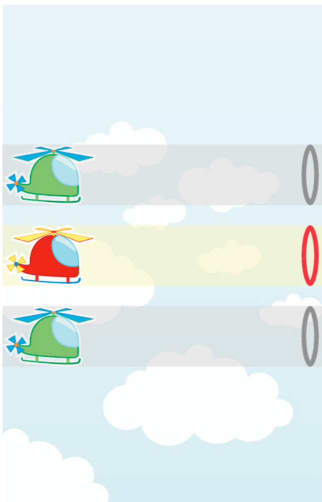
8.3.2 *SWIPE* GAME

The *Swipe* Game or Helicopter Game consisted of dragging a helicopter, by using a *swipe* gesture from the left side of the screen toward a destination target on the opposite side. While dragging the target, participants had to avoid moving other neighbouring ones at the same time. Once again, the intended target was visually distinguished from its neighbours as a means to avoid overly high cognitive demands or visual search capabilities that could bias the results.

The target helicopter appeared at one of three random onscreen locations. In a similar form to the previous task, these locations where chosen to be near the centre of the device's display.

Unlike the *Tap* Game, participants only progressed from one target to the next when they effectively dragged the target helicopter from its initial position to the target destination.

Figure 8.2 Screenshot of the Swipe Game



8.4 RESULTS

In the following section, we first present individual results for the *Tap* Game, then for the *Swipe* Game, and the questionnaire results regarding participants' subjective preferences. For each game, we analysed the results according to the three dependent variables: (1) accuracy, (2) task completion times, and in the specific case of *swipe* (3) the number of attempts per task.

8.4.1 *TAP* GAME

8.4.1.1 ACCURACY

In order to create the design patterns, we had to determine how *tap* target sizes influence users' accuracy rates. Accuracy was measured as the number of accurate target acquisitions divided by the number of attempts. The number of accurate target acquisitions was always one, as the next target would appear immediately after the current one was accurately selected, so for example 1 (hit) / 3 (attempts) = 33% (accuracy rate). Table 8.2 presents overall mean accuracy rates, both for *tap* target sizes and spacing sizes between *tap* targets.

Table 8.2 Mean accuracy rates for the Tap Game according to target size and spacing size between targets

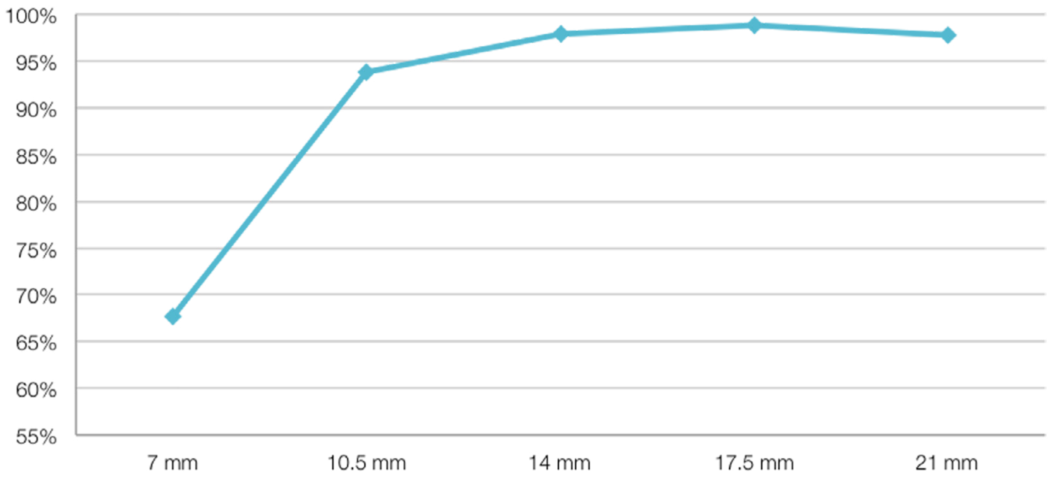
Target spacing / Target sizes	0 mm	3.5 mm	7 mm	10.5 mm	single-target	Grand Total
7 mm	70.87%	72.50%	65.83%	67.92%	61.25%	67.67%
10.5 mm	92.36%	93.19%	94.72%	95.97%	92.50%	93.75%
14 mm	97.50%	99.17%	98.75%	97.36%	96.94%	97.94%
17.5 mm	98.75%	99.17%	98.75%	99.17%	98.33%	98.83%
21 mm	98.75%	98.75%	97.78%	98.61%	95.14%	97.81%
Grand Total	91.68%	92.56%	91.17%	91.81%	88.83%	91.21%

We will now look at individual accuracy measures, first according to *tap* target sizes, then according to spacings sizes between *tap* targets.

HOW DID *TAP* TARGET SIZES INFLUENCE ACCURACY?

Firstly, we evaluated the influence of *tap* target sizes on participants accuracy. An overview of mean accuracy rates according to *tap* target sizes is provided in Graph 8.1. Overall, our data suggests that for targets larger than 14 mm square, participants' accuracy was over 97%. However, for targets smaller than this, accuracy decreased to 93.75% for 10.5 mm targets, and to 67.67% for 7 mm targets (see Table 8.2). Moreover, a slight decrease in mean accuracy was also registered for the 21 mm targets. In this context, it would be interesting to further investigate this trend and assess if accuracy continues to decline as targets get larger than 21 mm.

Graph 8.1 Accuracy (%) according to *tap* target sizes



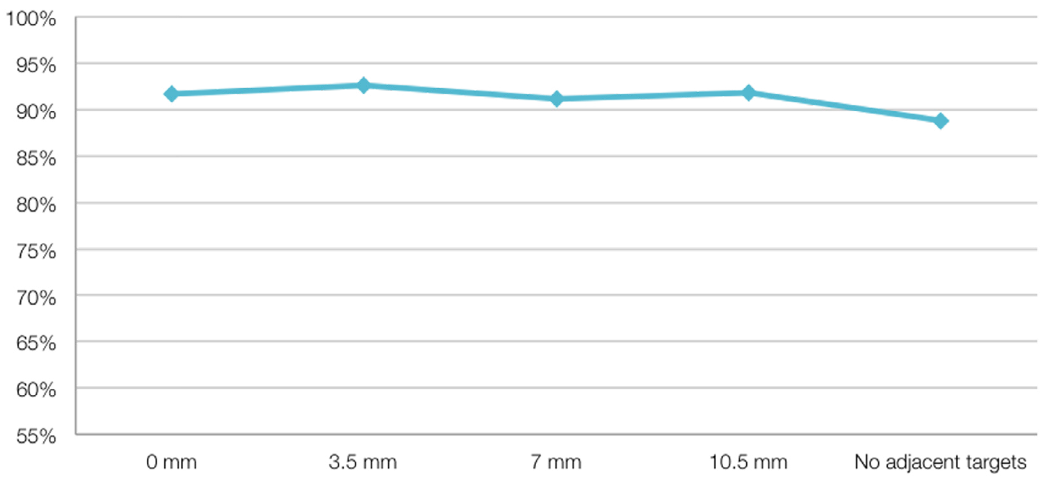
For statistical evaluation purposes, a repeated measures ANOVA, which is generally used for the analysis of within-group study designs with more than one independent variable (Lazar, Feng, & Hochheiser, 2010), with Greenhouse-Geisser correction showed that the influence of target sizes on accuracy was significant ($F(1.184, 46.160) = 46.914$, $P < 0.001$). Participants' accuracy decreased as target sizes got smaller. Mean accuracy was significantly lower for button sizes below 14 mm, although no significant differences where found for targets larger than 14 mm square.

In sum, participants were most accurate with *tap* targets between 14mm and 21 mm square.

HOW DID SPACING SIZES BETWEEN *TAP* TARGETS INFLUENCE ACCURACY?

Secondly, we analysed the effect of spacing sizes between targets on accuracy. Accordingly, Graph 8.2 provides an overview of our results. Overall, accuracy levels seemed to maintain themselves stable across all conditions (between 91.68% and 91.81%), decreasing only in the single-target condition to 88.83% (see Table 8.2). Nonetheless, participants were most accurate with 3.5 mm spacing, followed by 10.5 mm, and then by 0 mm. Where 7 mm spacing and the single-target conditions were the ones with the lowest accuracy rates.

Graph 8.2 Accuracy (%) according to spacing size between *tap* targets



For statistical purposes, a repeated measures ANOVA showed that spacing between targets had no significant effect on accuracy ($F(3, 117) = 0.649$, P = 0.585). Meaning that spacing between targets did not seem to influence older adults accuracy in acquiring *tap* targets. However, a repeated measures ANOVA with a Greenhouse-Geisser correction showed that accuracy was significantly influenced by the presence, or absence, of neighbouring targets ($F(3.592,140.090) = 3.825$, $P < 0.01$). Where participants' accuracy was significantly lower in the single-target condition, as opposed to when a target was surrounded by other neighbouring ones. One explanation for this finding could be that since there are no neighboring targets, accuracy might be lower because participants were not as preoccupied in acquiring the correct target while also missing it's neighbours, therefore putting less effort into aiming for the correct target.

Overall, participants seem to be more accurate in the adjacent-targets condition, rather than in the single-target condition. Where the best spacing size revealed to be 3.5 mm with an accuracy rate of 92.56%.

8.4.1.2 TASK COMPLETION TIME

Besides accuracy, task completion times were also considered, as in many cases time is an important factor in HCI. Task completion times were considered as the total amount of time participants needed to correctly activate a target. We will now look at how *tap* target sizes, and spacing sizes between *tap* targets influenced the time it took participants to complete tasks. The following table presents an overview of our results (in seconds).

Table 8.3 Mean task completion times (in seconds) for the Tap Game according to target size and spacing size between targets

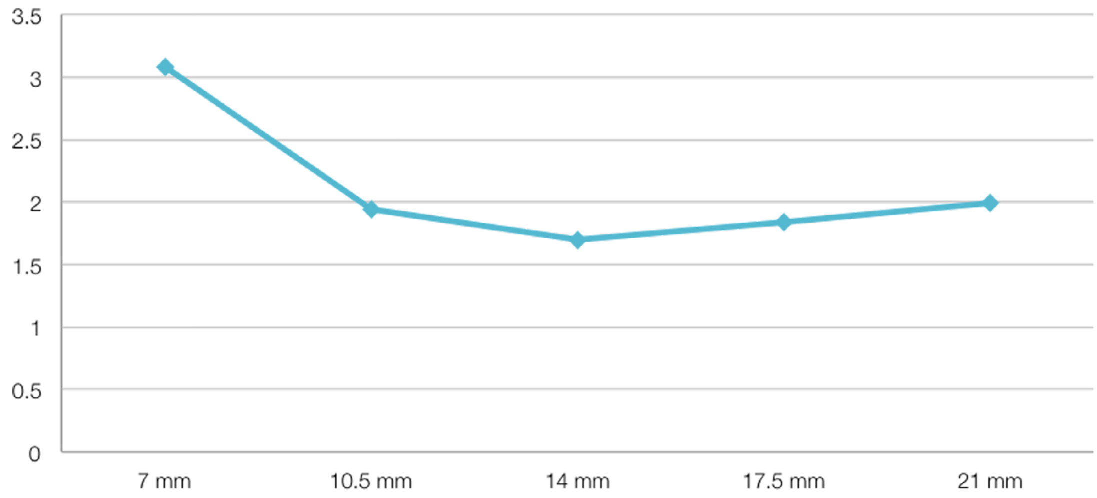
Target spacing / Target sizes	0 mm	3.5 mm	7 mm	10.5 mm	single-target	Grand Total
7 mm	3.08	2.80	3.24	2.89	3.41	3.08
10.5 mm	2.01	1.86	1.79	1.91	2.13	1.94
14 mm	1.68	1.64	1.62	1.72	1.83	1.70
17.5 mm	1.72	1.68	1.83	1.75	2.20	1.83
21 mm	1.90	1.69	1.91	1.94	2.51	1.99
Grand Total	2.08	1.93	2.08	2.04	2.41	2.11

We will now discuss task completion times individually, first according to *tap* target sizes, and second according to spacing sizes between *tap* targets.

HOW DID *TAP* TARGET SIZES INFLUENCE TASK COMPLETION TIMES?

Firstly, Graph 8.3 provides an overview of task completion times according to *tap* target sizes. As illustrated in the graph, it seems that task completion times increased for targets that are either smaller, or larger than 14 mm square. Accordingly, the lowest mean completion time was 1.70 seconds, and it was registered in the 14 mm condition. The highest were 3.08 seconds for the 7 mm target and 2.11 seconds for the 21 mm targets. Where an accentuated increase can be seen between 7 and 10.5 mm.

Graph 8.3 Graph 8.3 Task completion times (in seconds) according to *tap* target sizes

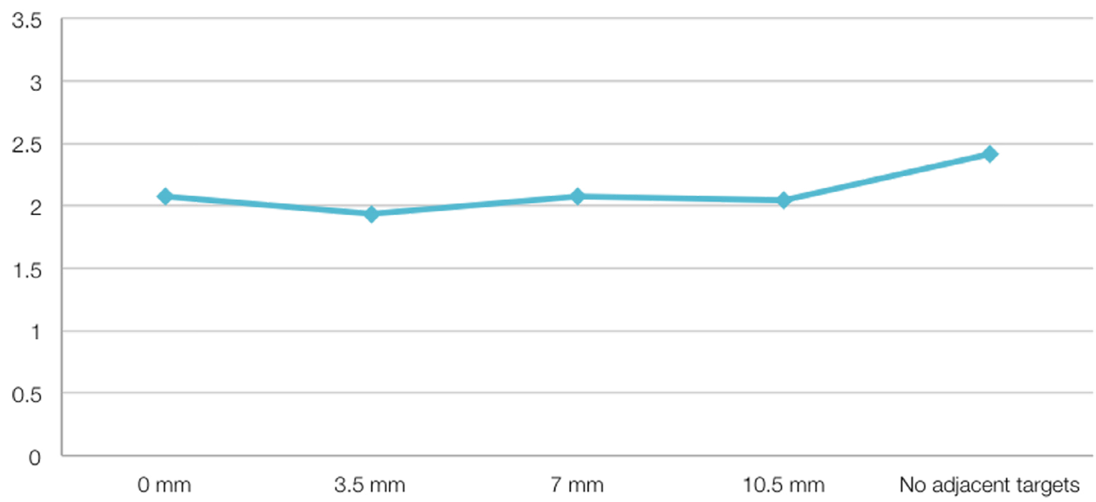


In accordance, a repeated measures ANOVA with Greenhouse-Geisser correction showed that task completion time was in fact influenced by *tap* target sizes ($F(1.456, 56.770) = 24.895$, $P < 0.001$). Where no significant difference was registered for target sizes between 10.5 mm and 17.5 mm, but size was influent in the 7 mm and 21 mm conditions. Meaning that participants' took longer to correctly acquire both the smallest (7 mm) and the largest targets (21 mm). In addition, these findings are consistent with those regarding accuracy rates according to *tap* target sizes.

HOW DID SPACING SIZES BETWEEN *TAP* TARGETS INFLUENCE TASK COMPLETION TIMES?

Regarding spacing sizes between targets, mean task completion times seemed to maintain themselves between 1.93 seconds and 2.08 seconds throughout all spacing sizes, increasing to 2.41 seconds only in the single-target condition (see Table 8.3). Graph 8.4 shows mean task completion times for the single target condition, as well as according to spacing sizes for the neighbouring targets condition.

Graph 8.4 Task completion times (in seconds) according to spacing size between *tap* targets



For statistical purposes, a repeated measures ANOVA showed that spacing between targets had a significant impact on task completion times ($F(3, 117) = 3.056$, $P < 0.05$). Where no significant difference was found for spacing sizes larger or smaller than 3.5 mm. In other words, participants were quicker in acquiring targets with spacings between them of 3.5 mm (1.93 seconds) but no difference was detected for all other spacing conditions. These findings are consistent with those regarding accuracy rates and spacing sizes between *tap* targets.

When comparing the adjacent targets condition with the single-target condition, a repeated measures ANOVA with Greenhouse-Geisser correction showed a significant increase in task completion times ($F(3.203, 124.933) = 16.601$, $P < 0.001$). Where participants were slower in acquiring single-targets (2.41 seconds) than in acquiring targets surrounded by neighbours (Mean = 2.03 seconds).

Overall, regarding *tap* target acquisition, participants' performance seems to be best when *tap* targets are larger than 14 mm square, with 3.5 mm spacing between them. Similarly, for the single-target condition best performance is also registered for the 14 mm square targets.

8.4.2 *SWIPE* GAME

For the *Swipe* Game analysis, three dependent variables were considered: (1) accuracy, (2) task completion times, and (3) number of attempts per target. However, contrary to the *Tap* Game, task completion times were not the amount of time it took to correctly acquire a target, but rather the total amount of time participants needed to drag the helicopter from its initial to its final position. In addition, the number of attempts per target is considered as the number of *swipe* gestures necessary to drag the helicopter from one location to another, in order to complete a task.

8.4.2.1 ACCURACY

Much like for the *Tap* Game, accuracy was measured as the number of accurate target acquisitions divided by the number of attempts. It is important to notice that accuracy was measured only for the acquisition of the *swipe* target, before moving it to another location. Our interest lies in assessing if the intent of the movement — whether to perform a *tap* or a *swipe* gesture — influences participants' accuracy in acquiring such targets. The following table presents mean accuracy rates for both independent variables — target sizes and spacing size between targets.

Table 8.4 Mean accuracy rates for the Swipe Game according to target size and spacing size between targets

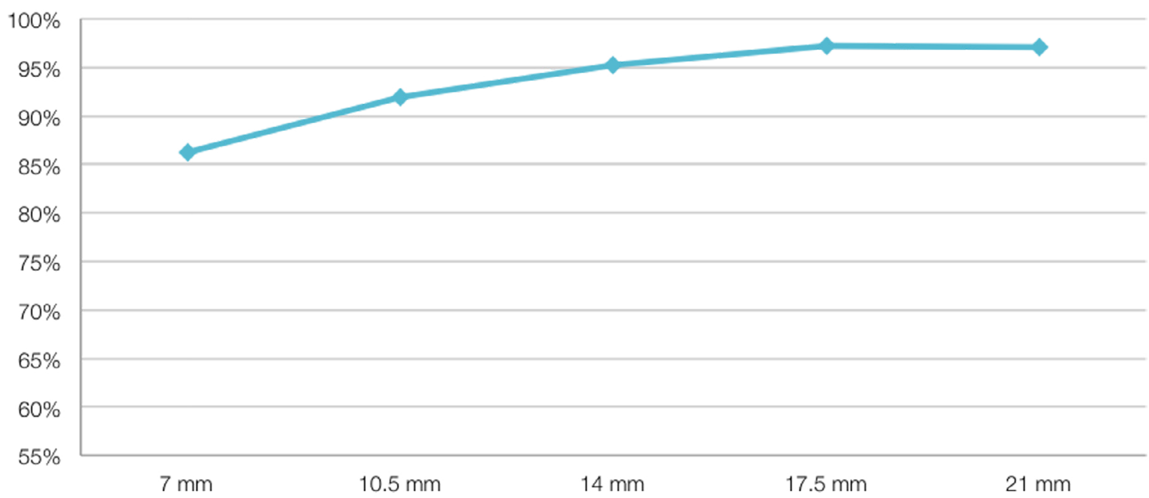
Target spacing / Target sizes	0 mm	3.5 mm	7 mm	10.5 mm	single-target	Grand Total
7 mm	88.03%	86.49%	84.44%	88.30%	83.99%	86.25%
10.5 mm	92.01%	93.13%	92.42%	90.28%	91.66%	91.90%
14 mm	97.36%	96.67%	94.31%	93.68%	94.17%	95.24%
17.5 mm	96.94%	95.38%	98.33%	97.36%	98.19%	97.24%
21 mm	98.75%	99.04%	96.18%	94.79%	96.46%	97.05%
Grand Total	94.63%	94.15%	93.14%	92.88%	92.89%	93.54%

In the following sections, we will firstly look at the results according to *swipe* target sizes, and then according to spacing sizes between *swipe* targets.

HOW DID *SWIPE* TARGET SIZES INFLUENCE ACCURACY?

Firstly, we evaluated the influence of *swipe* target sizes on participants accuracy. Accordingly, Graph 8.5 gives us an summary of the results. Overall, our data suggests that for targets larger than 17.5 mm square participants' accuracy was over 97%. However, for the 14 mm targets accuracy decreased to 95.24%, for the 10.5 mm it went down to 91.90%, and finally for the 7.5 mm accuracy was only 86.25% (see Table 8.4). In this context, it seems that as targets get smaller accuracy also decreases.

Graph 8.5 Accuracy (%) according to *swipe* target sizes



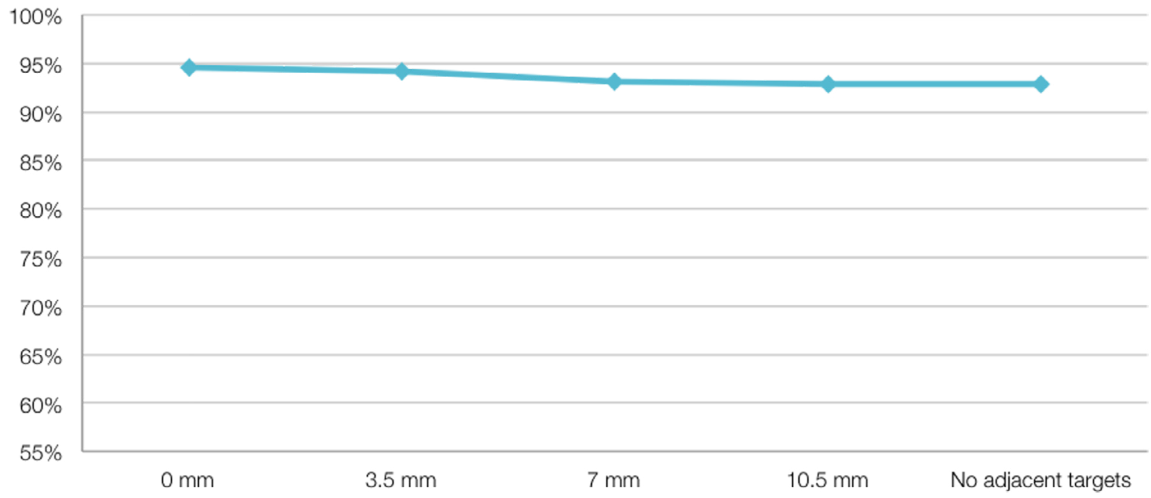
Considering statistical analysis, a repeated measures ANOVA with a Greenhouse-Geisser correction showed that the mean accuracy measures for different *swipe* target sizes was indeed significant ($F(2.083, 81.247) = 16.809$, $P < 0.001$). Mean accuracy measures decreased as target dimensions became smaller. Accuracy was significantly lower for *swipe* target sizes below 10.5 mm (91.90%), but no significant differences were found for *swipe* targets larger than this.

Overall, our data suggests that older adults are most accurate with *swipe* targets larger than 10.5 mm square. Still, the best performance was registered for the larger 17.5 mm targets.

HOW DID SPACING SIZES BETWEEN *SWIPE* TARGETS INFLUENCE ACCURACY?

Secondly, we analysed the effect of spacing sizes between *swipe* targets on accuracy. An illustrated overview of our results is provided in Graph 8.6. Where it seems that accuracy rates were more or less equally spread through all conditions, maintaining values between 93.14% and 94.63%. However, a slight decrease can be observed for the 10.5 mm and single-target conditions, at 92.88% and 92.89% respectively. The following graph presents mean accuracy rates according to *swipe* target sizes.

Graph 8.6 Mean accuracy (%) according to spacing size between *swipe* targets



Contrastingly, a repeated measures ANOVA with a Greenhouse-Geisser correction showed that the mean accuracy measures for different spacing sizes between *swipe* targets was not significant ($F(2.295, 89.516) = 16.809$, $P = 0.132$). Furthermore, unlike in the *Tap* Game, participants' accuracy was not influenced by the presence, or lack-of, neighbouring targets ($F(3.064, 119.492) = 1.609$, $P = 0.190$).

In sum, participants were most accurate in the 17.5 mm condition (97.24%), although no significant difference was found in relation to the smaller 10.5 mm target (91.90%), nor to the larger 21 mm target (97.05). In addition, participants' accuracy does not seem to be affected by issues related to spacings between neighbouring targets, although they were most efficient in the 0 mm spacing condition.

8.4.2.2 TASK COMPLETION TIMES

In addition to mean accuracy measures, mean task completion times were also taken into account. As in many cases, time is an important factor in operating human-computer interfaces. This is especially true when considering mobile interaction which often unfolds as users are on-the-go and in adverse environments (Oulasvirta, Tamminen, Roto, & Kuorelahti, 2005).

For the *Swipe* Game, task completion times were viewed as the total amount of time a participant needed to drag a target from its initial to its final position. Accordingly, Table 8.5 presents mean task completion times according to *swipe* target sizes, and spacing sizes between *swipe* targets.

Table 8.5 Mean task completion times for the Swipe Game according to target size and spacing size between targets

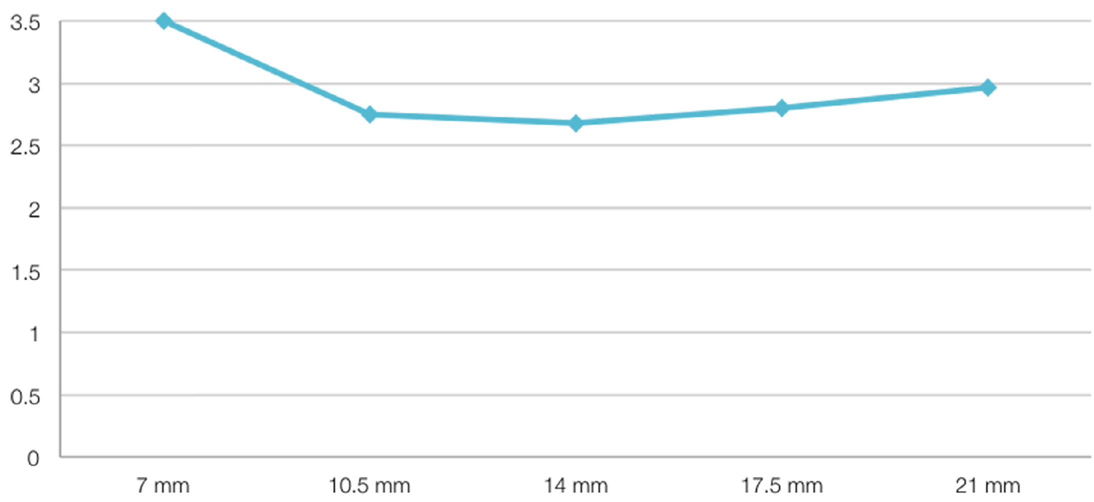
Target spacing / Target sizes	0 mm	3.5 mm	7 mm	10.5 mm	single-target	Grand Total
7 mm	2.92	3.02	2.87	4.61	4.06	3.50
10.5 mm	2.62	2.71	2.48	2.44	3.51	2.75
14 mm	2.26	2.72	2.72	3.11	2.60	2.68
17.5 mm	3.09	2.57	2.54	2.94	2.84	2.80
21 mm	2.79	2.65	2.60	3.29	3.50	2.97
Grand Total	2.74	2.74	2.64	3.28	3.30	2.94

We will now consider task completion times with more detail, firstly according to *swipe* target sizes, and secondly, according to spacing sizes between *swipe* targets.

HOW DID *SWIPE* TARGET SIZES INFLUENCE TASK COMPLETION TIMES?

Considering Graph 8.7, it appears that participants became slower at dragging both the smaller and the larger targets. Where for the intermediate 14 mm target, participants took an average of 2.68 seconds to drag it from one location to the other. While for the 21 mm they took 2.97 seconds, and for the 7 mm this value was 3.5 seconds.

Graph 8.7 Task completion times (in seconds) according to *swipe* target sizes



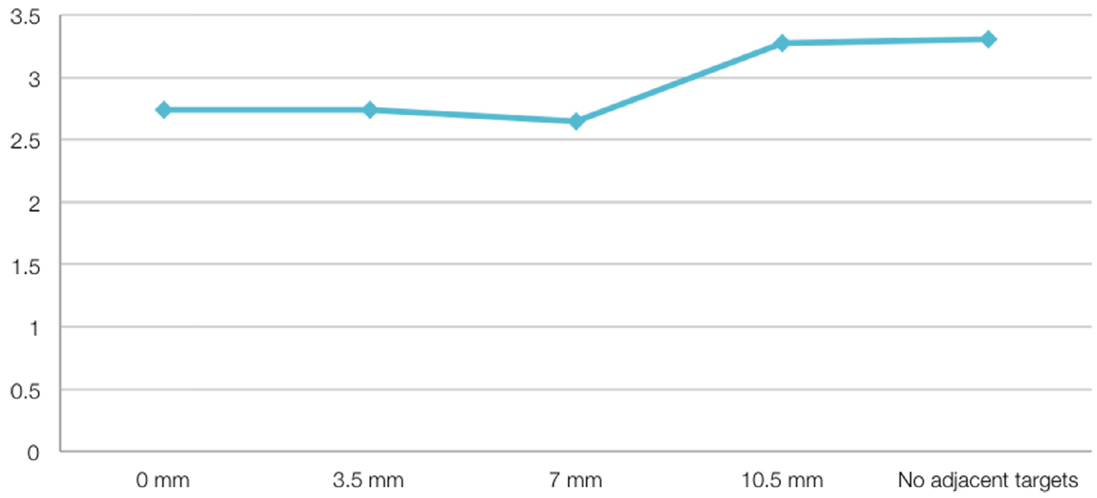
However, contrary to the *Tap* Game, a repeated-measures ANOVA with a Greenhouse-Geisser correction, revealed that *swipe* target sizes did not have a significant effect on task completion times (F(2.675, 104.314) = 2.691, P = 0.056).

In sum, even though no significant effect of *swipe* target sizes on task completion times was found, it seems that participants were generally quicker with targets between 10.5 and 17.5 mm.

HOW DID SPACING SIZES BETWEEN *SWIPE* TARGETS INFLUENCE TASK COMPLETION TIMES?

Regarding the influence of spacing sizes between *swipe* targets on task completion times, Graph 8.8 shows us an overview of the results. In general, it seems that participants were slower both for the 10.5 mm and single-target conditions. Where an accentuated increase from 2.64 to 3.28 seconds was found from the 7 mm to the 10.5 mm spacing size. On the other hand, for spacings between 0 mm and 7 mm, task completions times were relatively stable with values between 2.64 and 7.74 seconds.

Graph 8.8 Task completion times (in seconds) according to spacing sizes between *swipe* target



For statistical purposes, a repeated-measures ANOVA with a Greenhouse-Geisser correction was conducted, which revealed that spacing sizes between targets did not have a significant effect on the time it took participants to complete *swipe* tasks ($F(1.668, 65.044) = 2.441$, $P = 0.104$). Meaning that the size of spacing between *swipe* targets did not cause participants to be quicker or slower in completing tasks. However, the presence or absence of neighbouring targets did influence task completion times ($F(2.155, 84.028) = 3.210$, $P < 0.05$), where participants were quicker in adjacent-targets condition, rather than in the single-target one.

In sum, although spacing sizes between *swipe* targets did not have a significant effect on task completion times, participants were quicker with spacings between 0 mm and 7 mm.

8.4.2.3 NUMBER OF *SWIPES* PER TARGET

For the *Swipe* Game, an additional dependent variable was considered — number of attempts per target. The number of attempts was understood as the number *swipes* needed for participants to drag a target from its initial to its final location. The following table presents a summary of the results according to *swipe* target sizes, and spacing sizes between *swipe* targets.

Table 8.6 Mean number of attempts per target for the Swipe Game according to target size and spacing size between targets

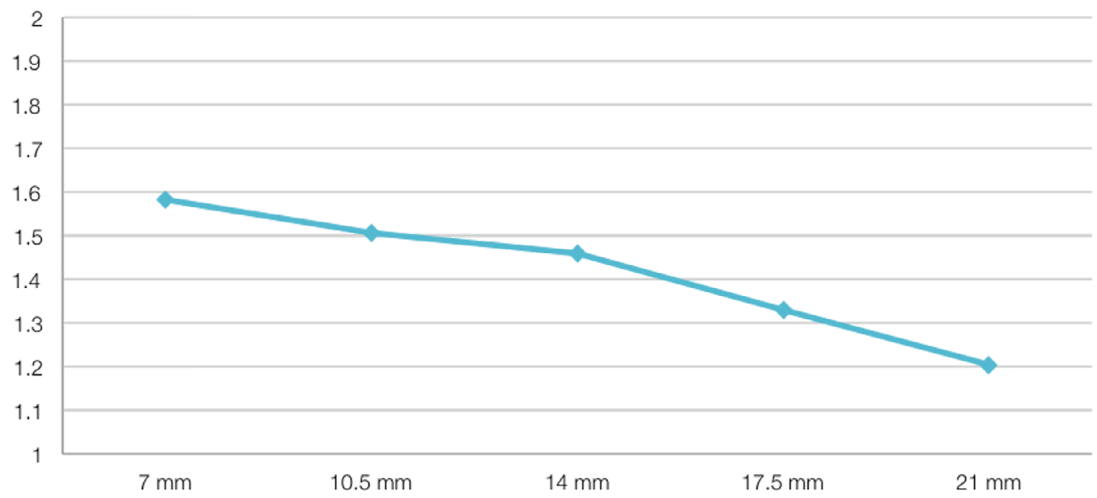
Target spacing / Target sizes	0 mm	3.5 mm	7 mm	10.5 mm	single-target	Grand Total
7 mm	1.51	1.34	1.41	1.68	1.97	1.58
10.5 mm	1.48	1.49	1.41	1.47	1.69	1.51
14 mm	1.36	1.51	1.46	1.42	1.55	1.46
17.5 mm	1.25	1.26	1.37	1.30	1.48	1.33
21 mm	1.16	1.21	1.17	1.23	1.26	1.20
Grand Total	1.35	1.36	1.36	1.42	1.59	1.42

Like for all previously discussed dependent variables, we will now detail the results regarding the number of attempts, firstly according to *swipe* target sizes, and then in relation to spacing *sizes* between *swipe* targets.

HOW DID *SWIPE* TARGET SIZES INFLUENCE THE NUMBER OF *SWIPES* PER TARGET?

As illustrated in Graph 8.9, the number of attempts needed to drag a target from one side of the screen to the other decreased as *swipe* targets got larger. Accordingly, for the 21 mm target, only 1.20 attempts were needed on average, while for the 7 mm target an average of 1.58 attempts were performed. Furthermore, and accentuated decline was be found for targets larger than 14 mm.

Graph 8.9 Mean number of attempts according to *swipe* target sizes

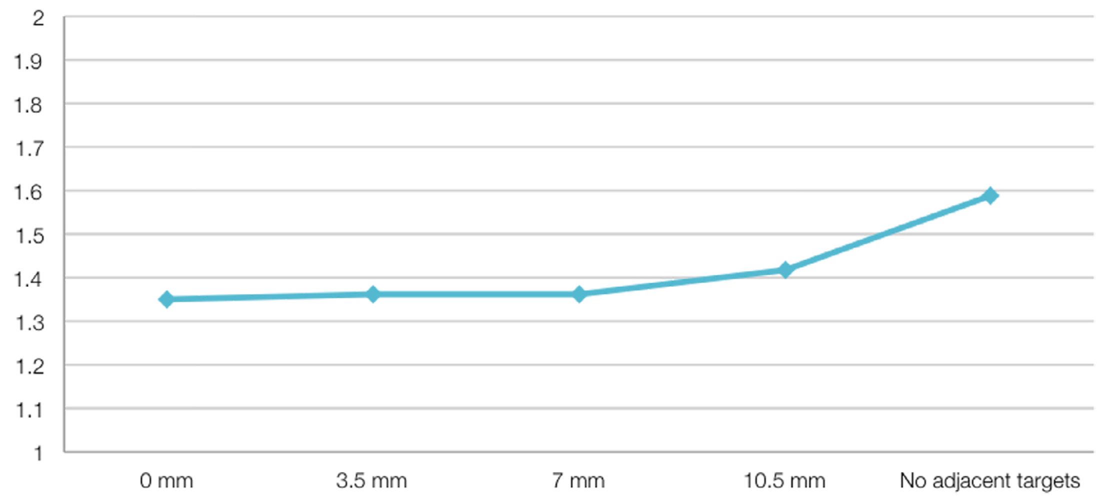


In this context, a repeated measures ANOVA with a Greenhouse-Geisser correction confirmed that target sizes did indeed have a significant effect on the number of *swipes* needed to transport the target from one edge of the screen to another ($F(2.183, 85.142) = 3.331$, $P < 0.05$). In other words, as targets got larger participants needed significantly less *swipe* gestures to drag them to the intended destination.

HOW DID SPACING SIZES BETWEEN *SWIPE* TARGETS INFLUENCE THE NUMBER OF *SWIPES* PER TARGET?

In addition, considering Graph 8.10 it appears that spacing sizes between *swipe* targets influenced the number of attempts performed. Where in the 0 mm condition, an average of 1.35 attempts was registered, while in the 10.5 mm condition an average of 1.42 attempts were performed. Furthermore, the single-target condition revealed to have the most negative effect on participants performance, requiring an average of 1.59 attempts. Overall, it seems that for very large spacings such as 10.5 mm, or for single-targets, participants needed to perform more gestures in order to complete the tasks.

Graph 8.10 Mean number of attempts according to spacing sizes between *swipe* targets



However, a repeated measures ANOVA with a Greenhouse-Geisser correction showed that spacing sizes between targets did not have a significant effect on the number of attempts necessary to complete *swipe* tasks ($F(1.9, 74.116) = 0.681$, $P = 0.502$). Nonetheless, the effect of the single-target versus the adjacent-target condition was significant ($F(1.868, 72.870) = 3.787$, $P < 0.05$). Which means that participants made significantly more attempts in the single-targets condition, rather than in the adjacent-targets condition.

In sum, participants seemed to perform less *swipe*s when targets were 21 mm square, without spacing between them. While the single-target condition revealed to be the less adequate for older adults, as they needed to perform more gestures in order to solve the same tasks.

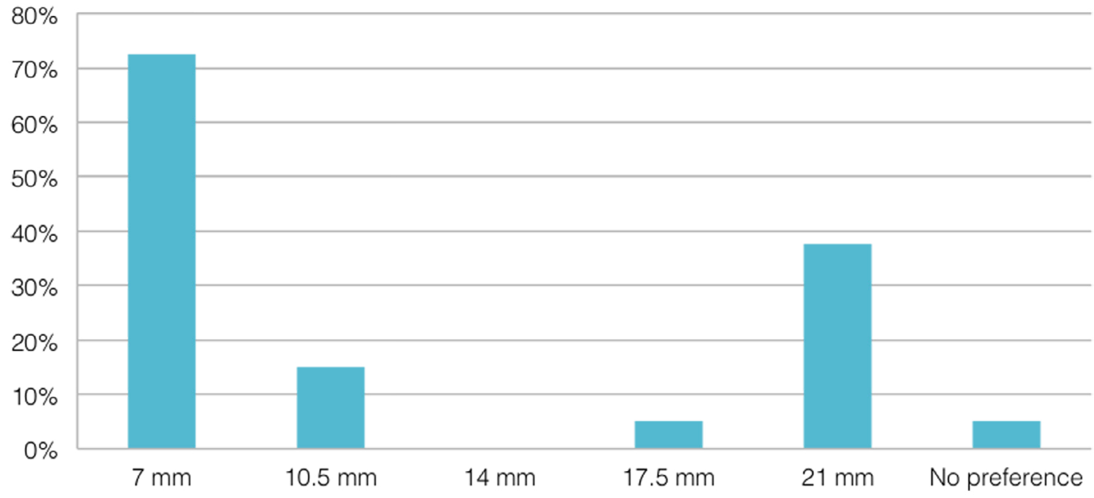
8.4.3 SUBJECTIVE PREFERENCES

In addition to the *tap* and *swipe* games, a post-session questionnaire was conducted in order to assess participants' subjective preferences regarding target sizes for both the *tap* and *swipe* gestures, preferred gesture type, and levels of fatigue associated with each one. Firstly, we asked participants to rate the target sizes they felt were most inadequate, and then asked them which gesture they preferred, or thought was more fun. Lastly, participants would rate the gesture they thought was the most physically demanding (see questionnaire in Appendix B.1). We will now look at the detailed results of this questionnaire.

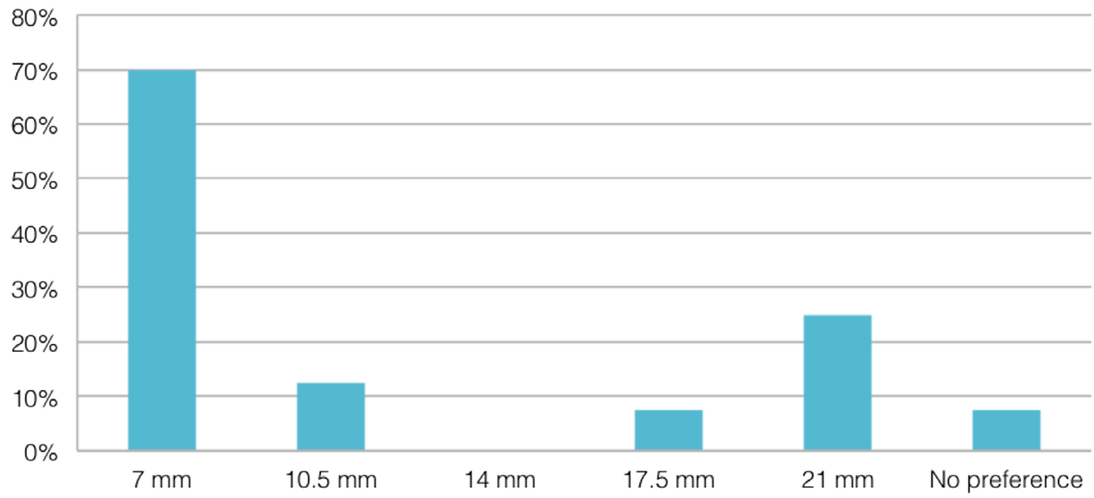
8.4.3.1 SUBJECTIVE PREFERENCES REGARDING TARGET SIZES

Regarding target sizes, participants were asked to choose those they felt were most inadequate, for both *tap* and *swipe*. Accordingly, Graphs 8.11 and 8.12 provide an overview of the results. Overall, it seems that participants demonstrated a strong preference for targets between 10.5 and 17.5 mm, where the best rating was given to the intermediate 14 mm targets. Additionally, they found both the largest and the smallest targets to be the most inadequate, showing that older adults do not necessarily prefer larger sizes targets in every situation.

Graph 8.11 Participants' selection of the worst target sizes for *tap*



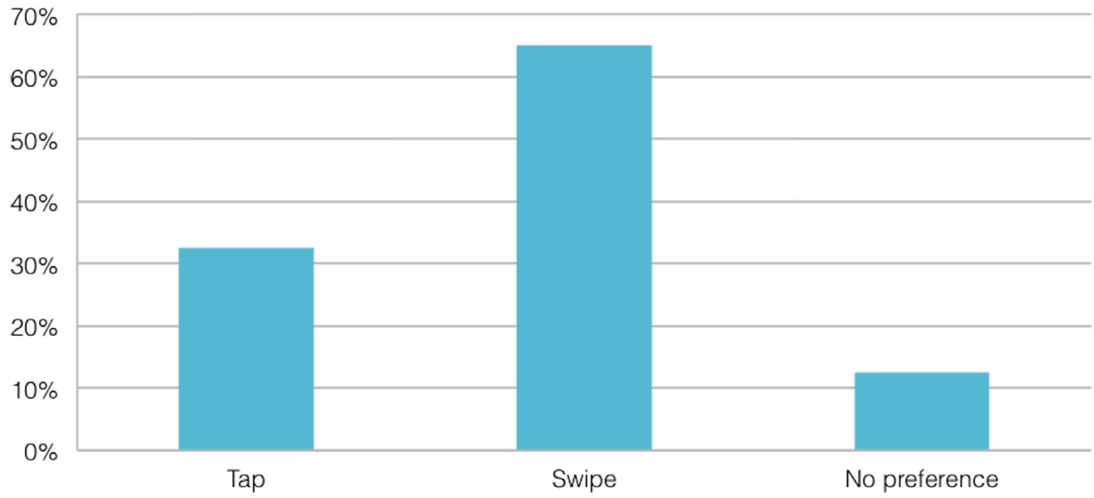
Graph 8.12 Participants' selection of the worst target sizes for *swipe*



8.4.3.2 SUBJECTIVE PREFERENCES REGARDING GESTURE TYPE

As previously discussed, participants were asked to choose the gesture they preferred, or found more fun. As such, Graph 8.13 provides an overview of the results. Where participants clearly point to an overall preference for *swipe* gestures, which was chosen by more than 60% of participants. Followed by *tap* gestures with slightly more than 30%, and lastly by about 10% with no gesture preference at all.

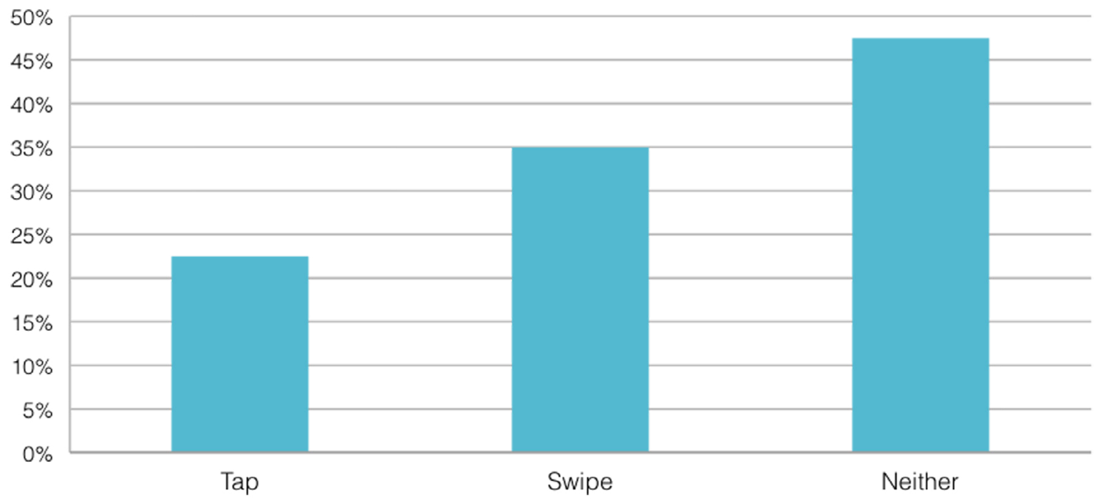
Graph 8.13 Participants' gesture preference



8.4.3.3 SUBJECTIVE ASSESSMENT OF FATIGUE

Lastly, participants were required to choose which gesture was more physically demanding. Accordingly, as shown in Graph 8.14, most participants felt that neither gesture was particularly difficult. However, about 35% of participants still felt that *swipe* was harder than *tap,* even though they also considered it to be the most fun gesture.

Graph 8.14 Participants' classification for the most difficult gesture



In sum, participants showed a general preference for targets that are neither too large, nor to small. The ideal target sizes were chosen to be those between 10.5 and 17.5 mm square. Regarding gestures, they generally felt that although *swipe* was more fun it is also more physically demanding. Which leads us to believe that when opting for one gesture over another, *swipe* should be favoured for leisure contexts, and *tap* for efficiency, as participants were faster in acquiring *tap* targets with an average of 2.11 seconds, than *swipe* targets with an average of 2.94 seconds.

8.5 DISCUSSION

The aim of this study was to assess the influence of touch-target sizes, and spacing sizes between targets on older adults' performance of *tap* and *swipe* gestures. Accordingly, our objective was to answer the following questions:

- RQ6: Are recommended touch-target sizes, found in official guidelines, adequate for older adults performing *tap* and *swipe* gestures?
- RQ7: Are current recommendations regarding spacing sizes between touch-targets adequate for older adults performing *tap* and *swipe* gestures?

Accordingly, the results from this study can be summarised as follows:

- For *tap* targets:

    - 14 mm square appears to be the better target size, both for adjacent-targets and for single-targets.
    - In cases of limited screen real-estate, a minimum of 10.5 mm square appears to be adequate.
    - Participants generally preferred targets between 10.5 and 17.5 mm square.
    - Regarding spacing between targets, 3.5 mm seems to be the best.
    - In cases of limited screen real-estate, a minimum spacing of 0 mm is acceptable.

- For *swipe* targets:

    - 17.5 mm square appears to be the better target size, both for adjacent-targets and for single-targets.
    - In cases of limited screen real-estate, a minimum of 14 mm square appears to be acceptable.
    - Participants generally preferred targets between 10.5 and 17.5 mm square.
    - Regarding spacing between targets, values within the interval between 0 mm to 7 mm seem to be the most adequate.
    - The *Swipe* gesture was found to be more fun, while also being more physically demanding than *tap*.

In order to answer RQ6, we compared the minimum recommended *tap* target sizes provided by Android, Apple and Windows Phone, with our results and found that older adults perform better with targets twice the size of these recommendations. Where 7 mm is the minimum advised size and 14 mm is the condition in which our participants were most accurate. Next, regarding *swipe* targets we could not find any specific official recommendations, but found that in order to reach the same level of accuracy, *swipe* targets need to be larger (17.5 mm) than *tap* targets (14 mm). In addition, we noted that accuracy started to decrease for the largest *tap* target size. However, further investigation would be needed to confirm or deny this tendency, and assess if accuracy would continue to diminish for larger targets.

In turn, for RQ7 we found that older adults are most accurate with 3.5 mm spacing between *tap* targets, and with 0 mm spacing between *swipe* targets, while current recommendations advise spacings of 1.5 to 2 mm spacing. However, given the gap between our spacing conditions, from 0 to 3.5 mm, we cannot securely assess whether the 1.5 to 2 mm spacings would be adequate for older adults.

Regarding spacing sizes, our results are consistent with those of (Jin et al., 2007), where lager spacing sizes did not enhance older adults acquisition of *tap* targets.

Overall, it seems that the intention of a movement — whether to perform a *tap* or a *swipe* — influences participants overall performance. Accordingly, *tap* targets do not need to be as big as *swipe* targets, and spacing between targets seems to be less important for *swipe* gestures than for *tap* gestures.

Finally, the results from these findings were documented the following set of design patterns, which can be viewed in Section 10:

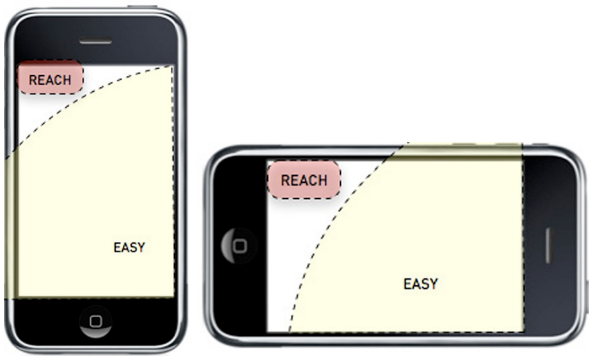
- TARGET SIZES FOR TAP GESTURES
- TAP TARGET SIZES FOR LIMITED SCREEN REAL ESTATE
- TARGET SIZES FOR SWIPE GESTURES
- SWIPE TARGET SIZES FOR LIMITED SCREEN REAL ESTATE
- SPACING BETWEEN TARGETS FOR TAP AND SWIPE GESTURES

9 PHASE FOUR: EVALUATING SMARTPHONE ACTIVITY ZONES AND *SWIPE* GESTURE ORIENTATIONS

After evaluating *tap* and *swipe* target sizes and spacings (see Section 8), we proceeded to investigate smartphone activity zones again for both *tap* and *swipe*. As well as the influence of *swipe* gesture orientations on these activity zones. For the purpose of this study, activity zones are understood as the regions on a smartphone's display where users can more easily reach, and where they are more accurate. While the gesture orientation issues that we refer to above, are primarily the influence that *swipe* gesture orientations (e.g., left-to-right, right-to-left, top-to-bottom, bottom-to-top) might have on participants' performance.

Dan Saffer, in a blog article[1] (Saffer, 2011), defined smartphone activity zones as seen in Figure 9.1. Looking at these images, we can see that the activity zones primarily consider one-handed thumb based interaction. Contrastingly, as seen from the data collected in our first study (see Section 6.2.4), most older adult participants used their index fingers, and not their thumbs for interaction. For this reason, we consider that further investigation is needed regarding activity zones and older adults interaction with smartphones.

Figure 9.1 Dan Saffer's image for smartphone activity zones



In addition, several other efforts have been made to define activity zones on mobile touchscreen interfaces. Parhi, Karlson and Bederson (2006) carried-out a study with twenty younger adults in order to evaluate thumb-use and the performance of both discrete and serial *tap gestures*. They found that

1 http://www.kickerstudio.com/blog/2011/01/activity-zones-for-touchscreen-tablets-and-phones/

participants were most accurate with targets placed toward the centre of the device, and less accurate toward the left edge and bottom-right-corner of the device. Contrastingly, Perry and Hourcade (2008) found that participants were more accurate in acquiring targets on the edge of the screen, while being quicker and more comfortable with targets toward the centre of the screen. More recently, Henze, Rukzio and Boll (2011) found that participants were most accurate in acquiring *tap* targets in the centre and toward the right and bottom edges of the screen. However, all of these studies were conducted with younger adults, and therefore cannot provide guidance in designing for an older population. Also, in the first two studies, the tasks were performed by participants either while standing or walking, however conducting tests with older adults, while walking or standing is, in many cases, not possible due to participants' several health-related issues.

Besides activity zones, our aim was to investigate the effect of *swipe* gesture orientation on *swipe* activity zones. In other words, does the orientation of a *swipe* gesture influence the Sections of the screen where participants can reach more easily? The results would then provide us with guidance relative to interaction modes based on two different concepts, such as the horizontal scroll of the Windows Phone or the prevalence of the vertical scroll in Android devices.

Accordingly, the aim of this last phase of our research was to answer the following questions:

- RQ8: Are activity zones on smartphones the same for younger and older adults?
- RQ9: In the particular case of *swipe*, does gesture orientation influence such activity zones?

Until this point, we are unaware of research that was conducted to evaluate activity zones, or specific gesture orientation issues with older adults. Stößel, Wandke and Blessing (2009) conducted a study that included the evaluation of different *swipe* gesture orientations. However, all gestures in this study were performed at the centre of the device's display and therefore cannot provide data regarding *swipe* activity zones in function of specific gesture orientations. Furthermore, studies have mainly concentrated on assessing activity zones for *tap* gestures, leaving a gap in the analysis of other common smartphone gestures such as *swipe*.

Finally, in order to evaluate the above mentioned issues, we designed two games — the *Tap* Game and the *Swipe* Game. The following Sections will provide further detail regarding the study's (1) participants, (2) apparatus used, (3) procedure, (4) results, and finally (5) discussion of our main findings.

9.1 PARTICIPANTS

Forty older adults (18 female and 22 male), with ages between 65 and 95 (Mean = 75.25) agreed to participate in this study. Participants were recruited from several retirement homes and day-care centres within the city of Porto. We did not collect any data that allows for identifying participants, and all agreed to take part in this study (see session script in Appendix A.4). The following table provides an overview the ages and gender of each participant.

Table 9.1 Participant data

Participant Nº	Age	Gender
1	83	F
2	67	F
3	70	M
4	88	F
5	81	F
6	68	F
7	67	F
8	67	M
9	67	M
10	73	M
11	80	M
12	82	M
13	65	F
14	77	F
15	79	F
16	65	M
17	71	F
18	66	M
19	70	M
20	72	M
21	66	M
22	74	M
23	83	M
24	82	F
25	75	M
26	86	M
27	82	M
28	70	M
29	77	M
30	82	M
31	75	M
32	67	M
33	74	F
34	74	M
35	77	F
36	73	F
37	86	F
38	83	F
39	71	F
40	95	F

9.2 APPARATUS

All tests were performed on a HTC Desire (the Samsung Nexus S used in the previous phase was no longer available) measuring 123.9 x 63 mm, with a 480 x 800 px display at 252 PPI. All participant data was logged on the smartphone itself, consequently there was no need to collect any audio or video during any of the sessions.

Unlike the first and second set of tests, and similarly to the third phase, we did not conduct these sessions in a separate room but rather where participants were already sitting. We found that older adults were generally less willing to participate when they were asked to go to a separate room with the facilitator. Therefore, due to time constraints and the high number of participants required for this phase of testing, we opted to conduct the sessions in the leisure rooms were participants were already sitting, watching television or playing card games.

9.3 PROCEDURE

In order to evaluate the influence of targets' onscreen locations on participants performance, we first designed a grid for both the *tap* and the *swipe* tests. For the *tap* condition we had a total of 28 positions, as seen in Figure 9.2. While for *swipe* a total of (7 horizontal positions * 2 orientations) + (4 vertical positions * 2 orientations) = 22 conditions, as seen in Figures 9.3 to 9.6. Each position would be tested a total of three times per participant, which results in 28 * 3 = 84 *taps*, and 22 * 3 = 66 *swipes* per participant. Furthermore, given the results from the previous study regarding target sizes, we decided to adopt the smallest acceptable target sizes for both *tap* and *swipe* — 10.5 mm and 14 mm square respectively (see Section 8). We chose these particular sizes as they would allow for testing more screen locations than the bigger ideally recommended targets, while still allowing for acceptable performance measures.

Figure 9.2 Grid for *tap* tests

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28

In the same way as the previous phase of testing with users, given the high number of gesture repetitions that each participant was required to perform, we decided to develop two games that we thought would better motivate participants. Games have been found to provide enjoyable experiences, while motivating players to achieve a defined goal even when certain actions need to be extensively repeated (Lazzaro, 2008).

Likewise, games have been found to benefit older adults by contributing to the improvement of reaction times, visuo-motor coordination, and overall quality of life (Torres, 2011).

Figure 9.3 Grid for left-to-right *swipe*

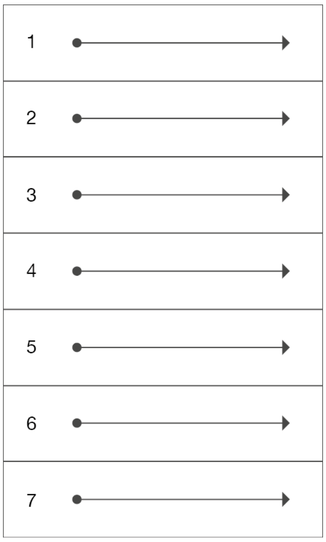


Figure 9.5 Grid for right-to-left *swipe*

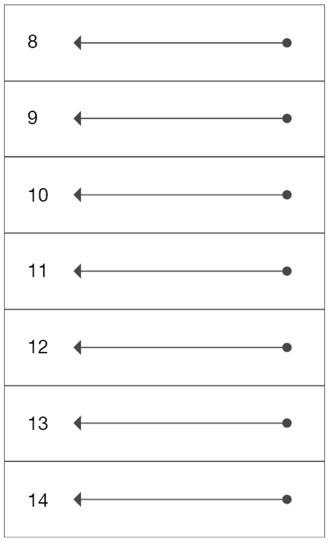


Figure 9.4 Grid for bottom-to-top *swipe*

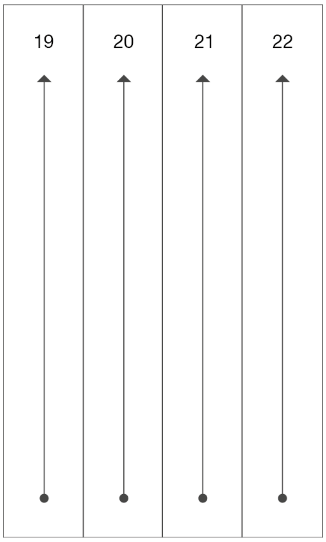
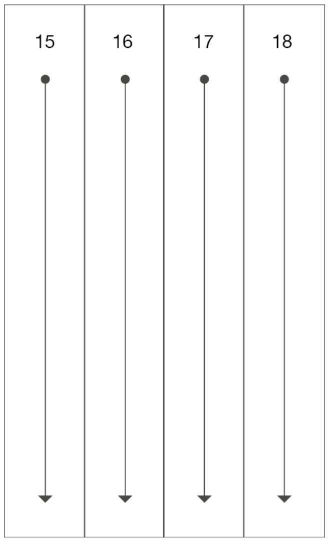


Figure 9.6 Grid for top-to-bottom *swipe*



Each game was meant to measure two dependent variables: (1) accuracy, and (2) touch offsets. In the same way as the previous research phase, accuracy was defined as the number of times a target was missed before correctly acquiring it, so if a participant tried to hit a target twice but only managed to do so on the third try, then accuracy would be 1 (accurate hit)/3 (attempts) = 33% (accuracy rate). Touch offsets are measured as the distance between a target's centre point and participants' actual touches on the smartphone's display. Again, like in phase three, for both games, participants would first view a tutorial on how to play. Next, they would play a short trial where no data was collected. This was done in order to give participants an opportunity to learn how to play before we collected the actual data, thus avoiding biases related to learning issues. Lastly, participants would play the actual games.

Next, we will discuss the design and inherent procedure of both games, first for *tap* and then for *swipe*.

9.3.1 *TAP* GAME

In the *Tap* Game, participants were required to smash a mole by performing a *tap* gesture. The mole would randomly appear at one of the twenty-eight grid locations seen in Figure 9.2. This game mimicked the traditional "Whack-A-Mole". Where only a single target appears at a time, and the following one would only appears if the current is correctly acquired, or if participants miss it more than three times. Finally, participants would be notified when the game ended by the screen seen in Figure 9.12.

Figure 9.7 Screenshot of Tap Game

9.3.2 *SWIPE* GAME

The *Swipe* Game consisted of dragging an animal, from its initial position toward a destination target on the opposite side of the screen. In order to do so, participants were not allowed to cross the barriers seen in Figures 9.8 to 9.11, making all *swipe* gestures strictly horizontal or vertical. As barriers were not allowed to be crossed, only the animal with the red target directly opposite to it was meant to be moved. The draggable item appeared randomly at one of the 11 onscreen locations seen in Figures 9.3 to 9.6, where the gesture orientation could be one of four options: left-to-right, right-to-left, top-to-bottom and bottom-to-top).

Figure 9.8 Screenshot for left-to-right *swipe*

Figure 9.9 Screenshot for right-to-left *swipe*

Figure 9.10 Screenshot for top-to-bottom *swipe*

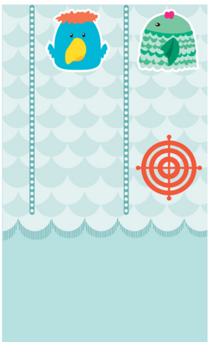


Figure 9.11 Screenshot for bottom-to-top *swipe*

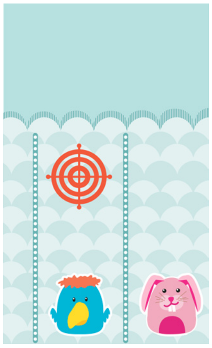


Figure 9.12 Screen indicating the end of the game

Unlike the *Tap* Game, participants only progressed from one target to the next when they effectively dragged the correct animal from its initial position to the target destination. Once again, participants knew that the game had ended when the screen seen in Figure 9.12 appeared.

9.4 RESULTS

Before a more detailed analysis of the results, and given the nature of this research, where we aim to assess the influence of target locations on older adults users' performance, it is important to interpret these results knowing that 85% of our participants interacted with their right hand, while 15% interacted with their left, as can be seen in Table 9.2.

Table 9.2 Hand that the participants used to interact with the smartphone

Right hand	Left hand
85%	15%

In the following Section, we first present individual results for the *Tap* Game, then for the *Swipe* Game. For each game, we analysed the results according to the two dependent variables: (1) accuracy, and (2) touch offsets.

9.4.1 *TAP* GAME

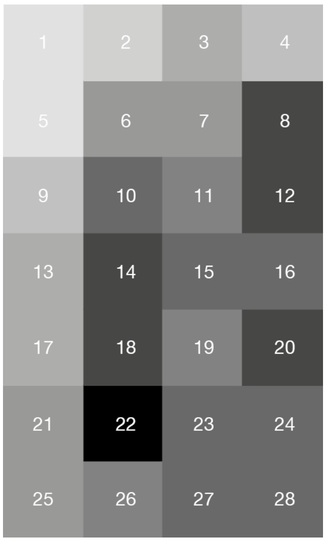
9.4.1.1 ACCURACY

We analysed the collected data to investigate the relation between target locations and accuracy rates. Accuracy was measured as the number of accurate target acquisitions divided by the number of attempts. The number of accurate target acquisitions was always one, as the next target would appear immediately after the current one was accurately selected, so for example 1 (hit) / 3 (attempts) = 33% (accuracy rate).

Accordingly, for each of the 28 grid locations we determined mean accuracy rates. The following Hitmap visually presents accuracy rates according to each location, were darker areas represent those were participants were more precise. In addition, a more detailed view of our results regarding accuracy rates is available in Table 9.2.

Overall, mean accuracy rates were over 80% for all target locations. They reached values slightly higher than 94% in only two conditions, which can be seen in Hitmap 9.1 as the darkest areas. Overall, participants were most accurate toward the centre, right edge, and bottom-right-corner of the display. These results differ from our expectations, as most users interacted with their index fingers (see Section 9.4.3), and we therefore expected a more even distribution of mean accuracy rates across all locations. Nonetheless, they are consistent with the findings of Henze, Rukzio and Boll (2011) in the Samsung Galaxy S and LG Optimus One conditions, and with those of Parhi, Karlson, and Bederson (2006) regarding one-handed thumb use, for younger adults. Still, most participants interacted with their right-hand (Table 9.12), and therefore the results cannot be generalised for left-handed older adults.

Hitmap 9.1 Mean accuracy according to *tap* target locations



Accordingly, a repeated measures ANOVA with Greenhouse-Geisser correction revealed that accuracy was significantly affected by *tap* target locations ($F(12.522, 488.376) = 3.709$, $P < 0.001$). Finally, individual mean accuracy rates for each grid location can be seen in the following table.

Table 9.3 Mean accuracy rates according to *tap* target locations

Grid locations	Mean Accuracy (%)
1	80.00%
2	82.08%
3	87.36%
4	84.72%
5	81.67%
6	89.92%
7	89.58%
8	94.72%
9	89.17%
10	93.06%
11	90.69%
12	94.03%
13	87.78%
14	94.86%

15	92.36%
16	93.19%
17	87.78%
18	94.58%
19	91.94%
20	94.58%
21	89.58%
22	97.50%
23	93.75%
24	93.19%
25	89.03%
26	91.11%
27	93.75%
28	93.75%
Grand Total	90.56%

9.4.1.2 TOUCH OFFSETS

Regarding performance metrics, in addition to mean accuracy rates we also analysed the offset between target positions and participants actual touch positions, for each grid location. For determining offsets, all distances were measured in pixels and converted to mm by obtaining a pixel to mm ratio based on the dimensions of the screen used for the evaluation (see Section 9.2 for details regarding apparatus).

As we can see in Table 9.3, touches were systematically offset to the right and bottom of targets' centre points. However, with the exception of the first grid position where offsets were shifted to the top and right. Overall, mean deviations on the x-axis amounted to 2.56 mm, and on the y-axis to 2.27 mm.

Table 9.4 Mean offsets for the x-axis and y-axis according to target locations (in mm)

Grid locations	Mean offsets for x-axis (mm)	Mean offsets for y-axis (mm)
1	4.51	5.36
2	3.58	3.96
3	2.43	4.14
4	2.08	3.73
5	4.07	3.40
6	2.34	3.14
7	2.43	2.69
8	2.04	2.21
9	3.39	2.11
10	2.55	2.80
11	2.73	3.02
12	2.22	3.03

13	3.30	2.93
14	2.25	2.31
15	2.49	2.81
16	2.44	2.36
17	3.11	3.28
18	2.38	2.00
19	2.37	3.24
20	2.26	2.58
21	3.19	2.82
22	2.25	1.87
23	2.06	1.90
24	2.15	2.99
25	3.25	3.21
26	2.86	2.96
27	2.50	3.65
28	1.79	2.52
Grand Total	2.68	2.97

Additionally, Hitmap 9.2 provides an overview of mean touch offsets for each grid location. The darker the area, the more deviation exists between the target's centre and participants' touches. As we can see, targets toward the top, left and bottom edges of the screen suffered from larger offsets.

Hitmap 9.2 Mean offsets according to grid locations

A repeated measures ANOVA with Greenhouse-Geisser correction revealed that target locations did indeed have a significant effect of touch offsets ($F(10.474, 408.467) = 4.114$, $P < 0.001$). In sum, offsets were significantly influenced by target positions, and offsets were larger for targets near the top, left and bottom edges of the screen.

9.4.2 SWIPE GAME

9.4.2.1 ACCURACY

Similarly to the previous game, we analysed the collected data to investigate the relation between target locations and accuracy rates. Accuracy was measured as the number of accurate target acquisitions divided by the number of attempts. The number of accurate target acquisitions was always one, as the next target would appear immediately after the current one was accurately acquired, so for example 1 (hit) / 3 (attempts) = 0.33 (accuracy rate). In the case of *swipe,* accuracy was measured for acquiring a target before being able to move it from one location to another. The following tables present a summary of accuracy rates according to target locations and gesture orientation, while Graphs 9.1 to 9.4 provide an illustrated overview of these results.

Table 9.5 Mean accuracy rates for the left-to-right *swipe* orientation

Grid locations and gesture orientation	Mean accuracy (%)
1 (left-to-right)	90.26%
2 (left-to-right)	86.76%
3 (left-to-right)	88.71%
4 (left-to-right)	92.21%
5 (left-to-right)	91.60%
6 (left-to-right)	89.91%
7 (left-to-right)	91.49%
Grand Total	90.13%

Table 9.6 Mean accuracy rates for the right-to-left *swipe* orientation

Grid locations and gesture orientation	Mean accuracy (%)
8 (right-to-left)	89.03%
9 (right-to-left)	88.89%
10 (right-to-left)	90.22%
11 (right-to-left)	90.99%
12 (right-to-left)	90.61%
13 (right-to-left)	92.28%
14 (right-to-left)	90.12%
Grand Total	90.31%

Table 9.7 Mean accuracy rates for the top-to-bottom *swipe* orientation

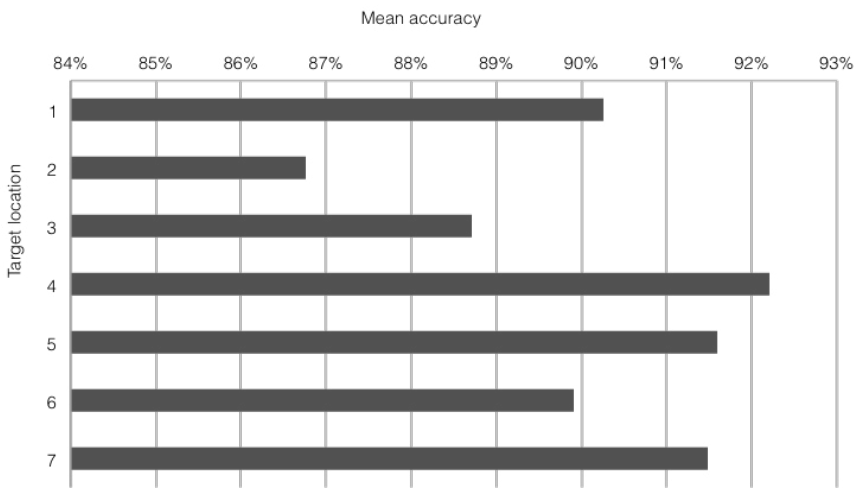
Grid locations and gesture orientation	Mean accuracy (%)
15 (top-to-bottom)	89.55%
16 (top-to-bottom)	88.58%
17 (top-to-bottom)	89.48%
18 (top-to-bottom)	93.24%
Grand Total	90.20%

Table 9.8 Mean accuracy rates for the bottom-to-top *swipe* orientation

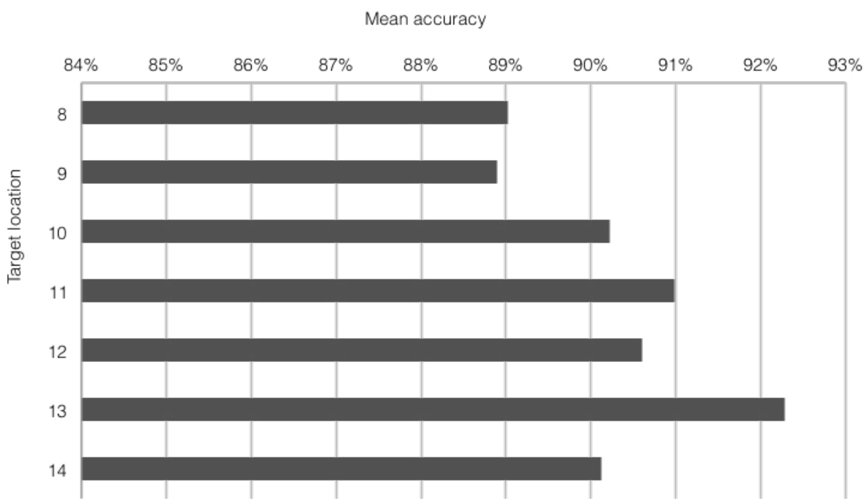
Grid locations and gesture orientation	Mean accuracy (%)
19 (bottom-to-top)	87.47%
20 (bottom-to-top)	87.88%
21 (bottom-to-top)	93.67%
22 (bottom-to-top)	89.37%
Grand Total	89.58%

Firstly, considering the horizontal conditions, for left-to-right *swipes* mean accuracy was higher for targets toward the bottom half of the screen. Accuracy for positions one, two and three were 90.26%, 86.76% and 88.71%, while for positions four, five, seven mean accuracy was 92.21%, 91.60% and 91.49% respectively. Similarly, for the right-to-left orientation, accuracy was also higher toward the bottom portion of the screen. Where for locations eight and nine mean accuracy was 89.03% and 88.89% respectively, while other locations such as eleven, twelve and thirteen reached levels of 90.99%, 90.61% and 92.28%.

Graph 9.1 Accuracy according to target locations for the left-to-right *swipe* orientation

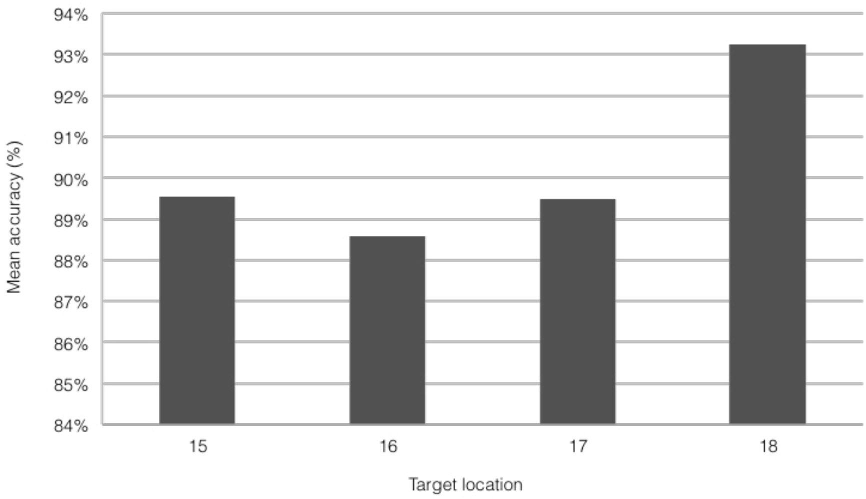


Graph 9.2 Accuracy according to target locations for the right-to-left *swipe* orientation



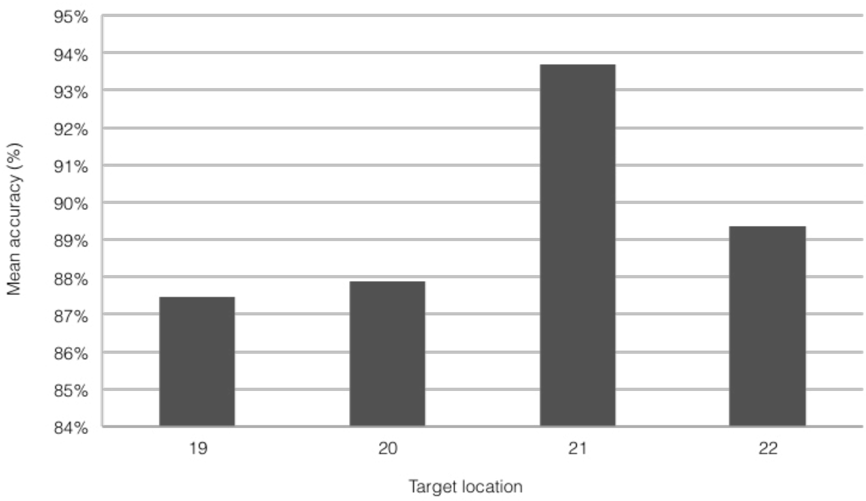
Regarding the vertical *swipe* conditions, for the top-to-bottom direction, participants were most accurate toward the right edge of the screen. Graph 9.3 summarises these results, were we can see that location eighteen reaches an accuracy rate over 93%, while for locations fifteen, sixteen and seventeen mean accuracies of 89.55%, 88.58% and 89.48% were observed.

Graph 9.3 Accuracy according to target locations for the top-to-bottom *swipe* orientation



Similarly, for the bottom-to-top orientation, participants were most accurate toward the right half of the screen. Mean accuracy for location twenty-one reached 93.67%, while for locations nineteen, twenty, and twenty-one these values were 87.47%, 87.88% and 89.37% respectively.

Graph 9.4 Accuracy according to target locations for the bottom-to-top *swipe* orientation



Overall, it seems that participants were most accurate in the left-to-right and top-to-bottom conditions. In addition, the orientation that revealed to be the most problematic was bottom-to-top, and is in accordance with participants' statements while performing the tests, as they would often state that the targets at the bottom of the screen were harder to touch and drag. Additionally, for statistical analysis, a repeated measures ANOVA was conducted for each gesture orientation in order to assess the influence of target locations on participants´ accuracy. Accordingly, for the left-to-right condition, a repeated measures ANOVA revealed that target locations did not have a significant effect on mean accuracy rates ($F(6, 234) = 1.166$, $P = 0.325$), nor on the right-to-left condition ($F(6, 234) = 0.457$, $P = 0.840$). In the same way, in none of the vertical conditions did target locations influence accuracy ($F(3, 117) = 1.414$, $P = 0.242$) for top-to-bottom, and ($F(3, 117) = 1.966$, $P = 0.123$) for bottom-to-top. Lastly, a further repeated measures ANOVA with Greenhouse-Geisser correction revealed that gesture orientation also did not affect mean accuracy rates.

In sum, although no statistical significance was found, it seems that participants were more accurate in the left-to-right and top-to-bottom conditions. Also, for the horizontal orientations accuracy was generally higher for targets located to the bottom portion of the screen. While for the vertical conditions, it was found that participants were more accurate toward the right half of the screen.

9.4.2.2 OFFSETS

In addition to mean accuracy rates , we also measured the offset between targets and participants actual touches. The offset was defined as the distance from the centre of a target to participants actual touches on the screen. Furthermore, for determining offsets, all distances were measured in pixels and converted to mm by obtaining a pixel to mm ratio based on the dimensions of the screen used for the evaluation (see Section 9.2 for details regarding the apparatus used). Tables 9.8 to 9.11 provides detailed results according to each target location and respective gesture orientation, while an illustrated overview of these results is provided by Graphs 9.5 to 9.8.

Table 9.9 Mean offsets for each grid location in the left-to-right *swipe* orientation

Grid locations and gesture orientation	Mean offset for x-axis (mm)	Mean offset for y-axis (mm)	Mean offset for both axes (mm)
1 (left-to-right)	2.12	3.76	2.94
2 (left-to-right)	2.32	3.48	2.90
3 (left-to-right)	2.34	3.30	2.82
4 (left-to-right)	2.43	3.07	2.75
5 (left-to-right)	2.11	3.19	2.65
6 (left-to-right)	2.15	3.10	2.62
7 (left-to-right)	2.17	3.35	2.76
Grand Total	2.23	3.32	2.78

Table 9.10 Mean offsets for each grid location in the right-to-left *swipe* orientation

Grid locations and gesture orientation	Mean offset for x-axis (mm)	Mean offset for y-axis (mm)	Mean offset for both axes (mm)
8 (right-to-left)	4.39	2.95	3.67
9 (right-to-left)	4.02	3.22	3.62
10 (right-to-left)	4.14	2.79	3.47
11 (right-to-left)	4.60	2.96	3.78
12 (right-to-left)	4.37	2.73	3.55
13 (right-to-left)	4.31	2.52	3.41
14 (right-to-left)	4.37	2.94	3.65
Grand Total	4.31	2.87	3.59

Table 9.11 Mean offsets for each grid location in the top-to-bottom *swipe* orientation

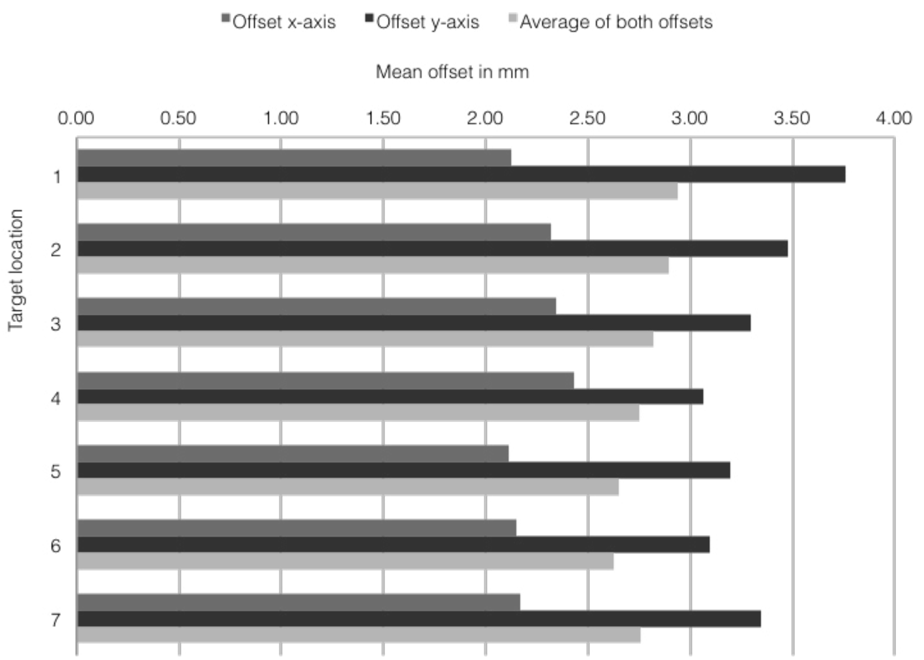
Grid locations and gesture orientation	Mean offset for x-axis (mm)	Mean offset for y-axis (mm)	Mean offset for both axes (mm)
15 (top-to-bottom)	3.41	2.25	2.83
16 (top-to-bottom)	3.18	2.42	2.80
17 (top-to-bottom)	2.64	2.31	2.48
18 (top-to-bottom)	2.91	2.29	2.60
Grand Total	3.04	2.32	2.68

Table 9.12 Mean offsets for each grid location in the bottom-to-top *swipe* orientation

Grid locations and gesture orientation	Mean offset for x-axis (mm)	Mean offset for y-axis (mm)	Mean offset for both axes (mm)
19 (bottom-to-top)	3.03	4.27	3.65
20 (bottom-to-top)	3.05	4.40	3.72
21 (bottom-to-top)	2.32	3.95	3.13
22 (bottom-to-top)	2.30	3.94	3.12
Grand Total	2.68	4.14	3.41

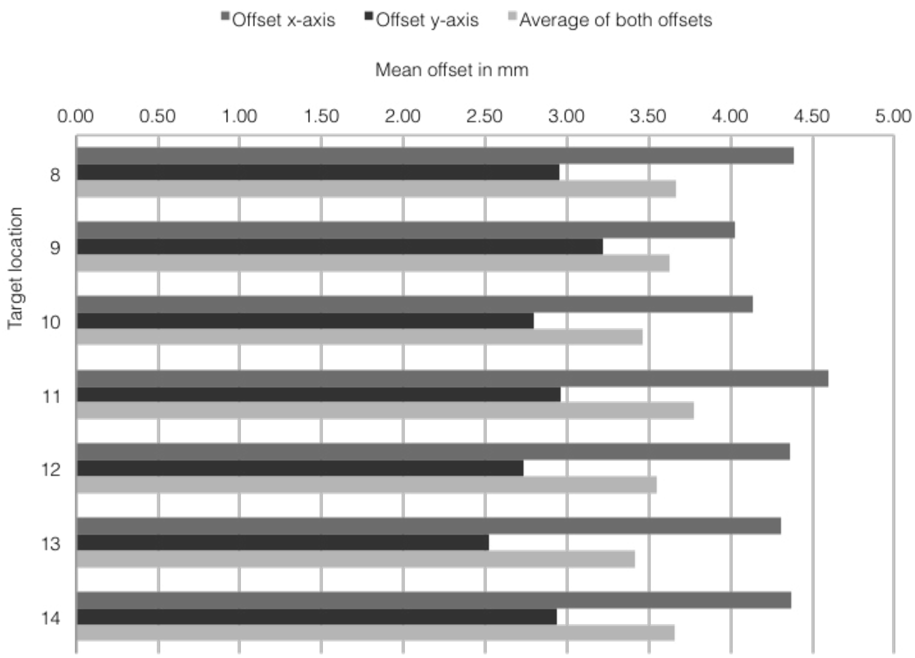
Regarding the data presented in the tables and charts, we will now discuss our main findings in further detail. Firstly, for the left-to-right *swipe* orientation, offsets along the y-axis were generally larger than those for the x-axis, although offsets along the x-axis were also registered. Meaning that participants generally touched the screen to the right and bottom of targets' centre coordinates. Also, offsets were larger for targets located toward the top portion of the screen, where mean offset for positions one and two were 2.90 and 2.94 mm respectively, and for positions five, six and seven these values were 2.65, 2.62 and 2.76 mm respectively. These findings are consistent with the previously discussed results were participants were most accurate toward the bottom portion of the screen.

Graph 9.5 Average of x and y offsets for the left-to-right *swipe* orientation



Next, for the right-to-left *swipe* orientation, and contrary to the previous condition, larger offsets were registered along the x-axis. Also, offsets were larger at the centre, top and bottom edges of the screen. Where locations with the lowest offset were those between the centre and top, and the centre and bottom edges of the display. For locations eight, nine, eleven and fourteen mean registered accuracy rates were 3.67, 3.62, 3.78 and 3.65 mm respectively. While for intermediate locations such as ten, twelve, and thirteen accuracy rates were lower at 3.47, 3.55 and 3.41 mm respectively. These findings are in accordance with those regarding accuracy rates, where participants were most accurate for locations eleven, twelve and thirteen. Lastly, it seems that overall touch offsets were larger for the right-to-left condition than for left-to-right.

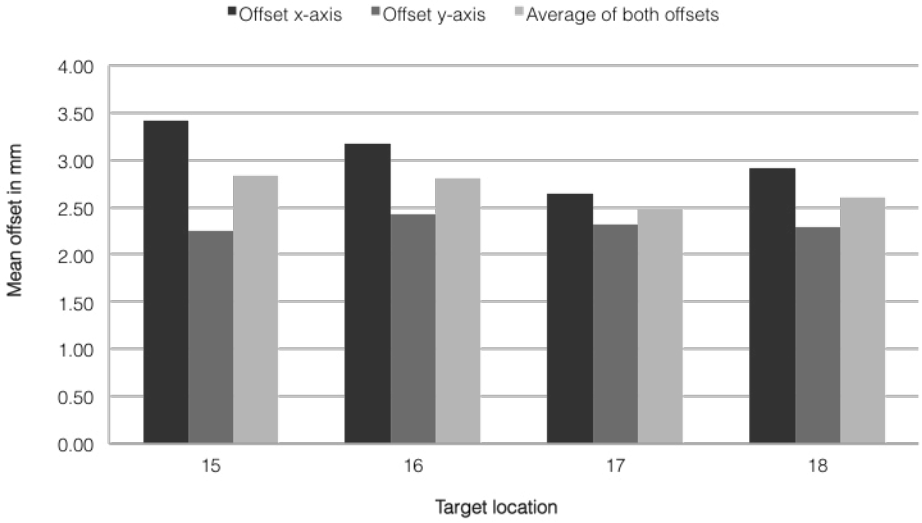
Graph 9.6 Average of x and y offsets for the right-to-left *swipe* orientation



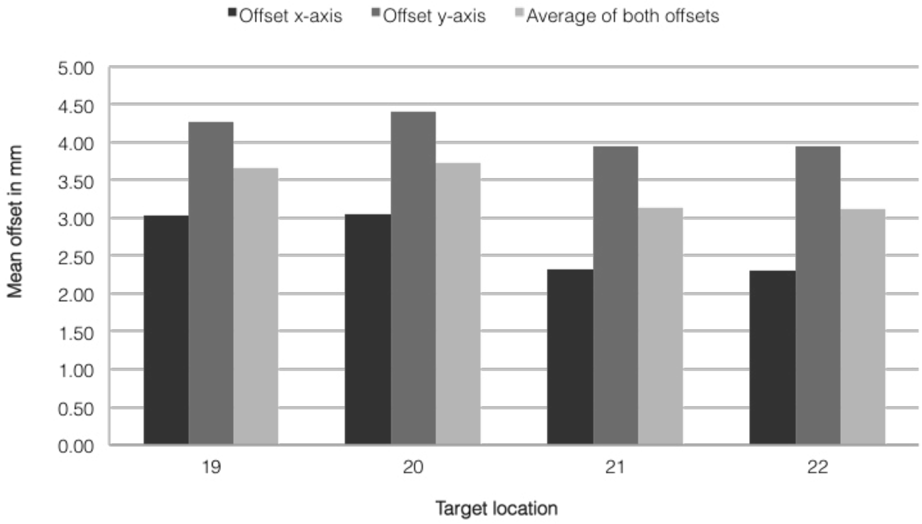
Next, for the top-to-bottom *swipe* orientation, larger offsets were registered along the x-axis than on the y-axis. Additionally, offsets were smaller for targets located toward the right edge of the display (Graph 9.7), which is consistent with the results regarding mean accuracy measures. Overall, mean offsets for locations seventeen and eighteen were 2.48, and 2.60 mm, while for locations fifteen and sixteen these values were higher at 2.83, and 2.80 mm respectively.

Finally, considering the bottom-to-top orientation, it seems that offsets along the y-axis were larger than those along the x-axis. Additionally, larger offsets occurred toward the left of the screen. This is consistent with the previously discussed accuracy rates were participants were more precise toward the right edge of the display. Overall, the location with the lowest average offset was twenty-two with 3.12 mm offset, and the one with the largest was location twenty with an average of 3.72 mm offset.

Graph 9.7 Average of x and y offsets for the top-to-bottom *swipe* orientation



Graph 9.8 Average of x and y offsets for the bottom-to-top *swipe* orientation



Overall, it seems that offsets were larger for the right-to-left and bottom-to-top conditions, which is consistent with the previously discussed results regarding mean accuracy rates. Furthermore, for targets in the left-to-right condition participants' y-axis offsets were larger, meaning that they touched the screen further to the right of targets. While for the right-to-left condition, participants would touch the screen further to the bottom of the targets. Similarly, for targets in the top-to-bottom condition, participants would generally touch the screen toward the bottom of a target. While for the bottom-to-top orientation, they would perform a touch further to the right of the target. Considering most participants were right-handed (see Section 9.43), this is consistent with the angle in which an index finger approaches a touchscreen.

For statistical analysis, a repeated measures ANOVA was conducted to assess the influence of target locations on touch offsets. The results showed that for the left-to-right condition, no significant effect was found on touch offsets along the x-axis ($F(6, 234) = 1.435$, $P = 0.202$). However, a significant effect was found for the y-axis ($F(6, 234) = 2.177$, $P < 0.05$). Regarding the right-to-left orientation, again no significance was found for the x-axis ($F(6, 234) = 1.100$, $P = 0.363$), although a significant effect of target locations on touch offsets was indeed encountered for the y-axis ($F(6, 234) = 2.756$, $P < 0.02$). Next, considering the vertical *swipe* conditions, a significant influence of target locations on touch offsets was found for the top-to-bottom condition, along the x-axis ($F(3, 117) = 4.756$, $P < 0.01$), but not on the y-axis ($F(3, 117) = 0.298$, $P = 0.827$).Finally, for the bottom-to-top condition, a significant effect was found along the x-axis ($F(3, 117) = 6.899$, $P < 0.001$), but not on the y-axis ($F(3, 117) = 2.067$, $P = 0.108$).

In sum, it seems that offset were higher for both the right-to-left and bottom-to-top conditions. Additionally, y-axis offsets were significant for the horizontal *swipe* conditions; while x-axis offsets were significant for *vertical swipe*s. This could mean that, for *swipe* targets placed in locations were lower accuracy rates were registered (top and right halves of the screen), it might be needed to shift their centre coordinates according to the mean offsets found for the x and y axes, or enlarge their touchable areas by these offset measures. For example, considering a left-to-right horizontal *swipe* target, placed at the top edge of the display where mean accuracy rates were lower, it might be beneficial to enlarge the target's touchable area by 2.23 mm to the right and 3.32 mm to the bottom (see Table 9.8).

9.4.3 GESTURE CHARACTERISTICS

We will now discuss specific gesture characteristics regarding posture and number of fingers used for interaction. Contrary to the results of the first phase of testing (see Section 6.2), most participants' held the smartphone in their left hand instead of placing it on a table. This could however be explained by the fact that the tests were conducted in the daycare centres' leisure rooms where tables where not always available for participants to place the devices. Or it can also be explained by the fact that only the phone, and not the phone plus the Noldus Mobile Device Camera[2] were being used. Overall, as shown in Table 9.12, 67.5% of participants held the smartphone with their left hand, while 15% held it with their right, another 15% placed the device on a table, and the remaining 2.5% held it in both hands.

Table 9.13 How participants placed or held the smartphone while performing tasks

On table	In left hand	In right hand	In Both Hands
15%	67.5%	15%	2.5%

Additionally, Table 9.13 provides an overview of which fingers participants' used for interaction. Where much like on the first phase of tests (see Section 6.2) 75% of participants used only their index finger for interaction. Furthermore, only 5% of participants used their thumbs, which is contrary to what is generally accepted for younger adults who prefer to use their thumbs to perform most tasks, except those involving text entry (Karlson, Bederson, & L., 2006). Additionally, 12.5% of participants used both their index finger and thumb interchangeably.

Table 9.14 Fingers used for interaction while performing test tasks

Index	Index and Thumb	Thumb	Middle and index	Middle, Index and Thumb	Ring, Index and Thumb
75%	12.5%	5%	2.5%	2.5%	2.5%

2 http://www.noldus.com/human-behavior-research/accessories/mobile-device-camera-mdc

9.5 DISCUSSION

The objective of this phase of our study was to answer the following research questions:

- Are comfortable activity zones on smartphones the same for younger and older adults?
- In the particular case of *swipe*, does gesture orientation influence older adults' performance?

Accordingly, by intersecting our findings for all dependent variables in each condition, we found that target locations did influence participants' overall performance for both *tap* and *swipe* gestures. Firstly regarding *tap*, our results suggest that these targets are more easily acquired when placed toward the centre, right edge and bottom right corner of the display. Even though most participants used their index fingers for interaction, targets located at the top-left corner, as well as at the left and top edges of the display suffered from lower accuracy rates and higher average offsets. This is consistent with the findings of several other authors regarding younger adults and activity zones for *tap* on mobile touchscreen devices. Parhi, Karlson and Bederson (2006) investigated one-handed thumb interaction with 20 younger adults. The authors found that participants had the most difficulty with targets placed near the left edge, and bottom-right-corner of the display. While targets placed toward the centre of the display were found to be the best (Parhi et al., 2006). In addition and still regarding one-handed thumb input, Park, Han, Park et al., (2008) carried out a study with thirty younger adults and defined pressing convenience regions as those placed toward the centre of the display, while avoiding the edges of the device (Park, Han, Park, & Cho, 2008). More recently, Henze, Rukzio and Boll (2011) found that targets placed near the border of the smartphones were generally more difficult to hit than those placed toward the centre. However, our findings contrast with those of Perry and Hourcade (2008), where the authors found that participants were more accurate at *tapping* targets near the edges of the screen ,while being quicker and more comfortable when *tapping* targets toward the centre of the device (Perry & Hourcade, 2008).

Regarding *tap* targets and activity zones, our findings lead us to believe that for targets placed within problematic regions it could be beneficial to shift their position according to the mean offset values that were discovered. For example, considering a left-to-right *swipe* orientation, it might be beneficial to shift targets placed near the top of the display by 2.23 mm to the right, 3.32 mm to the bottom. On the other hand, instead of moving targets, we suggest that when the required space is available, it would be better to simply enlarge the touchable area around the target. By moving targets, or enlarging contact areas, we hope to compensate for the "fat finger problem" (Vogel & Baudisch, 2007), as well as for issues regarding target occlusion by the users fingers and hands during interaction.

Secondly, regarding our findings for the *Swipe* Game, we found that for horizontal orientations, the intersection of all three independent variables suggests that participants' performance was best for *swipe* targets placed within the bottom half of the display. While for the vertical conditions, our findings reveal that participants perform best with *swipe* targets located at the right half of the display. It would however be interesting to conduct this study with a group of younger adults, in order to assess potential differences, or similarities regarding activity zones for *swipe* gestures. As to our knowledge, no further research has been conducted to investigate these issues with neither younger, nor older adults.

In addition, our results suggest that for targets placed within problematic regions, it could be beneficial to either shift targets of enlarge contact areas, by the mean offset values that were discovered. These offset values were 2.23 x 3.32 mm for the left-to-right orientation, 4.31 x 2.87 mm for right-to-left, 3.04 x 2.32 mm to top-to-down *swipes,* and finally 2.68 x 4.14 mm for the bottom-to-top orientation.

However, since we did not control which fingers or hand participants used to interact, future research is needed regarding particular forms of interaction. This could mean investigating right-handed versus left-handed input, and thumb versus index finger input modes, as these conditions could significantly influence the results.

Finally, the results from these findings were documented in the following design patterns, which can be viewed in Section 10:

- ACTIVITY ZONES AND TOUCH OFFSETS FOR *TAP* GESTURES
- ACTIVITY ZONES AND TOUCH OFFSETS FOR *SWIPE* GESTURES

10 INTERACTION DESIGN PATTERNS FOR SMARTPHONES TARGETED AT OLDER ADULTS

This chapter presents the interaction design patterns created from the main findings of our four research phases. Accordingly, the following sections discuss (1) our goals in creating this set of patterns, then they present the (2) outline and structure of the patterns, and finally (3) the patterns themselves are presented.

10.1 GOALS AND CONTRIBUTIONS OF THE PATTERNS

Our research aimed to further the understanding of gestural interaction on smartphones for older adults. In this context, our intention is that the patterns, presented in this section, provide guidance regarding (1) the most adequate gestures for older adults, (2) the use of contextual help mechanisms to teach gestures to users, (3) target sizes for *tap* and *swipe* gestures, (4) spacing sizes between adjacent *tap* or *swipe* targets, as well as (4) smartphone activity zones and touch offsets for these gestures.

In this context, our main objective in creating the patterns was to document our results in an easily understandable, and readily available form. So that all practitioners involved in creating smartphone interfaces for older adults, could have access to the results of our research work in the form of design guidance. Accordingly, we decided to construct a Website[1] (Figures 10.1 and 10.2) to host the patterns, as it seemed to be the most adequate solution for disseminating these patterns to all interested parties. In this way, we hope to, in the future, contribute to enhancing the usability of smartphone interfaces designed for older adults.

10.2 PATTERN STRUCTURE

Our patterns largely follow the structure presented by Christopher Alexander in “A Pattern Language: Towns, Buildings, Construction” (1977), and that was later reused by Jan Borchers in “A Pattern Approach to Interaction Design” (2001).

1 http://roxanneleitao.com/designpatterns

Each pattern starts with its name written in small caps. An individual ranking is attributed to each pattern, representing the level of confidence that the authors deposit in it. This ranking can range from zero to two asterisks, where zero represents the lowest level of confidence and two represents the highest.

The pattern identification elements are followed by the context that describes the reader's current situation, as well as the goal of the pattern and the environment within which it is located. The title and context will give the reader an immediate perception whether the pattern is applicable, or not, to their particular problem.

After the context is set, the problem statement is presented in bold and is followed by a longer problem description. It is in the problem description, that contradicting forces are explained and the problem's empirical background is presented.

Finally, the solution appears in bold and includes references to other related patterns. These references point to other patterns in the language, and offer readers further guidance in constructing usable UIs for older adults.

Unlike Alexander's patterns, we do not present an image of a real-world application of the patterns, as they have not yet been put into practice. We could provide examples of interfaces that unintentionally meet the criteria defined in each pattern but thought that would not aid in the comprehensibility of the patterns themselves.

Figure 6.1 Screenshot of homepage

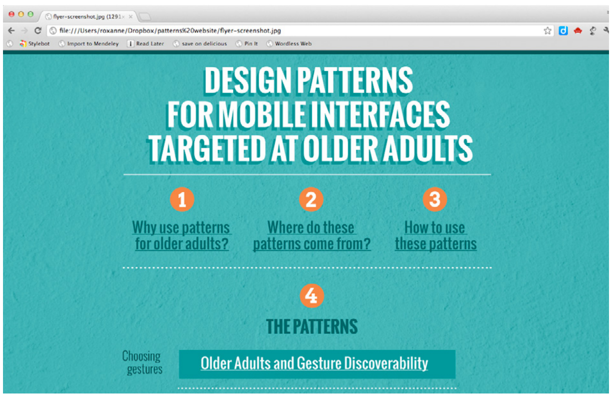
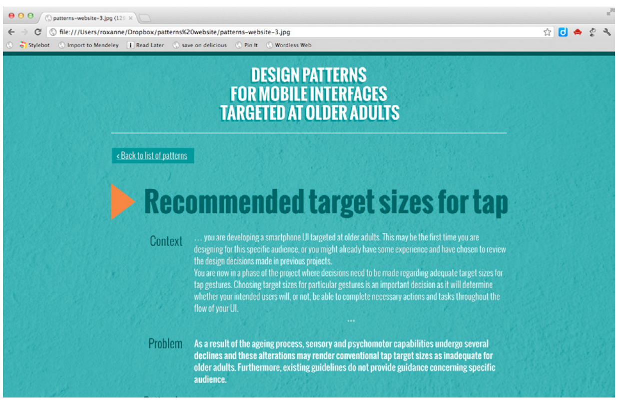


Figure 6.2 Screenshot of a pattern



10.3 SET OF INTERACTION DESIGN PATTERNS

10.3.1 SMARTPHONE GESTURES FOR OLDER ADULTS *

... you are developing a smartphone UI targeted at older adults. This may be the first time you are designing for this specific audience, or you might already have some experience and have chosen to review the design decisions made in previous projects. You are in the early stages of your interface design, and had reviewed official recommendations on how to correctly apply standard gestures to your smartphone interface. However, your user-interface is targeted at older adults who might not be technology proficient, and therefore not be familiar with gestural interfaces, nor with the gestures used to operate them.

+++

Touchscreen interfaces suffer from usability issues related to the lack of cues that inform users on the gestures available to operate the system. However, due to limited screen real-estate issues on smartphones, it might not be possible or advisable to have UI buttons for every possible function. In addition, your target audience are older adult users who in many cases may not have prior experience with gestural interaction. In this context, you need to know which existing gestures are the most intuitive for older adults.

Multitouch devices, such as smartphones, offer a wide variety of functions that are accessible to users through the use of gestural commands[2]. However, these gestures have largely been created by systems' designers over time as the evolution of touchscreen technology progressed. In this context, the design of gestures might have been more concerned with systems' recognition issues, rather than the end-usability of such gestures (Wobbrock, Morris, & Wilson, 2009). In addition, several authors have pointed out that in many cases these interfaces lack affordances (D. Norman, 1990), or cues that inform users on the gestures available to interact these systems (Bau & Mackay, 2008; Bragdon et al., 2010; D. A. Norman, 2010).

Accordingly, our research with older adults aimed to evaluate the discoverability of current smartphone gestures. In order to do so we employed the method described in (Wobbrock et al., 2009). Which consisted of showing an animation depicting the consequence of a gesture for each task. We would then explain the task to participants, and ask them to perform a gesture they thought could provoke the consequence seem in the animation. Our results showed that *tap* and *swipe* gestures were overall those that were best understood by older adults, and were used to solve almost all of the tasks. While other common smartphone gestures such as *pinch, spread, tap and hold,* and *double-tap*, were performed either by very few, or by no participants at all.

Tap and *swipe* are the most essential gestures used to operate a smartphone. Where most commands and functionalities available by the use of other gestures such as *pinch, spread, touch and hold,* and *double-tap* are also available through contextual menus, or specific UI buttons. Meaning that if older adults are able to use *tap* and *swipe,* they will have access to most functions available on existing smartphones.

2 Android: http://developer.android.com/design/patterns/gestures.html

iPhone: https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html#//apple_ref/doc/uid/TP40006556-CH7-SW1

Windows Phone 7: http://www.windowsphone.com/en-us/how-to/wp7/start/gestures-flick-pan-and-stretch

Therefore...

When designing smartphone interfaces for older adults, make sure that commands or actions that are activated by the use of complex gestures such as *pinch, spread, touch and hold,* and *double-tap*, are also available through menus, or dedicated UI buttons. In order to access these menus and UI buttons, older adults should only need to employ *tap* and *swipe* gestures. Additionally, FOR NOVICE USERS, PROVIDE DEMONSTRATIONS OF AVAILABLE GESTURES, as in many cases your older adult users may be completely new to the gestural interaction paradigm, and not know where or how to start using your interface.

10.3.2 FOR NOVICE USERS, PROVIDE DEMONSTRATIONS OF AVAILABLE GESTURES **

... You are designing a smartphone interface targeted at older adult users. You have been SELECTING SMARTPHONE GESTURES FOR OLDER ADULTS. However, you are concerned with novice users who might not have any prior experience with touchscreen interaction, and therefore might not know how to employ gestures to operate your smartphone interface.

+++

In many cases, older adults might not have any prior touchscreen experience. Therefore, they might not know how to employ gestures in order to effectively manipulate a smartphone interface. In this context, the need might arise for demonstrating available gestures to your users, as well as the particular tasks which each gesture resolves.

Several authors have pointed out the lack of cues, or affordances (D. Norman, 1990), available on gestural interfaces (Bau & Mackay, 2008; Bragdon et al., 2010; D. A. Norman, 2010). Where in many cases, users do not know which gestures are available to interact with a given system. Accordingly, the need to provide demonstrations of available gestures has been identified in several works regarding different kinds of gestural interfaces (Bau & Mackay, 2008; Bragdon et al., 2010; Kurtenbach, Moran, & Buxton, 1994). However, most of these efforts have been conducted for younger adults users. In this context, our own work aimed to evaluate the influence of animated tutorials that demonstrate gestures applied to smartphone tasks, on older adults' performance of gestures. Our results revealed that the animated tutorials did in fact enhance older adults' performance of *tap* and *swipe* gestures, where correct gesture performance was higher for older adults who viewed tutorials than for those who did not. Furthermore, most participants only required viewing each tutorial once before carrying-out a correct gesture. In this way, it seems that not only are older adults capable of learning *tap* and *swipe* gestures, but that these help mechanisms may only be needed during an initial training phase, after which they will probably become unnecessary.

Therefore ...

For novice older adult users, provide contextual help mechanisms that demonstrate gestures and how they should be used to manipulate your interface. These tutorials should not only tell users where on the interface certain gestures should be carried-out, but should also demonstrate the physical performance of these gestures.

10.3.3 RECOMMENDED TARGET SIZES FOR *TAP* GESTURES **

...you are now in a phase of the project where decisions need to be made regarding adequate target sizes for *tap* gestures. Choosing target sizes for a particular gestures is an important decision as it will determine whether your intended users will, or not, be able to complete necessary actions and tasks throughout the flow of your UI.

+++

As a result of the ageing process, sensory and psychomotor capabilities undergo several declines and these alterations may render conventional *tap* target sizes as inadequate for older adults. Furthermore, existing smartphone OS guidelines do not provide guidance concerning specific audiences, such as older adults.

Previous research has explored adequate target sizes for *tap* gestures on large touch-surfaces (Colle & Hiszem, 2004), PDAs (Parhi, Karlson, & Bederson, 2006; Park, Han, Park, & Cho, 2008; Perry & Hourcade, 2008; Sears & Zha, 2003), or more recently on tablets (Jin, Plocher, & Kiff, 2007) and smartphones (Henze, Rukzio, & Boll, 2011), but very few have explored target sizes for older adults on smartphones (Kobayashi et al., 2011).

Consequently, most guidelines that are currently available[3] do not aid designers in creating a smartphone UIs that adequately respond to older adults' specific characteristics.

It is commonly accepted that visual acuity, visual search capabilities (Fisk, Rogers, Charness, Czaja, & Sharit, 2009), fine-motor skills, hand dexterity (Carmeli, Patish, & Coleman, 2003) and touch sensitivity (Carmeli et al., 2003; Fisk et al., 2009; Nusbaum, 1999; Wickremaratchi & Llewelyn, 2006) suffer considerable losses with age. Additionally, natural age-related declines of the sensory and psychomotor systems can be further aggravated by diseases such as Age-related Macular Degeneration, cataracts, presbyopia and glaucoma — relative to visual abilities, and multiple sclerosis, arthritis, osteoporosis, stroke and Parkinson's disease — related to psychomotor issues (Kurniawan, 2008). Movement can be severely affected by these diseases, causing symptoms such as weakness, numbness, loss of muscle coordination, pain, stiffness, tremors, rigidity and slow movement (Kurniawan, 2008). Therefore, one cannot safely assume that target sizes that have been found to be adequate for younger adults will also provide a comfortable user experience for the elderly.

It is clear that special considerations need to be taken into account when designing UIs for older adults. Targets for all gestures should be resized to fit the elderly population's particular characteristics. *Tap* target sizes are no exception.

Accordingly, our own research revealed that older adults were most accurate, and took less time to correctly acquire *tap* targets larger than 14 mm, where registered mean completion times for this target size were 1.7 seconds, and the mean accuracy rates were 97.94%.

Therefore...

3 Android: http://developer.android.com/design/style/metrics-grids.html

iPhone: https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

Windows Phone: http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx

If screen real estate is not an issue and the task requires high performance levels, use targets for tap gestures that are at least 14 mm square. Otherwise, in cases where screen real estate is very limited and smaller *tap* targets cannot be avoided see RECOMMENDED *TAP* TARGET SIZES FOR LIMITED SCREEN REAL ESTATE.

10.3.4 RECOMMENDED *TAP* TARGET SIZES FOR LIMITED SCREEN REAL ESTATE *

… you have used RECOMMENDED TARGET SIZES *TAP* GESTURES, but have found this range of target sizes does not provide an adequate solution for all *tap* target size-related issues due to screen real estate limitations.

+++

Using RECOMMENDED TARGET SIZES FOR *TAP* GESTURES is generally the most desired solution. However, the necessary screen real estate is not always available on smartphones.

Other interface elements might occupy most of the available screen real estate, depending on the particular function of each screen/page within the application structure, or you might need more *tap* targets than can comfortably fit on one screen when using RECOMMENDED TARGET SIZES FOR *TAP* GESTURES.

Opting for a range of smaller sizes than those that are considered to be ideal could solve the problem. In these cases, the trade-offs would be lower accuracy rates and higher task completion times for your users. Using a smaller target size is acceptable in such situations as long as you are aware that measures such as accuracy and task completion times will suffer. Inevitably, opting for smaller target sizes will cause the UI to be more difficult to operate and could result in some level of frustration and anxiety among users (Czaja & Sharit, 1998; Laguna & Babcock, 1997; Turner, Turner, & Van De Walle, 2007).

Therefore, it is important to understand within which range of smaller target sizes older adults' mean accuracy rates and task completion times maintain themselves at an acceptable level, even though they will be naturally lower than when using RECOMMENDED TARGET SIZES FOR TAP GESTURES.

Our own research work suggests that older adults are able to use a certain range of smaller *tap* target sizes while still maintaining performance measures at satisfactory levels. This range of smaller target sizes includes those between 10.5 and 14 mm, where mean accuracy for the 14 mm targets was 93.75%, and mean task completion times were 1.94 seconds. Official guidelines recommend a minimum target size of 7 mm. However, for this target size participants' mean accuracy decreased to 67.67%, and task completion times increased to 3.08 seconds.

Therefore…

When using RECOMMENDED TARGET SIZES FOR *TAP* GESTURES is not possible, and average target selection times of 1.94 seconds are acceptable, use a minimum target size of 10.5 mm square.

10.3.5 RECOMMENDED TARGET SIZES FOR *SWIPE* GESTURES **

... you are now in a position where you need to decide on specific target sizes for *swipe* gestures. They are an important issue, as they will determine if your users will, or not, be able to complete many actions and tasks throughout the flow of your UI.

+++

Selecting a range of target sizes that are most adequate for a given group of users requires a thorough understanding of their particular characteristics, expectations and preferences. Official smartphone OS guidelines such as, Windows Phone's "User Experience Design Guidelines"[4], Google's "Android Design"[5], and Apple's "iOS Human Interface Guidelines"[6], do not provide guidance in designing *swipe* targets for specific groups of users such as older adults.

These official guidelines recommend target sizes that are smaller than the average human finger (10 to 14 mm) (Dandekar, Raju, & Srinivasan, 2003), raising issues such as target occlusion while performing a gesture and/or accidentally touching neighbouring targets.

It is well accepted that visual acuity (Fisk et al., 2009), movement control, hand-eye coordination, hand dexterity (Carmeli et al., 2003) and touch sensitivity (Carmeli et al., 2003; Fisk et al., 2009; Nusbaum, 1999; Wickremaratchi & Llewelyn, 2006) suffer considerable losses during the ageing process. Thus making it harder to see small targets, and to perform the necessary movements in order to accurately acquire them.

Additionally, vision and psychomotor capabilities can be further compromised by common diseases among older adults such as Age-related Macular Degeneration, cataracts, presbyopia glaucoma — relative to visual abilities; and multiple sclerosis, arthritis, osteoporosis, stroke and Parkinson's disease — related to psychomotor issues. Movement can be severely affected by these diseases, causing symptoms such as weakness, numbness, loss of muscle coordination, pain, stiffness, tremors, rigidity and slow movement (Kurniawan, 2008).

Inevitably, accurately acquiring small targets becomes increasingly difficult as age progresses. Providing targets that are too small makes a UI more difficult to use and could result in frustration and anxiety among older adults (Czaja & Sharit, 1998; Laguna & Babcock, 1997; Turner et al., 2007) and should therefore be avoided.

Target sizes should be adjusted to meet the specific needs of older adults, in order to provide a more comfortable and enjoyable user experience.

Accordingly, our own work revealed that participants were quicker, and more accurate with *swipe* targets larger than 17.5 mm square. For this target size participants' mean accuracy level was 97.24%, and mean task completion times were 2.8 seconds. Revealing that the end intention of a movement — whether to finalise in a *tap* or *swipe* — influences older adults' accuracy and speed in acquiring targets. Where *swipe* targets need to be larger than *tap* targets.

Therefore...

4 http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx

5 http://developer.android.com/design/style/metrics-grids.html

6 https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

In cases where available screen space for *swipe* targets is not an issue and the task requires high performance measures, use target sizes for *swipe* gestures that are at least 17.5 mm square. Otherwise, when screen real estate is limited and smaller *swipe* targets cannot be avoided see RECOMMENDED *SWIPE* TARGET SIZES FOR LIMITED SCREEN REAL ESTATE.

10.3.6 SWIPE TARGET SIZES FOR LIMITED SCREEN REAL ESTATE *

You have employed RECOMMENDED *SWIPE* TARGET SIZES throughout most of the *swipe* targets that make up your UI. However, in some cases you have found that this range of sizes does not provide a satisfactory solution.

+++

Using RECOMMENDED *SWIPE* TARGET SIZES throughout your entire user interface is the ideal solution. However, in cases where screen real estate is limited, this might not be possible.

The amount of available screen space is mainly influenced by the number of targets that need to be displayed, as well as by all of the remaining content that makes up your interface. Throughout the screen flow of a particular application, there might be cases where large target sizes are not an issue, but other situations where large amounts of content are needed, or a numerous group of *swipe* targets requires displaying. Consequently, there might not be enough space to accommodate all elements while still using RECOMMENDED *SWIPE* TARGET SIZES.

Hence, depending on the amount of content, as well as on the number of *swipe* targets that make up a particular screen, it might be necessary to reduce *swipe* target sizes.

In that case, it is important to know within what specific range of smaller *swipe* target sizes older adults' accuracy rates and task completion times, maintain themselves within acceptable levels. Although these values will be inevitably lower than with RECOMMENDED *SWIPE* TARGET SIZES, they might still be within satisfactory standards depending on the performance requirements of the task they are assigned to. A UI designer should always be aware that reducing target sizes could make a product more difficult to use. This additional difficulty might provoke frustration and anxiety among older adults. This particular audience is generally more susceptible than their younger counterparts toward negative feelings while interacting with technology (Czaja & Sharit, 1998; Laguna & Babcock, 1997; Turner et al., 2007).

Our own work suggests that older adults are able to use a certain range of smaller *swipe* target sizes while still maintaining performance measures at satisfactory levels. This range of smaller target sizes includes those between 10.5 and 14 mm, where mean accuracy for the 10.5 mm targets was 95.24%, and mean task completion times were 2.68 seconds. For targets smaller than this, mean accuracy decreased to 91.90%, and task completion times increased to 2.75 seconds for the 10.5 mm targets, and for the 7 mm targets mean accuracy lowered to 86.25%, and task completion times increased to 3.5 seconds.

Therefore...

When the necessary screen real estate to implement RECOMMENDED TARGETS SIZES FOR *SWIPE* GESTURES is not available, and the task does not require high performance levels, then use target sizes for *swipe* gestures that are at least 14 mm square.

10.3.7 SPACING BETWEEN TARGETS FOR *TAP* AND *SWIPE* GESTURES **

...you have chosen the types of gesture you will employ for each target, as well as the dimensions of these targets. Now, you are now in a phase of the project where decisions need to be made regarding adequate spacing sizes between adjacent-targets. Choosing spacing sizes between adjacent-targets is an important decision, as it may determine the levels of comfort, and efficiency with which your users are able to get things done on your interface.

+++

As a result of the ageing process, sensory and psychomotor capabilities undergo several declines, and these alterations may render common interfaces to be unusable. In this context, it is of paramount importance to take these age-related changes into account when designing smartphone interfaces for older adults. Furthermore, existing smartphone OS guidelines do not provide guidance regarding spacing sizes between adjacent-targets for specific audiences, such as older adults.

It is commonly accepted that visual acuity (Fisk et al., 2009), movement control, hand-eye coordination, hand dexterity (Carmeli et al., 2003) and touch sensitivity (Carmeli et al., 2003; Fisk et al., 2009; Nusbaum, 1999; Wickremaratchi & Llewelyn, 2006) suffer considerable losses during the ageing process. Additionally, vision and psychomotor capabilities can be further compromised by common diseases among older adults such as Age-related Macular Degeneration, cataracts, presbyopia glaucoma — relative to visual abilities; and multiple sclerosis, arthritis, osteoporosis, stroke and Parkinson's disease — related to psychomotor issues. Movement can be severely affected by these diseases, causing symptoms such as weakness, numbness, loss of muscle coordination, pain, stiffness, tremors, rigidity and slow movement (Kurniawan, 2008). Thus, making it harder to see small targets and distinguish them when spacing between targets is very reduced.

Previous research has explored the influence of spacing dimensions between adjacent-targets on participants' performance. (Colle & Hiszem, 2004) and (Sun, Plocher, & Qu, 2007) found that with younger adults the spacing between *tap* targets had no significant effect on participants' performance. In addition, (Sun et al., 2007) revealed that, contrary to what was expected, performance did not improve as spacings became larger. Similarly, (Jin et al., 2007) found that older adults had longer reaction times with larger spacing sizes between *tap* targets, and that spacing should be between 2.17 and 12.7 mm. Additionally, existing smartphone OS guidelines recommend spacing of 1.5 to 2 mm, which is lower than those found by (Jin et al., 2007) for older adults using a larger fixed touchscreen.

Regarding spacing sizes between adjacent-targets, our own work showed that spacing sizes did not influence participants performance as much as target sizes did. It seems that older adults were able to easily acquire *tap* targets with spacings between each other of 0 to 10.5 mm, and *swipe* targets with spacings of 0 to 7 mm between each other.

Therefore...

Depending on the screen real-estate available, allow for 0 to 10.5 mm spacing between adjacent *tap* targets, or for 0 to 7 mm spacing between adjacent *swipe* targets.

10.3.8 ACTIVITY ZONES AND TOUCH OFFSETS FOR *TAP* GESTURES **

… you have selected adequate gestures for all targets on your smartphone interface, and have decided on target sizes for *tap* gestures, as well as on spacing sizes between adjacent *tap* targets. You are now seeking information regarding the placement of *tap* targets on the smartphone's display, in order to compensate for issues related to older adults' reachability of certain screen regions.

+++

You have a series of *tap* targets that you need to distribute throughout your interface. However, not all screen regions allow for the same levels of efficiency, and accuracy in target selection. In this context, you need to place *tap* targets requiring higher levels on efficiency in regions that are more easily reachable and therefore allow for higher level of performance.

Activity zones are defined as the regions on the smartphone's display that allow for better performance. Dan Saffer, in a blog article[7] (Saffer, 2011), defined smartphone activity zones as those comprising the uppermost left corner, right and bottom edges, and centre of the display. However, these activity zones primarily consider one-handed thumb input, and as seen in our results most older adult participants used their index fingers for interaction. Several efforts have been made to define activity zones on mobile touchscreen interfaces, Parhi, Karlson and Bederson (2006) carried-out a study with twenty younger adults in order to evaluate thumb-use and the performance of both discrete and serial tap gestures. They found that participants were most accurate with targets placed toward the centre of the device, and less accurate toward the left edge, and bottom-right-corner of the device. Contrastingly, Perry and Hourcade (2008) found that participants were more accurate in acquiring targets on the edge of the screen, while being quicker and more comfortable with targets toward the centre of the screen. More recently, Henze, Rukzio and Boll (2011) found that participants were most accurate in acquiring tap targets in the centre, and toward the right and bottom edges of the display. However, these studies were conducted with younger adults, and therefore cannot provide guidance in designing for an older population.

Our own research results showed that even though older adults used their index finger and not their thumbs for interaction, that these activity zones were still similar to those outlined by (Parhi et al., 2006) and (Henze et al., 2011). However, contrary to the activity zones defined by Dan Saffer in the blog article, the uppermost left corner of the display was the region that registered the lowest performance measures with older adults. Still, most of our participants used their right hand for interaction, and therefore our results cannot be generalised for left-handed older adult participants. In addition, we found that offsets between the target's centre point and participants actual touches on the screen were registered for all regions of the display. Which leads us to believe that for targets placed in more problematic regions, it might be necessary to enlarge their touchable area by the offset measures found in our research.

Therefore …

When placing tap targets, be sure that those requiring high levels of performance are placed toward the centre, right edge and bottom right corner of the display. However, when screen real-estate is limited and it is necessary to place targets in regions with lower performance measures, then enlarge these targets' touchable areas by 2.68 mm to the right, and 2.97 mm to the bottom, for right-handed users.

7 http://www.kickerstudio.com/blog/2011/01/activity-zones-for-touchscreen-tablets-and-phones/

10.3.9 ACTIVITY ZONES AND TOUCH OFFSETS FOR *SWIPE* GESTURES **

… you have selected adequate gestures for all targets on your smartphone interface, and have decided on target sizes for *swipe* gestures, as well as on spacing sizes between adjacent *tap* targets. Now, you are looking for information regarding the placement of *swipe* targets on the smartphone's display, in order to compensate issues related to users' reachability of certain smartphone screen regions.

+++

You have a series of *swipe* targets that you need to distribute throughout your interface. However, not all screen regions allow for the same levels of efficiency, and accuracy in target selection.

Activity zones are defined as the regions on the smartphone's display that are more easily reachable, and therefore allow for better performance measures. Several authors have investigated activity zones for *tap* targets on mobile touchscreen devices with younger adults (Henze et al., 2011; Parhi et al., 2006; Perry & Hourcade, 2008), but to our knowledge none have addressed activity zones for *swipe* gestures.

Accordingly, our research with older adults revealed that for horizontal *swipes* participants performed best with horizontal *swipe* targets places toward the bottom half of the screen, and for vertical *swipes* best performance measures were found toward the right half of the screen. In addition, we found that offsets between the targets centre and participants actual touches were registered for all regions of the display. Which leads us to believe that for targets placed in more problematic regions, it might be necessary to enlarge their touchable area by the offsets found in out own research, in order to compensate for reachability issues.

Therefore …

For *swipe* targets requiring high levels of efficiency, place horizontal *swipe* targets toward the bottom half of the screen, and vertical *swipe* targets toward the right half of the screen. However, when screen real-estate is limited and it is necessary to place targets in regions were lower performance measures were registered, then enlarge these targets' touchable areas by 3.27 mm to the right, and 3.1 mm to the bottom for horizontal *swipe* targets, and by 2.86 mm to the right, and 3.23 mm to the bottom for vertical *swipe* targets.

11 DISCUSSION

The previous chapters described the procedures and results of our four phases of tests with users. They also summarised, and discussed our main findings. This chapter will now re-address the work presented in this document in order to discuss our research methods, and the results obtained, by addressing subjects such as: (1) potential issues regarding participants' and their characteristics, (2) sample sizes and their implications, (3) possible issues related to the apparatus used in the tests, and finally (4) possible limitations of the methods employed, for each of the four phases of our research.

11.1 PARTICIPANTS AND SAMPLE SIZES

Participants' gender distribution was uneven throughout all phases of testing, where in phases one, two and three we had more female than male participants, and in phase four this tendency was inverted with more male than female participants. However, this could not be avoided, as we had access to different adults day-care centres, and retirement homes throughout the various stages of our work. Only a few of these centres were available at a time, and therefore we could not choose where we wanted to perform the tests, but rather where we had permission to do so. In addition, most of the persons in these centres are women, and the prevalence of male participants, in the fourth phase of research, can be explained by the fact that this phase was conducted at a time where we had recently gained access to a new leisure centre, were older adults males would gather to play cards. Still, during phase four it was also not possible to balance male and female participants, as at the time we did not have access to centres with female users. Nonetheless, considering the nature of our tests, we do not consider that a more even distribution of participants' gender would influence our results, as the variables we measured in our tests should not be dependent on gender differences.

Regarding sample sizes, we find that in the future, phase one and two could indeed by conducted with more participants. However, during our research we found that after conducting tests with a few users, we started to see the results repeating, as no new gestures were being performed, and most participants were making use of solely *tap* and *swipe* gestures. Still, given the small sample size our results do not allow for statistical generalisation, but they do provide valuable insight into the understanding of gestural interaction on smartphones for older adults, as well as the way in which gestural interaction is understood and carried-out by older adult users. In this context, the insight provided by our results, could in the future be the basis for further investigation with a larger sample of older adults.

Finally, our participants were all Portuguese older adults with low technology-proficiency. If our study was conducted in different cultural and socio-economic conditions, our results could be different.

11.2 APPARATUS USED

During the first two phases of our research, it was necessary to attach a Noldus Mobile Device Camera[1] to the smartphone, in order to video record participants hands while they performed gestures. However, when comparing results regarding how participants held the smartphone, we found that in the first phase, most of them placed the smartphone on a table. On the other hand, during the fourth phase of research, there was no camera attached to the smartphone, and in most cases participants did not have anywhere to place the device. As a result, participants held the smartphone in one hand while interacting with the other. For these reasons, our results regarding participants' posture, number of hands and fingers used for interaction, need to be interpreted in light of the limitations imposed by the apparatus used in phase one, as well as by the limitations imposed by participants' physical environments in phase four. However, given the diverse range of contexts within which mobile devices are used, whether on-the-go or in other adverse environments (Oulasvirta, Tamminen, Roto, & Kuorelahti, 2005), we consider that our results were not limited by the fact that participants had to adapt their posture according to the limitations imposed by the apparatus and physical environment, as in many cases this is what might happen in real-world usage scenarios.

11.3 RESEARCH STRATEGIES AND RESULTS

PHASE ONE

As described in Chapter 6, during our first phase of research we employed the research method described in (Wobbrock, Morris, & Wilson, 2009). Our aim was to (1) assess the discoverability of existing smartphone gestures, and (2) elicit a set user-defined gestures from participants. However, as the results documented in Section 6.2.4 demonstrate, older adults did not generally perform novel gestures. This could have happened because most participants had no prior experience with touchscreen technology (Table 6.2), and therefore did not have the prior knowledge on how such systems work, that would enable them to be creative in performing gestures. Accordingly, this led us to question whether the results would have been different if another method was employed. However, although no new gestures were found, this study and the method used allowed us to assess that participants did not generally perform existing smartphone gestures, with the exception of *tap* and *swipe*.

PHASE TWO

As discussed in Chapter 7, in the second phase of our research, we made use of animated tutorials to teach gestures to older adult participants. Our results (Section 7.4) revealed that participants' performance of correct gestures did indeed increase with the introduction of tutorials. However, we cannot assess the efficacy of these tutorials in real-world usage scenarios. Where interaction with smartphones might happen on-the-go, or in other adverse environments (Oulasvirta et al., 2005) where the necessary time to view tutorials might not be available. Furthermore, we cannot provide recommendations as to how and when these tutorials should be shown. Should they be displayed to the user on the first utilisation of the device? Should these contextual help mechanisms appear when the system detects that participants' might need help? Further investigation would be needed to answer these questions. Nonetheless, our results seem

1 http://www.noldus.com/human-behavior-research/accessories/mobile-device-camera-mdc to indicate that tutorials can enhance older adults' performance of gestures, but further investigation in needed into the actual implementation of the tutorials into real-world utilisation scenarios.

Finally, we compared the performance of correct gestures between the first phase of research and the second phase. However, participants were not the same in both studies, and therefore it would be interesting to conduct this study by the use of a within-subjects design.

PHASE THREE

As presented in Chapter 8, phase four of our research aimed to evaluate the influence of (1) target sizes, and (2) spacing sizes between adjacent-targets, on participants' performance of *tap* and *swipe* gestures.

Considering our experience from the first phase of research, and the fact that participants began to feel anxious or preoccupied if sessions took longer than 30 to 45 minutes, we were only able to test five target sizes and five spacing sizes between targets. However, our results show that performance started decreasing slightly for the larger 21 mm targets. It would be interesting to, in the future, evaluate if this tendency is true, as in many cases, smartphone interfaces for older adults are designed with extremely large targets[2], that could indeed be limiting performance instead of enhancing it.

The method used in this phase, which made use of two games, seemed to motivate older adults to participate in our study, where in many cases, they would approach the test facilitator and ask to play the games next. In this context, regarding participants subjective preferences, it could be argued that the overall preference for the *swipe* gesture was influenced by the game designed for this task. As participants generally found it more fun to drag a helicopter from one side of the screen to the other, instead of *tapping* over an insect. However, although games were found to motivate participants, we cannot assess to which extent they might have influenced the results, where participants might have tried to finish quickly, or be overly accurate in order to win. Still, in order to overcome these issues, we did not include points, or a time counter in the games, with the objective of avoiding participants feeling pressurised to win. Finally, both games were simple and easy to play, as we intended to avoid the effect of cognitive-related issues in our results —if the games were overly cognitively demanding, then task completion times might have been affected by the time participants need to understand the objective of the game before playing.

PHASE FOUR

As discussed in Chapter 9, most participants in this phase of research used their right hand to carry-out all tasks. Therefore, the activity zones we defined based our results, cannot be generalised to left-handed older adults, as activity zones will potentially be greatly influenced by the hand participants that use to interact. Accordingly, in the future it will be necessary to validate these results with left-handed participants.

2 BIG Launcher: https://play.google.com/store/apps/details?id=name.kunes.android.launcher.activity&hl=en

AlzNav: https://play.google.com/store/apps/details?id=pt.fraunhofer.navigator&feature=search_result#?t=W251bGwsMSwxLDEsInB0LmZyYXVuaG9mZXIubmF2aWdhdG9yIl0

WP for Senior Citizens: http://www.windowsphone.com/en-in/apps/b51b275f-3417-4b10-87fe-5db8717bf76f

EyeRead: http://itunes.apple.com/us/app/eyeread/id345271596?mt=8

Regarding the method employed in this phase, and in a similar way to the previous phase, we found the use of games to be a motivating factor among older adult participants, and plan to further explore this finding in future tests with users.

12 CONCLUSIONS AND FUTURE WORK

The overall aim of this research was to advance the understanding of older adults and gesture-based interaction on smartphones, in order to enhance the usability of smartphones. More specifically, we aimed to (1) investigate issues regarding current smartphone gesture discoverability, (2) the possibility of identifying a novel set of user-defined gestures, and (3) to assess the influence of certain interface characteristics — target sizes, spacing sizes between targets, and targets' onscreen locations — on the performance of such gestures. Accordingly, phase one of our research (Section 6) assessed the discoverability of current smartphone gestures, while exploring the possibility of creating a novel user-defined gesture set. Next, phase two aimed to teach current smartphone gestures to older adults by the use of contextual tutorials. Then, phases three and four investigated the influence of touch-target sizes, spacing sizes between targets, targets' onscreen locations, and gesture orientation, on older adults performance of *tap* and *swipe* gestures.

Accordingly, the following sections review our research questions and objectives, summarise our main findings according to each question, and offer conclusions based on our findings. Additionally, we will also discuss the value of this study and outline future work.

12.1 SUMMARY OF FINDINGS AND CONCLUSIONS

In this section, we will present a summary of our main findings and conclusions according to each of the research questions presented in Section 1.3.

RQ1: ARE CURRENT SMARTPHONE GESTURES EASILY DISCOVERABLE FOR OLDER ADULTS?

The literature identified a set of opposing opinions regarding the intuitiveness, or usability, of current gestural interfaces. On the one hand, there is the belief that this form of interaction provides a natural an intuitive experience, where learning is quicker and easier (Loureiro & Rodrigues, 2011; Sears, Plaisant, & Shneiderman, 1990; Wigdor & Wixon, 2011; Wolf, 1986), while on the other hand, it is believed that these interfaces suffer from a lack of cues, or affordances (D. Norman, 1990), which in turn generate gesture discoverability issues (Bau & Mackay, 2008; Bragdon et al., 2010; D. A. Norman, 2010) (further detail in section 3.3). Accordingly, the first phase of our research (see Section 6) revealed that gesture discoverability on smartphones could indeed be an issue for older adults, where most participants did not perform the correct gesture for a set of common smartphone tasks (see Section 6.2.4). Still, we found that *tap* and *swipe* were the most widely understood and performed gestures, while others such as *pinch, spread, double tap,* and *touch and hold* were understood by very few, or by no participants at all (Section 6.2.4). In this context, it was concluded that tap and swipe might be adequate for older adults, but that further research was needed.

RQ2: DO OLDER ADULTS WITHOUT PRIOR TOUCHSCREEN EXPERIENCE PERFORM THE SAME GESTURES AS THOSE CURRENTLY IMPLEMENTED BY SYSTEM DESIGNERS? IF NOT, WHICH GESTURES DO THEY PERFORM?

During the literature review, we found that most gestures available for commercial systems, such as smartphones, were created by systems' designers(Wobbrock, Morris, & Wilson, 2009). In turn, this could mean that the design of these gestures might have been more concerned with system recognition issues, rather than their end-user usability (Wobbrock et al., 2009). In this context, we identified several research efforts that aim to investigate the potential of user-defined gestures to enhance usability (Beringer, 2002; Liu, Pinelle, Sallam, Subramanian, & Gutwin, 2006; Mauney, Howarth, Wirtanen, & Capra, 2010; Ruiz, Li, & Lank, 2011; Voida, Podlaseck, Kjeldsen, & Pinhanez, 2005; Wobbrock et al., 2009) (see Section 3.2 for more detail regarding these studies). Accordingly, during our first phase of research one of our goals was to elicit novel gestures from participants for a set of common smartphone tasks (Section 6). However, our findings revealed that older adults did not generally perform novel gestures. Besides, when they did, these gestures were carried-out by a very low number of participants, and could therefore not be generalised into a set of novel user-defined gestures. Overall, it seems that participants had difficulty in understanding gesture-based interaction. Nonetheless, the most performed gestures were *tap* and *swipe*, being generally applied to solve all tasks (the results from this study can be found in Section 6.2.4 of this document).

RQ3: WHAT ARE THE MAIN CHARACTERISTICS OF PERFORMED GESTURES, SUCH AS NUMBER OF FINGERS AND HANDS USED?

During phase one of our research (Section 6), where we investigated the discoverability of current smartphone gestures, and invited participants to perform novel user-defined gestures, we also analysed which fingers they used for interaction and how they held the smartphone itself. We found that most users preferred to place the smartphone on a table while carrying-out the tasks, instead of holding it with one hand and interacting with the other. However, it is important to keep in mind that our results could be influenced by the apparatus used in the tests, were a small mobile device camera was fixed onto the smartphone (see apparatus used in this study in Section 6.2.2). In addition, the majority of users used only their index finger for interaction, while only a reduced number used their thumbs, or more than one finger (Section 6.2.4). The subject of number of fingers and hands used for interaction was again revisited in Section 9, while we were evaluating the effect of targets' onscreen location on participants' performance. As in these tests no mobile camera was fixed to the smartphone, and in many cases no table was available for participants to place the device, our results were slightly different. Unlike in phase one, most participants then held the device in their left hand and used their right hand to operate it. On the other hand, similarly to the first phase most participants continued to only use their index finger for interaction (see Section 9.4.3 for detailed results).

RQ4: IF CURRENT SMARTPHONE GESTURES PROVE TO BE PROBLEMATIC, AND IF OLDER ADULTS DO NOT PROPOSE A NOVEL SET OF USER-DEFINED GESTURES, CAN WE EFFECTIVELY TEACH THEM HOW TO USE THE CURRENT ONES?

Given the results from our previous tests with users, where we found that (1) participants were nor able to discover or make use of most available smartphone gestures, (2) nor did they propose new ones, we decided to find out if we could effectively teach current gestures to older adults.

In the literature review, we found that several authors have considered older adults to be capable of learning how to use new technologies (Broady, Chan, & Caputi, 2010; Czaja & Sharit, 1998). The authors go further to refer that in cases when the correct teaching and learning strategies are employed (Broady et al., 2010; Dickinson, Eisma, Gregor, Syme, & Milne, 2005), that older adults are not only able to learn, but are also interested in adopting such technologies (Section 2.4). Furthermore, several authors have identified the need for tutorials that demonstrate available gestures to users (Bau & Mackay, 2008; Bragdon et al., 2010; Kurtenbach, Moran, & Buxton, 1994). Accordingly, the results of our own investigation revealed that with the aid of gesture tutorials, older adults were indeed able to perform more correct gestures than in phase one of our study (detailed results can be found in Section 7.4). In addition, most participants only required viewing the tutorial once before performing a correct gesture. This leads us to believe that help mechanisms are indeed important for novel older adult users, but that as users gain experience these mechanisms might become unnecessary. In sum, it seems that although current gestures are not immediately discoverable by older adults, it is possible to make use of help mechanisms to aid interaction.

RQ5: ARE RECOMMENDED TOUCH-TARGET SIZES, FOUND IN OFFICIAL GUIDELINES, ADEQUATE FOR OLDER ADULTS PERFORMING *TAP* AND *SWIPE* GESTURES?

In the literature review we found that several authors have investigated the effect of *tap* target sizes on young adults performance with mobile touchscreen devices (Henze, Rukzio, & Boll, 2011; Parhi, Karlson, & Bederson, 2006; Perry & Hourcade, 2008) (see Section 8 for further detail). However, to our knowledge research regarding touch-target sizes and older adults' performance, is either dedicated to larger fixed touch-surfaces (Jin, Plocher, & Kiff, 2007), or has investigated very few target sizes, and no spacing sizes between adjacent-targets on mobile touchscreens (Kobayashi et al., 2011). Furthermore, official smartphone OS guidelines[1] recommend *tap* targets between 7 mm and 9 mm, which are smaller than the findings and consequent target size recommendations of the previously mentioned tests conducted with younger adults. Accordingly, our results revealed that for both *tap* and *swipe,* older adults perform better with targets that are larger than 14 mm for *tap,* and 17.5 mm for *swipe* (for a more detailed discussion of our results according to target sizes and spacings, see Section 8). In this context, it seems that current official guidelines' regarding target sizes might not be adequate when designing for older adults.

---

1 Android: http://developer.android.com/design/style/metrics-grids.html

iPhone: https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

Windows Phone: http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx

RQ6: ARE CURRENT RECOMMENDATIONS REGARDING SPACING SIZES BETWEEN TOUCH-TARGETS ADEQUATE FOR OLDER ADULTS PERFORMING *TAP* AND *SWIPE* GESTURES?

A review of the literature showed that the effect of spacing sizes between targets has been investigated for younger adults (Colle & Hiszem, 2004; Sun, Plocher, & Qu, 2007) and for older adults (Jin et al., 2007). However, to our knowledge the influence of spacing between targets on older adults performance with mobile touchscreens has not yet been explored. Furthermore, official guideline s[2] recommend an average of 1.5 to 2 mm spacing between targets, but it has not been assessed if these spacing sizes are adequate for older adults. Our own work revealed that spacing between targets did not have a significant effect on older adults performance. Nonetheless, participants were most accurate with 3.5 mm spacing between *tap* targets (Section 8.4), and with 0 to 7 mm spacing for *swipe* targets (Section 8.4). Revealing that the intention of a movement — whether to finalise in a *tap* or a *swipe* — does indeed seem to influence the amount of space needed between targets.

RQ7: ARE ACTIVITY ZONES ON SMARTPHONES THE SAME FOR YOUNGER AND OLDER ADULTS?

Activity zones on mobile devices have been extensively researched for young adult users (Henze et al., 2011; Parhi et al., 2006; Perry & Hourcade, 2008). However, to our knowledge no investigation has been conducted in this area with older adults. Our results reveal that targets onscreen location did have a significant effect on participants' performance of *tap* gestures. Where performance was best at the centre, right and bottom edges of the device's display (Section 9.4.1.1). However, for the *swipe* condition no significant effect of target location was found on participants performance. Nonetheless, performance was best toward the bottom half of the screen for the horizontal *swipes,* and toward the right half of the screen for the vertical *swipes* (Section 9.4.2.1). Still, a significant effect on the offsets between targets' centre points and participants' actual touches were found for both conditions. Revealing that for targets placed in more problematic locations, that it might be advisable to shift those targets according to the mean offsets found for those locations (see Sections 9.4.1.2 and 9.4.2.2 for results regarding target locations and touch offsets).

RQ8: IN THE PARTICULAR CASE OF *SWIPE*, DOES GESTURE ORIENTATION INFLUENCE SUCH ACTIVITY ZONES?

As discussed in the answer to the previous research question, targets' onscreen locations did not have a significant influence on participants' performance. Similarly, the orientation of swipe gestures did not significantly influence performance. Nonetheless, the orientations with the highest accuracy rates were left-to-right and top-to-bottom. Additionally, gesture orientation did have a significant impact on touch offsets. Meaning that for targets placed in more problematic locations, that their offsets should be adjusted according to the offsets found for the targets' position and gesture orientation (Section 9.4.2.1).

2 Android: http://developer.android.com/design/style/metrics-grids.html

iPhone: https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html

Windows Phone: http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx

RQ9: WHICH IS THE BEST FORM OF DOCUMENTING THE RESULTS FROM THIS RESEARCH, IN ORDER TO SHARE IT WITH PRACTITIONERS INVOLVED IN CREATING SMARTPHONE INTERFACES FOR OLDER ADULTS?

A review of literature allowed for a comparison between several forms of HCI knowledge documentation. When comparing design patterns, claims, heuristics and guidelines, we found that design patterns were those that best fitted the knowledge outcome of our work (Section 4.3). On the one hand, because they have been found to be a powerful tool for documenting and disseminating HCI knowledge (Dearden & Finlay, 2006), and on the other due to the fact that they have been successfully applied in pedagogical environments, and to teaching novice practitioners (Borchers, 2002; Koukouletsos, Khazaei, Dearden, & Ozcan, 2009). In addition, patterns have proven to constitute a powerful common language that allows multidisciplinary teams to better communicate (Erickson, 2000).

12.2 CONTRIBUTIONS

The research performed in the context of this thesis results in a number of contributions. These include the findings of the four phases of testing with older adults users. The first phase of research allowed for a better understanding regarding the suitability of current smartphone gestures for older adults, while offering insight into the gestures that are better understood, and performed by older adults. Previous research had only assessed whether older adults could indeed physically perform existing gestures (Stößel, Wandke, & Blessing, 2009, 2010), but not if these gestures were understood, or discoverable for older adults. Additionally, the second phase of research contributes to existing knowledge regarding gestural interaction and older adults, by demonstrating that the use of animated tutorials to explain gestures did enhance older adults performance of correct gestures; this agrees with other research regarding gestural systems, and gesture discoverability issues for less specific audiences (Bau & Mackay, 2008; Bragdon et al., 2010; D. A. Norman, 2010). Research phase three builds upon existing knowledge regarding target sizes and spacing between target sizes, by assessing these issues with older adults users. This phase allows for the creation of design advice for smartphone interface design, regarding target sizes, and spacing sizes between targets that are adequate for older adults users. Finally, phase four allowed for the definition of activity zones on smartphones for older adults, thus allowing for more informed decisions regarding the distribution of *tap* and *swipe* targets throughout an interface. In sum, the four phases of testing with users allowed for (1) a better understanding of existing gesture discoverability for older adults, (2) assessing the most adequate gestures for older adults, (3) determining best target sizes, and spacing sizes between targets for *tap* and *swipe* gestures, and finally (4) the definition of smartphone activity zones for older adults performing *tap* and *swipe* gestures. These results enable the design of more usable smartphone interfaces for older adults.

In this context, another important contribution of this work are the interaction design patterns that were built upon the results of our empirical work, as well as on our literature review. These design patterns have the aim of providing readily available guidance for all practitioners involved in designing interfaces for older adults. A large amount of research has been conducted regarding older adults and interface design, and findings have been documented in scientific publications, however sorting through this information will potentially be extensively time consuming. As a result the compact but explanatory characteristics of design patterns could provide better and readily available guidance for both experienced and novice designers working with older adults (Zajicek, 2004).

Furthermore, one of the main characteristics of design patterns is to constitute a common language with which all stakeholders in a project can efficiently communicate (Erickson, 2000). In the development of interfaces and other systems, it is common to constitute multidisciplinary teams, where involved parties can, for example, range from HCI practitioners, designers, software engineers, administrative staff, to actual end-users. Thus, the design patterns developed in this work intend found the basis of a common language that could more easily allow the active participation of older adult users in the development process of a smartphone interface. As well as, facilitate communication between all members of a team involved in creating these interfaces.

Additionally, our literature review brings together a set of topics related to gestural interaction, design patterns, and their relation toward older adults and interface development for this specific target-group. These topics include (1) age-related psychomotor, cognitive and sensory modifications and their impact on user interface design (Section 2.3), (2) older adults relationship with, and attitudes toward ICT devices (Section 2.4), (3) an historical context of touchscreen evolution and the gestures developed over time for these systems (Section 3.1); (4) an overview of relevant investigation into the definition of user-defined gestures for touch-surfaces (Section 3.2); (5) a discussion of the potential advantages and disadvantages of touch-based interaction for older adults (Section 3.3); (6) an historical review of design patterns (Section 4.1), and (7) a comparison of design patterns and other forms of HCI knowledge documentation (Section 4.2), and finally (8) a discussion of the potential advantages of using design patterns when developing interfaces for older adults (Section 4.3).

12.3 FUTURE WORK

Our research revealed that current smartphone gestures are not immediately usable by older adults. In many cases they do not know which gestures to perform, and require mechanisms that demonstrate available gestures, and explain which tasks each of them solve (see Section 6 for further detail regarding gesture discoverability and Section 7 on the use of animated tutorials to teach gestures). In addition, it was found that older adults without prior touchscreen experience generally did not perform novel gestures that are different to those that are currently implemented on smartphones (see section 6.2.4). Still, a few novel gestures were performed but none by a large enough number of participants to reach an acceptable level of agreement. However, this could be due to the low number of participants in our tests, where with a larger group of older adults novel gestures might indeed reach a higher level of agreement. In this context, it would be interesting to further this research with a larger number of older adults. As in that case, it might be possible to find patterns in new proposed gestures, and indeed create a novel user-defined gesture set.

In addition, during the second phase of our research we decided to only teach *tap* and *swipe* gestures to older adults. These two gestures revealed to be the easiest for older adults to understand during the first phase of research (Section 6.5), while also being the most essential to operate a smartphone (a more detailed discussion on why only these two gestures were considered can be found in Section 7). Our results showed that older adults were in fact able to quickly learn how to employ *tap* and *swipe* gestures to solve the tests' tasks. However, it would be interesting to assess the learnability of other gestures that seemed to be more complex during the first phase of research (see section 6.5), such as *tap and hold, double-tap, pinch and spread.*

Similarly, as touch-target sizes, spacing sizes between adjacent-targets, and smartphone activity zones, were assessed solely for *tap* and *swipe*, it would be interesting to evaluate the influence of these factors on the performance of all other remaining gestures (Table 6.1). As well as, to validate our results regarding activity zones with left-handed older adults. Furthermore, in the results of our tests for assessing target sizes and spacings, we found that participants performance started decreasing for the largest target size (see Section 8.4). In the future, it could be relevant to verify if performance continues to decrease as targets get larger.

Finally, the pattern set presented in Section 10 intends to be the beginning of a full-fledged pattern language. This language would consider a wide-range of aspects related to smartphone interface design for older adults. These considerations could include subjects such as information architecture, the display of information, navigation mechanisms, general layout considerations, the design of controls and flow of actions, as well as user input and output mechanisms. All these could be the focus of future research.

REFERENCES

Abraham, G., & Atwood, M. E. (2009). *Patterns or claims: do they help in communicating design advice?* Paper presented at the Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7, Melbourne, Australia.

Access Intelligence. (1993). Bellsouth, IBM unveil personal communicator phone. Retrieved from http://research.microsoft.com/en-us/um/people/bibuxton/buxtoncollection/a/pdf/press release 1993.pdf

Akamatsu, M., MacKenzie, I. S., & Hasbroucq, T. (1995). A comparison of tactile, auditory, and visual feedback in a pointing task using a mouse-type device. *Ergonomics, 38*, 816-827.

Alexander, C. (1979). *The Timeless Way of Building*: Oxford University Press.

Alexander, C. (1999). The origins of pattern theory: the future of the theory, and the generation of a living world. *Software, IEEE, 16*(5), 71-82. doi: 10.1109/52.795104

Alexander, C., Ishikawa, S., & Silverstein, M. (1977a). *A Pattern Language: Towns, Buildings, Construction*: Oxford University Press.

Alexander, C., Ishikawa, S., & Silverstein, M. (1977b). A Pattern Language: Towns, Buildings, Construction (Cess Center for Environmental). 1171.

American Diabetes Association. (2012). Eye Complications Retrieved 01 January, 2012, from http://www.diabetes.org/living-with-diabetes/complications/eye-complications/

American Psychological Association. (2012). Older Adults' Health and Age-Related Changes Retrieved 03 February, 2012, from http://www.apa.org/pi/aging/resources/guides/older.aspx

American Speech-Language-Hearing Association. (2012). Types of Hearing Loss Retrieved 08 November, 2011, from http://www.asha.org/public/hearing/disorders/types.htm

Android. (13 June 2012). User Interface Guidelines Retrieved 20 June 2012, 2012, from http://developer.android.com/guide/practices/ui_guidelines/index.html

Android. (2012). Android Design Retrieved 20 June 2012, 2012, from http://developer.android.com/design/index.html

Annett, M., Anderson, F., Goertzen, D., Halton, J., Ranson, Q., Bischof, W. F., & Boulanger, P. (2009). *Using a multi-touch tabletop for upper extremity motor rehabilitation*. Paper presented at the Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7, Melbourne, Australia.

Apple. (2007). Apple Unveils iPod touch Retrieved 5 April 2012, 2012, from http://www.apple.com/pr/library/2007/09/05Apple-Unveils-iPod-touch.html

Apple. (2010a, 7 March 2012). iOS Human Interface Guidelines Retrieved 8 April 2012, 2012, from http://developer.apple.com/library/ios/ - documentation/userexperience/conceptual/mobilehig/Introduction/Introduction.html

Apple. (2010b). iPad Arrives This Saturday Retrieved 3 April 2012, 2012, from http://www.apple.com/pr/library/2010/03/29iPad-Arrives-This-Saturday.html

Apple. (2012, 7 March 2012). Apps Respond to Gestures, Not Clicks. *iOS Human Interface Guidelines* Retrieved 5 April 2012, 2012, from http://developer.apple.com/library/ios/ - documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html#//apple_ref/doc/uid/TP40006556-CH7-SW4

Apple Computer, I. (1992). *Macintosh Human Interface Guidelines*: Addison-Wesley Publishing Company.

Apted, T., Kay, J., & Quigley, A. (2006). *Tabletop sharing of digital photographs for the elderly*. Paper presented at the Proceedings of the SIGCHI conference on Human Factors in computing systems, Montreal, Quebec, Canada.

Barfield, L., Burgsteden, W. V., Lanfermeijer, R., Mulder, B., Ossewold, J., Rijken, D., & Wegner, P. (1994). Interaction design at the Utrecht School of the Arts. *ACM SIGCHI Bulletin, 26*, 49-86. doi: 10.1145/181518.181525

Bau, O., & Mackay, W. E. (2008). *OctoPocus: a dynamic guide for learning gesture-based command sets*. Paper presented at the Proceedings of the 21st annual ACM symposium on User interface software and technology, Monterey, CA, USA.

Bayle, E., Bellamy, R., Casaday, G., Erickson, T., Fincher, S., Grinter, B., . . . Thomas, J. (1998). Putting it all together: towards a pattern language for interaction design: A CHI 97 workshop. *SIGCHI Bulletin, 30*, 17-23. doi: 10.1145/280571.280580

Beck, K., & Cunningham, W. (1987). Using Pattern Languages for Object-Oriented Programs. Submitted to the OOPSLA-87 workshop on the Specification and Design for Object-Oriented Programming.

Beringer, N. (2002). *Evoking Gestures in SmartKom - Design of the Graphical User Interface*. Paper presented at the Revised Papers from the International Gesture Workshop on Gesture and Sign Languages in Human-Computer Interaction.

Bernard, M., Liao, C. H., & Mills, M. (2001). The effects of font type and size on the legibility and reading time of online text by older adults. *CHI '01 extended abstracts on Human factors in computing systems - CHI '01*. New York, New York, USA: ACM Press.

Bierman, A., & Statland, D. (2010). Timing, Social Support, and the Effects of Physical Limitations on Psychological Distress in Late Life. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 65B*(5), 631-639. doi: 10.1093/geronb/gbp128

Borchers, J. (2000). *Interaction design patterns: twelve theses*. Paper presented at the BHCI Workshop on Patterns in Human Computer Interaction.

Borchers, J. (2001). *A Pattern Approach to Interaction Design*: John Wiley & Sons.

Borchers, J. (2002). Teaching HCI design patterns: Experience from two university courses. *Patterns in Practice A Workshop for UI Designers at CHI 2002 International Conference on Human Factors of Computing Systems*: Citeseer.

Bragdon, A., Uguray, A., Wigdor, D., Anagnostopoulos, S., Zeleznik, R., & Feman, R. (2010). *Gesture play: motivating online gesture learning with fun, positive reinforcement and physical metaphors*. Paper presented at the ACM International Conference on Interactive Tabletops and Surfaces, Saarbrucken, Germany.

Brewster, S. A. (2002). Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing, 6*, 188-205.

Broady, T., Chan, A., & Caputi, P. (2010). Comparison of older and younger adults' attitudes towards and abilities with computers: Implications for training and learning. *British Journal of Educational Technology, 41*, 473-485. doi: 10.1111/j.1467-8535.2008.00914.x

Buiza, C., Soldatos, J., Petsatodis, T., Geven, A., Etxaniz, A., & Tscheligi, M. (2009). HERMES: Pervasive computing and cognitive training for ageing well. *Distributed Computing, Artificial Intelligence, Bioinformatics, Soft Computing, and Ambient Assisted Living*, 756-763.

Buxton, B. (2007). Multi-Touch Systems that I Have Known and Loved Retrieved 19 June 2012, from http://www.billbuxton.com/multitouchOverview.html

Buxton, W., Billinghurst, M., Guiard, Y., Sellen, A., & Zhai, S. (1994-2011). Gesture Based InteractionHuman Input to Computer Systems: Theories, Techniques and Technology. Unfinished book manuscript., http://www.billbuxton.com/input14.Gesture.pdf. Retrieved from http://www.billbuxton.com/input14.Gesture.pdf.

Buxton, W., Fitzmaurice, G., Balakrishnan, R., & Kurtenbach, G. (2000). Large displays in automotive design. *Computer Graphics and Applications, IEEE, 20*(4), 68-75. doi: 10.1109/38.851753

Calvo-Palomino, R., de las Heras-Quirós, P., Santos-Cadenas, J., Román-López, R., & Izquierdo-Cortázar, D. (2009). Outdoors Monitoring of Elderly People Assisted by Compass, GPS and Mobile Social Network. *Distributed Computing, Artificial Intelligence, Bioinformatics, Soft Computing, and Ambient Assisted Living*, 808-811.

Carmeli, E., Patish, H., & Coleman, R. (2003). The Aging Hand. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58*, M146-M152. doi: 10.1093/gerona/58.2.M146

Carstensen, L. L., & Hartel, C. R. (2006). *When I'm 64*: National Academies Press.

Carstensen, L. L., Isaacowitz, D. M., & Charles, S. T. (1999). Taking time seriously: A theory of socioemotional selectivity. *American Psychologist, 54*(3), 165-181. doi: 10.1037/0003-066x.54.3.165

Carvalhais, M. (2008). Learning and studying interaction design through design patterns. *Proceedings of the 15th Conference on Pattern Languages of Programs - PLoP '08*. New York, New York, USA: ACM Press.

Cavanaugh, J. C., & Blanchard-Fields, F. (2006). *Adult Development And Aging*: Wadsworth/Thomson Learning.

Center for Tecnology and Aging. (2011). *mHealth Technologies : Applications to Benefit Older Adults*. Retrieved from http://www.techandaging.org/mHealth_Position_Paper_Discussion_Draft.pdf

Chang, R., Wang, F., & You, P. (2010). A Survey on the Development of Multi-touch Technology. *2010 Asia-Pacific Conference on Wearable Computing Systems*: IEEE.

Chaput, S., & Proteau, L. (1996). Aging and motor control. *The journals of gerontology Series B Psychological sciences and social sciences, 51*, P346-P355.

Chasteen, A. L., Bhattacharyya, S., Horhota, M., Tam, R., & Hasher, L. (2005). How Feelings of Stereotype Threat Influence Older Adults' Memory Performance. *Experimental Aging Research, 31*(3), 235-260. doi: 10.1080/03610730590948177

Chung, E. S., Hong, J. I., Lin, J., Prabaker, M. K., Landay, J. A., & Liu, A. L. (2004). Development and evaluation of emerging design patterns for ubiquitous computing. *Proceedings of the 2004 conference on Designing interactive systems processes practices methods and techniques DIS 04*, 233. doi: 10.1145/1013115.1013148

Colle, H. A., & Hiszem, K. J. (2004). Standing at a kiosk: Effects of key size and spacing on touch screen numeric keypad performance and user preference. *Ergonomics, 47*(13), 1406-1423. doi: 10.1080/00140130410001724228

Computer Chronicles (Producer). (1983). The H.P. Touch Computer (1983). Retrieved from http://www.youtube.com/watch?v=X-THdG5gVTw

comScore. (2012a). 2012 Mobile Future in Focus. Retrieved from http://www.comscore.com/Press_Events/Presentations_Whitepapers/2012/2012_Mobile_Future_in_Focus

comScore. (2012b). Smartphone Adoption Approaches Tipping Point Across Markets, from http://www.comscoredatamine.com/2012/02/smartphone-adoption-approaches-tipping-point-across-markets/

Cowley, N. L. O., & Wesson, J. L. (2005). *An experiment to measure the usefulness of patterns in the interaction design process*. Paper presented at the Proceedings of the 2005 IFIP TC13 international conference on Human-Computer Interaction, Rome, Italy.

Czaja, S. J., & Sharit, J. (1998). Age Differences in Attitudes Toward Computers. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 53B*, P329-P340. doi: 10.1093/geronb/53B.5.P329

Dalton, D. S., Cruickshanks, K. J., Klein, B. E. K., Klein, R., Wiley, T. L., & Nondahl, D. M. (2003). The Impact of Hearing Loss on Quality of Life in Older Adults. *The Gerontologist, 43*, 661-668. doi: 10.1093/geront/43.5.661

Dandekar, K., Raju, B. I., & Srinivasan, M. A. (2003). 3-D Finite-Element Models of Human and Monkey Fingertips to Investigate the Mechanics of Tactile Sense. *Journal of Biomechanical Engineering, 125*, 682. doi: 10.1115/1.1613673

Darroch, I., Goodman, J., Brewster, S. A., & Gray, P. D. G. (2005). The effect of age and font size on reading text on handheld computers. *HumanComputer Interaction INTERACT, 3585*, 253-266.

Dearden, A. M., & Finlay, J. (2006). Pattern languages in HCI: a critical review. *Human-Computer Interaction, 21*, 49-102.

Dickinson, A., Eisma, R., Gregor, P., Syme, A., & Milne, S. (2005). Strategies for teaching older people to use the World Wide Web. *Univers. Access Inf. Soc., 4*(1), 3-15. doi: 10.1007/s10209-003-0082-6

Dietz, P., & Leigh, D. (2001). *DiamondTouch: a multi-user touch technology*. Paper presented at the Proceedings of the 14th annual ACM symposium on User interface software and technology, Orlando, Florida.

Dix, A. (2004). *Human-Computer Interaction*: Pearson/Prentice-Hall.

Ellis, R. D., & Kurniawan, S. H. (2000). Increasing the Usability of Online Information for Older Users: A Case Study in Participatory Design. *International Journal of Human-Computer Interaction, 12*, 263-276. doi: 10.1207/S15327590IJHC1202_6

Emery, V. K., Edwards, P. J., Jacko, J. A., Moloney, K. P., Barnard, L., Kongnakorn, T., . . . Scott, I. U. (2003). Toward achieving universal usability for older adults through multimodal feedback. *Proceedings of the 2003 conference on Universal usability CUU 03, 73-74*, 46-53. doi: 10.1145/957205.957214

Erickson, T. (2000). *Lingua Francas for design: sacred places and pattern languages*. Paper presented at the Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York City, New York, United States.

European Commission, & Directorate-General for Employment, S. A. (2005). *Confronting demographic change: a new solidarity between the generations. Green paper*. (9789289493833). Office for Official Publications of the European Communities Retrieved from http://books.google.pt/books?id=DKVXAAAAYAAJ.

European Commission, & Economic Policy Committee. (2011). The 2012 Ageing Report: Underlying Assumptions and Projection Methodologies (pp. 294).

Eurostat. (2011a). File:Percentage of population aged 65 years and over on 1 January of selected years.PNG. Retrieved 20 May 2012 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Percentage_of_population_aged_65_years_and_over_on_1_January_of_selected_years.PNG&filetimestamp=20110609134420

Eurostat. (2011b). Population structure and ageing. Retrieved 20 May 2012 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_structure_and_ageing

Fincher, S. (1999). Analysis of Design: An Exploration of Patterns and Pattern Languages for Pedagogy. *Journal of Compututers in Maths and Science Teaching, 18*, 331-348.

Fine, S. L., Berger, J. W., Maguire, M. G., & Ho, A. C. (2000). Age-Related Macular Degeneration. *New England Journal of Medicine, 342*(7), 483-492. doi: doi:10.1056/NEJM200002173420707

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). *Designing for Older Adults: Principles and Creative Human Factors Approaches, Second Edition (Human Factors & Aging)*: CRC Press.

Fox, S. (2010). Mobile Health 2010 *Health San Francisco* (pp. 15): Pew Internet & American Life Project.

Gamberini, L., Alcaniz, M., Barresi, G., Fabregat, M., Ibanez, F., & Prontu, L. (2006). Cognition, technology and games for the elderly: An introduction to ELDERGAMES Project. *PsychNology Journal, 4*(3), 285-308.

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1995). *Design Patterns: Elements of Reusable Object-Oriented Software*: Addisson-Wesley.

Gayman, M. D., Turner, R. J., & Cui, M. (2008). Physical limitations and depressive symptoms: exploring the nature of the association. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 63*(4), S219-S228.

Gilbert, D. K., Rogers, W. A., & Samuelson, M. E. (2009). Long-term retention of a spatial mental model for younger and older adults. *Experimental Aging Research, 30*, 217-224.

Goodman, J., Brewster, S., & Gray, P. (2005). How Can We Best Use Landmarks to Support Older People in Navigation. *Journal of Behaviour and Information Technology, 24*, 3-20.

Graham, I. (2003). *A Pattern Language for Web Usability [Paperback]*: Pearson Education; 1st edition.

Gregor, P., Newell, A. F., & Zajicek, M. (2000). Designing for Dynamic Diversity - interfaces for older people. *Human Factors*.

Gregor, P., Newell, A. F., & Zajicek, M. (2002). *Designing for dynamic diversity: interfaces for older people*. Paper presented at the Proceedings of the fifth international ACM conference on Assistive technologies, Edinburgh, Scotland.

Griffiths, R., & Pemberton, L. (2000). Don't Write Guidelines Write Patterns! , from http://www.it.bton.ac.uk/staff/lp22/guidelinesdraft.html

Han, J. Y. (2005). Low-cost multi-touch sensing through frustrated total internal reflection. *Proceedings of the 18th annual ACM symposium on User interface software and technology - UIST '05*. New York, New York, USA: ACM Press.

Hansen, T. R., Eklund, J. M., Sprinkle, J., Bajcsy, R., & Sastry, S. (2005). *Using smart sensors and a camera phone to detect and verify the fall of elderly persons.* Paper presented at the European Medicine, Biology and Engineering Conference.

Hawthorn, D. (2000). Possible implications of aging for interface designers. *Interacting with Computers, 12*, 507-528. doi: 10.1016/S0953-5438(99)00021-1

Hawthorn, D. (2007). Interface design and engagement with older people. *Behaviour & Information Technology, 26*, 333-341. doi: 10.1080/01449290601176930

Hendrick, J. J., Jane Knox, V., Gekoski, W. L., & Dyne, K. J. (1988). Perceived Cognitive Ability of Young and Old Targets. *Canadian Journal on Aging/Revue canadienne du vieillissement, 7*(03), 192-203. doi: doi:10.1017/S0714980800007911

Henze, N., Rukzio, E., & Boll, S. (2011). 100,000,000 taps: analysis and improvement of touch performance in the large. *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services - MobileHCI '11*. New York, New York, USA: ACM Press.

Hollinworth, N. (2009). Improving computer interaction for older adults. *ACM SIGACCESS Accessibility and Computing*, 11-17. doi: 10.1145/1531930.1531932

Hoober, S., & Berkman, E. (2011). *Designing Mobile Interfaces*: O'Reilly Media.

Hutchins, E., Hollan, J., & Norman, D. (1985). Direct Manipulation Interfaces. *Human-Computer Interaction, 1*, 311-338. doi: 10.1207/s15327051hci0104_2

International Telecommunication Union. (2012). ICT Data and Statistics (IDS). Retrieved 15 May 2012 http://www.itu.int/ITU-D/ict/statistics/

Ishii, H., & Miyake, N. (1991). Toward an open shared workspace: computer and video fusion approach of TeamWorkStation. *Communications of the ACM, 34*, 37-50. doi: 10.1145/125319.125321

Jacko, J. A., Scott, I. U., Sainfort, F., Moloney, K. P., Kongnakorn, T., Zorich, B. S., & Emery, V. K. (2002). Effects of multimodal feedback on the performance of older adults with normal and impaired vision. *Universal Access Theoretical Perspectives Practice and Experience 7th ERCIM International Workshop on User Interfaces for All Revised Papers 2425 Oct 2002*: Springer-Verlag.

Jackson, G. R., & Owsley, C. (2003). Visual dysfunction, neurodegenerative diseases, and aging. *Neurologic Clinics, 21*, 709-728. doi: 10.1016/S0733-8619(02)00107-X

Jin, Z. X., Plocher, T., & Kiff, L. (2007). Touch screen user interfaces for older adults: button size and spacing. *Universal Acess in Human Computer Interaction Coping with Diversity, 4554*, 933-941.

Johnson, E. A. (1967). Touch Displays: A Programmed Man-Machine Interface. *Ergonomics, 10*, 271-277. doi: 10.1080/00140136708930868

Johnson, E. A. (1969). Touch Displays (patent). http://www.google.com/patents?id=xFZ0AAAAEBAJ&printsec=abstract&zoom=4 - v=onepage&q&f=false

Kang, H. G., Mahoney, D. F., Hoenig, H., Hirth, V. A., Bonato, P., Hajjar, I., & Lipsitz, L. A. (2010). In situ monitoring of health in older adults: technologies and issues. *Journal of the American Geriatrics Society, 58*, 1579-1586. doi: 10.1111/j.1532-5415.2010.02959.x

Karat, J., McDonald, J. E., & Anderson, M. (1986). A comparison of menu selection techniques: touch panel, mouse and keyboard. *International Journal of Man-Machine Studies, 25*(1), 73-88. doi: 10.1016/s0020-7373(86)80034-7

Karlson, A. K., Bederson, B. B., & L., J. (2006). Studies in (One-Handed) Mobile Design: Habit, Desire and Agility. Paper presented at the Proceedings of the 4th (ERCIM) Workshop on User Interfaces for All (UI4ALL).

Ketcham, C. J., Seidler, R. D., Van Gemmert, A. W. A., & Stelmach, G. E. (2002). Age-Related Kinematic Differences as Influenced by Task Difficulty, Target Size, and Movement Amplitude. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57*, P54-P64. doi: 10.1093/geronb/57.1.P54

Khandkar, S. H., & Maurer, F. (2010). A domain specific language to define gestures for multi-touch applications. *Proceedings of the 10th Workshop on Domain-Specific Modeling - DSM '10*. New York, New York, USA: ACM Press.

Knowlton, K. C. (1977). Computer Displays Optically Superimposed on Input Devices. *Bell System Technical Journal, 56*, 367-383.

Kobayashi, M., Hiyama, A., Miura, T., Asakawa, C., Hirose, M., & Ifukube, T. (2011). Elderly user evaluation of mobile touchscreen interactions. *Ifip International Federation For Information Processing*, 83-99.

Koukouletsos, K., Khazaei, B., Dearden, A., & Ozcan, M. (2009). Teaching Usability Principles with Patterns and Guidelines (Vol. 289, pp. 159-174): Springer US.

Krueger, M. W., Gionfriddo, T., & Hinrichsen, K. (1985). VIDEOPLACE: an artificial reality. *ACM SIGCHI Bulletin, 16*, 35-40. doi: 10.1145/1165385.317463

Kurniawan, S. H. (2008). Web Accessibility: A Foundation for Research. In S.-V. London (Ed.), *Human-Computer Interaction Series* (pp. 47-58).

Kurtenbach, G., Moran, T. P., & Buxton, W. (1994). Contextual Animation of Gestural Commands. [10.1111/1467-8659.1350305]. *Computer Graphics Forum, 13*(5), 305-314.

Laakso, S. A. (2003). User Interface Design Patterns Retrieved 15 June 2012, 2012, from http://www.cs.helsinki.fi/u/salaakso/patterns/

Laguna, K., & Babcock, R. L. (1997). Computer anxiety in young and older adults: Implications for human-computer interactions in older populations. *Computers in Human Behavior, 13*, 317-326. doi: 10.1016/S0747-5632(97)00012-5

Laursen, B., Jensen, B. R., & Ratkevicius, A. (2001). Performance and muscle activity during computer mouse tasks in young and elderly adults. *European Journal of Applied Physiology, 84*, 329-336.

Lazar, J., Feng, J. H., & Hochheiser, H. (2010). Research Methods in Human-Computer Interaction: John Wiley & Sons.

Lazzaro, N. (2008). Why we Play: Affect And The Fun of Games. In A. Sears & J. A. Jacko (Eds.), *The Human-computer interaction handbook: Fundamentals, Evolving Technologies and Emerging Applications, Second Edition* (pp. 679–700): Lawrence Erlbaum Associates.

Leung, R., McGrenere, J., & Graf, P. (2011). Age-related differences in the initial usability of mobile device icons. *Behaviour & Information Technology, 30*, 629-642. doi: 10.1080/01449290903171308

Linberg, T., Nasanen, R., & Muller, K. (2006). How age affects the speed of perception of computer icons. *Displays, 27*, 170-177. doi: 10.1016/j.displa.2006.06.002

Lineweaver, T. T., & Hertzog, C. (1998). Adults' Efficacy and Control Beliefs Regarding Memory and Aging: Separating General from Personal Beliefs. *Aging, Neuropsychology, and Cognition, 5*(4), 264-296. doi: 10.1076/anec.5.4.264.771

Liu, C., Zhu, Q., Holroyd, K. A., & Seng, E. K. (2011). Status and trends of mobile-health applications for iOS devices: A developer's perspective. *Journal of Systems and Software, 84*, 2022-2033. doi: 10.1016/j.jss.2011.06.049

Liu, J., Pinelle, D., Sallam, S., Subramanian, S., & Gutwin, C. (2006). *TNT: improved rotation and translation on digital tables*. Paper presented at the Proceedings of Graphics Interface 2006, Quebec, Canada.

Long, J. (2001). Software reuse antipatterns. *SIGSOFT Softw. Eng. Notes, 26*(4), 68-76. doi: 10.1145/505482.505492

Loureiro, B., & Rodrigues, R. (2011). *Multi-touch as a Natural User Interface for elders: A survey.* Paper presented at the Information Systems and Technologies (CISTI), 2011 6th Iberian Conference.

Maged, B., Angelo, M., Manuel, V., Armin, B., Robert, F., Igor, T., . . . Claudio, S. (2007). CAALYX: a new generation of location-based services in healthcare. *International Journal of Health Geographics, v6, p9*.

Mahemoff, M. J., & Johnston, L. J. (1998). Principles for a Usability-Oriented Pattern Language. *OZCHI*: IEEE Press.

Matsushita, N., & Rekimoto, J. (1997). HoloWall: Designing a Finger; Hand, Body, and Object Sensitive Wall. *Proceedings of the 10th annual ACM symposium on User interface software and technology - UIST '97*. New York, New York, USA: ACM Press.

Mauney, D., Howarth, J., Wirtanen, A., & Capra, M. (2010a). *Cultural similarities and differences in user-defined gestures for touchscreen user interfaces*. Paper presented at the Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems, Atlanta, Georgia, USA.

Mauney, D., Howarth, J., Wirtanen, A., & Capra, M. (2010b). Cultural similarities and differences in user-defined gestures for touchscreen user interfaces. *Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems - CHI EA '10*. New York, New York, USA: ACM Press.

Meer, E. V. (2003). PLATO: From computer-based education to corporate social responsibility. *Iterations: An Interdisciplinary Journal of Software*, 1-22.

Microsoft. (2012). User Experience Design Guidelines for Windows Phone. Retrieved from http://msdn.microsoft.com/en-us/library/hh202915(v=vs.92).aspx

Microsoft News Center. (2007). Microsoft Launches New Product Category: Surface Computing Comes to Life in Restaurants, Hotels, Retail Locations and Casino Resorts Retrieved 2 January 2012, 2012, from http://www.microsoft.com/en-us/news/press/2007/may07/05-29mssurfacepr.aspx

Microsoft Research. (2009). Simon. *Buxton Collection* Retrieved 30 March 2012, from http://research.microsoft.com/en-us/um/people/bibuxton/buxtoncollection/detail.aspx?id=40

Microsoft Surface. (2011a). The Power of PixelSense Retrieved 10 May 2012, 2012, from http://www.microsoft.com/surface/en/us/pixelsense.aspx

Microsoft Surface (Producer). (2011b, 20 March 2012). The Power of PixelSense (video). Retrieved from http://www.youtube.com/watch?v=_WB7P4jVktU&feature=plcp

Mitsubishi Electric Research Laboratories (Producer). (2006). Diamond Touch. Retrieved from http://www.merl.com/areas/DiamondTouch/DiamondTouch.mov

Molich, R., & Nielsen, J. (1990). Improving a human-computer dialogue. *Communications of the ACM, 33*, 338-348. doi: 10.1145/77481.77486

Muller, M. J., & Kuhn, S. (1993). Participatory design. *Commun. ACM, 36*(6), 24-28. doi: 10.1145/153571.255960

Murata, A., & Iwase, H. (2005). Usability of touch-panel interfaces for older adults. *Human Factors, 47*(4), 767-776.

Murata, J., Murata, S., Hiroshige, J., Ohtao, H., Horie, J., & Kai, Y. (2010). The Influence of Age-related Changes in Tactile Sensibility and Muscular Strength on Hand Function in Older Adult Females. *International Journal of Gerontology, 4*(4), 180-183. doi: 10.1016/j.ijge.2010.11.004

Museum of Natural History (Producer). (1988). Myron Krueger - Videoplace, Responsive Environment, 1972-1990s (video). Retrieved from http://www.youtube.com/watch?v=dmmxVA5xhuo

Mutschler, P. H. (1992). Where Elders Live. *Generations, 16*(2), 7-14.

Nakatani, L. H., & Rohrlich, J. A. (1983). Soft machines: A philosophy of user-computer interface design. *Proceedings of the SIGCHI conference on Human Factors in Computing Systems - CHI '83*. New York, New York, USA: ACM Press.

NASA. (1990). The Sensor Frame NASA Phase Graphic II Final Manipulator Report (pp. 1-28).

National Institute on Aging and the National Library of Medicine. (2002). Making Your Web Site Senior Friendly. Retrieved from http://www.nia.nih.gov/health/publication/making-your-website-senior-friendly

Neil, T. (2012). *Mobile Design Pattern Gallery* (First edition ed.): O'Reilly Media.

Newman, W., & Wellner, P. (1992). A desk supporting computer-based interaction with paper documents. *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '92*. New York, New York, USA: ACM Press.

Nielsen, J. (2002). Usability for Senior Citizens. Retrieved from http://www.nngroup.com/reports/seniors/

Nielsen, J. (2005). How to Conduct a Heuristic Evaluation Retrieved 25 November 2011, 2011, from http://www.useit.com/papers/heuristic/heuristic_evaluation.html

Nilsson, E. (2009). Design patterns for user interface for mobile applications. *Advances in Engineering Software, 40*, 1318-1328. doi: 10.1016/j.advengsoft.2009.01.017

Norman, D. (1988). *The Psychology Of Everyday Things*: Basic Books.

Norman, D. (1990). *The Design of Everyday Things*: Doubleday Business.

Norman, D. (2010). The way I see it: Natural user interfaces are not natural. *interactions, 17*, 6. doi: 10.1145/1744161.1744163

Norman, D., & Draper, S. (1986). User Centered System Design; New Perspectives on Human-Computer Interaction. *Annals of Physics*, xiii, 526.

Nusbaum, N. (1999). Aging and sensory senescence. *Southern medical journal*.

Oulasvirta, A., Tamminen, S., Roto, V., & Kuorelahti, J. (2005). *Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, Portland, Oregon, USA.

Paggetti, C., & Tamburini, E. (2005). *Remote management of integrated home care services: the dghome platform.* Paper presented at the From Smart Homes to Smart Care: International Conference on Smart Homes and Health Telematics (ICOST 2005).

Pak, R., & McLaughlin, A. (2010). *Designing Displays for Older Adults*: Taylor & Francis US.

Parhi, P., Karlson, A. K., & Bederson, B. B. (2006). Target size study for one-handed thumb use on small touchscreen devices. *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services - MobileHCI '06*. New York, New York, USA: ACM Press.

Park, Y. S., Han, S. H., Park, J., & Cho, Y. (2008). Touch key design for target selection on a mobile phone. *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services - MobileHCI '08*. New York, New York, USA: ACM Press.

Perry, K., & Hourcade, J. P. (2008). Evaluating one handed thumb tapping on mobile touchscreen devices. *Proceedings of graphics interface 2008*, 57-64.

Plaza, I., Martín, L., Martin, S., & Medrano, C. (2011). Mobile applications in an aging society: Status and trends. *Journal of Systems and Software, 84*, 1977-1988. doi: 10.1016/j.jss.2011.05.035

Ranganathan, V. K., Siemionow, V., Sahgal, V., & Yue, G. H. (2001). Effects of Aging on Hand Function. *Journal of the American Geriatrics Society, 49*(11), 1478-1484. doi: 10.1046/j.1532-5415.2001.4911240.x

Rekimoto, J. (2002). *SmartSkin: an infrastructure for freehand manipulation on interactive surfaces*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves, Minneapolis, Minnesota, USA.

Rico, J., & Brewster, S. (2010). *Usable gestures for mobile interfaces: evaluating social acceptability*. Paper presented at the Proceedings of the 28th international conference on Human factors in computing systems, Atlanta, Georgia, USA.

Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Pak, R. (2005). Touch a Screen or Turn a Knob: Choosing the Best Device for the Job. *Human Factors*, 271-288.

Ruiz, J., Li, Y., & Lank, E. (2011). *User-defined motion gestures for mobile interaction*. Paper presented at the Proceedings of the 2011 annual conference on Human factors in computing systems, Vancouver, BC, Canada.

Ryan, E. B., & See, S. K. (1993). Age-Based Beliefs About Memory Changes for Self and Others Across Adulthood. *Journal of Gerontology, 48*(4), P199-P201. doi: 10.1093/geronj/48.4.P199

Saffer, D. (2008). *Designing Gestural Interfaces: Touchscreens and Interactive Devices (Google eBook)* (Vol. 2008): O'Reilly Media, Inc.

Saffer, D. (2011). Activity Zones for Touchscreen Tablets and Phones Retrieved 05 January 2012, from http://www.kickerstudio.com/blog/2011/01/activity-zones-for-touchscreen-tablets-and-phones/

Salman, Y. B., Kim, Y.-H., & Cheng, H.-I. (2010). Senior-Friendly Icon Design for the Mobile Phone. *Camera*: IEEE.

Saxon, S. V., Etten, M. J., & Perkins, E. A. (2009). *Physical change & aging: a guide for the helping professions* (5th ed.): Springer Publishing Company.

Scanaill, C. N., Ahearne, B., & Lyons, G. M. (2006). Long-term telemonitoring of mobility trends of elderly people using SMS messaging. *Information Technology in Biomedicine, IEEE Transactions on, 10*(2), 412-413.

Sears, A., Plaisant, C., & Shneiderman, B. (1990). A new era for touchscreen applications: high precision, dragging icons, and refined feedback. *Advances in Human-Computer Interaction, 3*.

Sears, A., & Zha, Y. (2003). Data entry for mobile devices using soft keyboards: Understanding the effects of keyboard size and user tasks. *International Journal of Human-Computer, 16*, 163-184. doi: 10.1207/S15327590IJHC1602_03

Seeman, T. E., Lusignolo, T. M., Albert, M., & Berkman, L. (2001). Social relationships, social support, and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur Studies of Successful Aging. *Health Psychology, 20*(4), 243-255. doi: 10.1037/0278-6133.20.4.243

Seffah, A. (2010). *The evolution of design patterns in HCI: from pattern languages to pattern-oriented design*. Paper presented at the Proceedings of the 1st International Workshop on Pattern-Driven Engineering of Interactive Computing Systems, Berlin, Germany.

Shneiderman, B. (1984). *The future of interactive systems and the emergence of direct manipulation*. Paper presented at the Proc. of the NYU symposium on user interfaces on Human factors and interactive computer systems, New York, United States.

Shneiderman, B. (1991). Touch screens now offer compelling uses. *Software, IEEE, 8*(2), 93-94. doi: 10.1109/52.73754

Smith, M. W., Sharit, J., & Czaja, S. J. (1999). Aging, motor control, and the performance of computer mouse tasks. *Human Factors, 41*, 389-396.

Spiezle, C. (2001). Interface design guidelines for users of all ages. *Retrieved on May*, 1-17. Retrieved from http://www.agelight.com/webdocs/designguide.pdf

Sposaro, F., Danielson, J., & Tyson, G. (2010). *iWander: An Android application for dementia patients.* Paper presented at the Conference Proceedings of the International Conference of IEEE Engineering in Medicine and Biology Society.

Sposaro, F., & Tyson, G. (2009, 3-6 Sept. 2009). *iFall: An android application for fall monitoring and response.* Paper presented at the Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE.

Steg, H., Strese, H., Loroff, C., Hull, J., & Schmidt, S. (2006). Europe Is Facing a Demographic Challenge Ambient Assisted Living Offers Solutions *European Societies* (pp. 1-85).

Stößel, C., Wandke, H., & Blessing, L. (2009). An Evaluation of Finger-Gesture Interaction on Mobile Devices for Elderly Users Older users. *8 Berliner Werkstatt MenschMaschineSysteme*: VDI.

Stößel, C., Wandke, H., & Blessing, L. (2010). Gestural Interfaces for Elderly Users: Help or Hindrance? *Gesture in Embodied Communication and Human-Computer Interaction, 5934*, 269-280.

Sun, H., De Florio, V., Gui, N., & Blondia, C. (2009, 27-29 April 2009). *Promises and Challenges of Ambient Assisted Living Systems.* Paper presented at the Information Technology: New Generations, 2009. ITNG '09.

Sun, X., Plocher, T., & Qu, W. (2007). *An empirical study on the smallest comfortable button/icon size on touch screen*. Paper presented at the Proceedings of the 2nd international conference on Usability and internationalization, Beijing, China.

Sutcliffe, A. (2000). On the effective use and reuse of HCI knowledge. *ACM Transactions on Computer-Human Interaction, 7*, 197-221. doi: 10.1145/353485.353488

Sutcliffe, A. G., & Carroll, J. M. (1999). Designing claims for reuse in interactive systems design. *International Journal of Human-Computer Studies, 50*, 213-241. doi: 10.1006/ijhc.1999.0245

Sutherland, I. E. (1964). Sketch pad a man-machine graphical communication system. *Proceedings of the SHARE design automation workshop on - DAC '64*. New York, New York, USA: ACM Press.

The World Bank. (2012). Age dependency ratio, old (% of working-age population). Retrieved 20 April 2012 http://data.worldbank.org/indicator/SP.POP.DPND.OL

Tidwell, J. (1999a). Common Ground: A Pattern Language for Human-Computer Interface Design Retrieved 23 November 2011, 2011, from http://www.mit.edu/~jtidwell/common_ground.html

Tidwell, J. (1999b). The Gang of Four Are Guilty Retrieved 19 March 2012, 2012, from http://www.mit.edu/~jtidwell/gof_are_guilty.html

Tidwell, J. (2005). *Designing Interfaces*: O'Reilly Media.

Tidwell, J. (2010). *Designing Interfaces, 2nd Edition* (Second Edition ed.): O'Reilly Media.

Torres, A. C. S. (2011). Cognitive effects of video games on old people. *International Journal on Disability and Human Development, 10*, 55-58. doi: 10.1515/IJDHD.2011.003

Tsai, T. H., Chang, H. T., Chang, Y. M., & Huang, G. S. (2012). Sharetouch: A system to enrich social network experiences for the elderly. *Journal of Systems and Software*.

Turner, P., Turner, S., & Van De Walle, G. (2007). How older people account for their experiences with interactive technology. *Behaviour & Information Technology, 26*, 287-296. doi: 10.1080/01449290601173499

Umemuro, H. (2004). Lowering elderly Japanese users' resistance towards computers by using touchscreen technology. *Univers. Access Inf. Soc., 3*(3), 276-288. doi: 10.1007/s10209-004-0098-6

Van Duyne, D. K., Landay, J. A., & Hong, J. I. (2003). *The Design of Sites: Patterns, Principles, and Processes for Crafting a Customer-Centered Web Experience*: Addison-Wesley.

Van Duyne, D. K., Landay, J. A., & Hong, J. I. (2007). *The Design of Sites: Patterns For Creating Winning Web Sites*: Prentice Hall.

Van Welie, M. (2007). Patterns in Interaction Design, from http://www.welie.com/patterns/

Vandervoort, A. A. (2002). Aging of the human neuromuscular system. *Muscle & Nerve, 25*, 17-25. doi: 10.1002/mus.1215

Vogel, D., & Baudisch, P. (2007). *Shift: a technique for operating pen-based interfaces using touch*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, San Jose, California, USA.

Voida, S., Podlaseck, M., Kjeldsen, R., & Pinhanez, C. (2005). *A study on the manipulation of 2D objects in a projector/camera-based augmented reality environment*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, Portland, Oregon, USA.

Wagnild, G. (2001). Chapter 4 Growing Old at Home. *Journal of Housing For the Elderly, 14*(1-2), 71-84. doi: 10.1300/J081v14n01_04

Welie, M. V., Veer, G. C. V. D., & Eliëns, A. (2000). Patterns as tools for user interface design. 313-324.

Wellner, P. (Producer). (1991, 30 November 2012). Digital Desk (video). Retrieved from http://www.youtube.com/watch?v=S8lCetZ_57g

Wickremaratchi, M. M., & Llewelyn, J. G. (2006). Effects of ageing on touch. *Postgraduate medical journal, 82*, 301-304. doi: 10.1136/pgmj.2005.039651

Wigdor, D., & Wixon, D. (2011). *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture*: Elsevier Science & Technology.

Wobbrock, J. O., Aung, H. H., Rothrock, B., & Myers, B. A. (2005). Maximizing the guessability of symbolic input. *CHI '05 extended abstracts on Human factors in computing systems - CHI '05*. New York, New York, USA: ACM Press.

Wobbrock, J. O., Morris, M. R., & Wilson, A. D. (2009). User-defined gestures for surface computing. *Proceedings of the 27th international conference on Human factors in computing systems - CHI '09*. New York, New York, USA: ACM Press.

Wolf, C. G. (1986). Can People Use Gesture Commands? *SIGCHI Bull., 18*(2), 73-74. doi: 10.1145/15683.1044102

Wu, M., & Balakrishnan, R. (2003). *Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays*. Paper presented at the Proceedings of the 16th annual ACM symposium on User interface software and technology, Vancouver, Canada.

Yahoo! (2009). Yahoo! Design Pattern Library Retrieved 5 February 2012, 2012, from http://developer.yahoo.com/ypatterns/

Zajicek, M. (2004). Successful and available: interface design exemplars for older users. *Interacting with Computers, 16*, 411-430. doi: 10.1016/j.intcom.2004.04.003

Zajicek, M. (2006). Aspects of HCI research for older people. *Universal Access in the Information Society, 5*, 279-286. doi: 10.1007/s10209-006-0046-8

Zaphiris, P., Kurniawan, S., & Ellis, R. D. (2008). Older people and mobile phones: A multi-method investigation. *International Journal of Human-Computer Studies, 66*, 889-901. doi: 10.1016/j.ijhcs.2008.03.002

Ziefle, M. (2010). Information presentation in small screen devices: the trade-off between visual density and menu foresight. *Applied Ergonomics, 41*, 719-730.

Ziefle, M., & Bay, S. (2004). *Mental Models of a Cellular Phone Menu. Comparing Older and Younger Novice Users.* Paper presented at the Mobile Human-Computer Interaction – MobileHCI 2004.

APPENDIX A: TEST SCRIPTS FOR RESEARCH PHASES ONE, TWO, THREE AND FOUR

A.1 TEST SCRIPT: PHASE ONE OF TESTING WITH USERS

PRE-SESSION SCRIPT

First of all, I would like to thank you for agreeing to take part in this study. My name is Roxanne Leitão, and I am in the last year of my Master's degree in multimedia. For my final degree project I am looking to understand how mobile phones can be improved in a way that makes them easier to use. What I would like to understand throughout this session is how we can make use of gestures to operate with mobile phones.

During this session, I will ask you to perform some gestures on this surface [hand smartphone to participant]. I am not going to tell you which gestures to perform, as I would like you to carry-out the first gesture that comes to mind for each of the tasks. There are no right or wrong answers, nor any right or wrong gestures. We are here to further our insight into which gestures are most natural and intuitive, and therefore your contribution is extremely important to us.

Do you authorise use to video record your hands as you perform a gesture on the mobile phone? [Wait for answer]. The recording will help me in remembering exactly what happened during our session, as I might not have time to take all the necessary notes. The video recordings, or any other information, will not be shared with any third-parties. I will be the only person to watch the recordings.

Finally, I would like you to interrupt the session at any time if you need a break, or want to ask a question, or even if you do not want to continue the session. Do you have any questions or comments before we begin?

[Wait and answer questions accordingly]

SESSION SCRIPT

I am going to show you a short animated movie for each of the ten tasks. Each movie will repeat itself twice. After repeating, the movie will go back to the beginning and stay there. At this point, I will explain the task to you, and after the explanation I would like you to perform a gesture that you think could result in the consequence seen in the movie.

For each task I would like you to perform only one gesture. You can do this in any way you prefer, with any number of fingers or even your whole hand. In order to perform the gestures, I would like you to imagine that the images you see on the screen are like real world objects that you can touch and move with your fingers.

Before we begin, I would like you to hold this mobile phone as you would hold your own. Finally, do not be afraid to damage or break the equipment, as you will not be liable, nor are these phones easily damaged.

Do you have any questions or comments before we start?

[Procedure for each task: Let the user see the video. Once it has stopped ask them to verbally explain what they just saw. Then verbally explain the task according to the script (see individual task scripts below). Once explained, ask the participant to perform the gesture for that task].

TASK 1: SCROLL CONTENT

In this movie, the list of numbers was partially hidden to the bottom of the screen. In order to see the remaining numbers, the list was moved in an upward fashion. Now I would like you to perform a gesture that you think could make the list move up, in order to reveal the hidden numbers, much like what you saw in the previous animation.

TASK 2: PAN CONTENT

In this movie, the list of numbers was partially hidden. In order to see the remaining numbers, the list was moved toward the left of the screen. Now I would like you to perform a gesture that you think could provoke the action seen in the animation, in order to reveal the hidden numbers.

TASK 3: MOVE AN ITEM

What happened in this movie, was that the item in the bottom-left-corner was moved into the item present at the top-right-corner. I would now like you to perform a gesture that would move the item, just like what happened in the animation you just watched.

TASK 4: SELECT AN ITEM

What happened in this movie is that the red item, the top-right one, was selected. As a result of being chosen, the other items disappeared. Now I would like you to make a gesture, that you think would choose the red item. The red item is the one in the upper-right-corner.

TASK 5: STOP SCROLLING CONTENT

In this movie, a list of numbers moved from the top and toward the bottom of the screen, until it eventually disappeared. The list will start moving again in a few seconds, and I would like you to perform a gesture you think could stop that list from disappearing again.

TASK 6: ZOOM-IN

In this movie, the image got bigger so that we were able to see it better. Now I would like you to make a gesture that you think would make the image bigger again, similarly to what you saw in the previous animation.

TASK 7: ZOOM-OUT

In this movie, the image became progressively smaller. Now I would like you to make a gesture on the screen, that you think would make the image smaller, like what happened in the animation.

TASK 8: REVEAL CONTEXTUAL MENU

In this movie, a grey rectangle that is related to the object was opened. Now I would like you to make a gesture on the screen, that you think would make that same grey rectangle re-open, like you saw in the animation.

TASK 9: MAGNIFIED VIEW OF CURSOR

In this movie, a magnified view of the position of the red rectangle (cursor) appeared, between the letters "A" and "m", and then disappeared after a few seconds. I would now like you to perform a gesture that you think could provide a magnified view of red rectangle's position, much like what happened in the animation.

TASK 10: ROTATE AN ITEM

What happened in this movie was that the item was rotated 90º to the right. I would now like you to perform a gesture that you think could rotate that item, much like you saw in the previous animation.

POST-SESSION SCRIPT

Before we finnish, do you have any question or comment? [Wait for participant's answer].

I would like to thank you for taking part in our study. Your participation was extremely important to us. Thank you.

A.2 TEST SCRIPT: PHASE TWO OF TESTING WITH USERS

PRE-SESSION SCRIPT

First of all, thank you for agreeing to take part in this study. My name is Roxanne, and the work we will be doing here today is part of completing my Master's degree, at the faculty of engineering, here in Porto.

I am here to learn about older adults and the usability of mobile phones. During this session I will ask you to complete five tasks. For each task, I will show you a movie that demonstrates how you should perform a gesture on the screen of this mobile phone in order to solve a certain task. After viewing the movie, I will ask you to perform the same gesture you just saw, in order to solve the task at hand.

If you feel comfortable enough, I would like you to think out-loud while you perform the tasks. Please remember that you are not being tested. There are no right or wrong answers. We are here to get a better understanding of the use of gestures to operate mobile phones.

Do you authorise use to video record your hands as you perform a gesture on the mobile phone? [Wait for answer]. The recording will help me in remembering exactly what happened during our session, as I might not have time to take all the necessary notes. The video recordings, or any other information, will not be shared with any third-parties. I will be the only person to watch the recordings.

Please fell free to interrupt the session at any moment. Whether you need a break, or have a question, or want to end the session completely.

The whole session should not take longer that 20 to 30 minutes.

Before we begin, do you have any questions or comments?

[Wait for questions or comments and answer accordingly]

SESSION SCRIPT

The session will work in the following way: (1) I am going to ask you to solve five tasks, (2) for each task I will show you a short-movie demonstrating the gesture you should use to solve a given task, (3) you will then be asked to solve a task by using one of the demonstrated gestures. You can view the movie more than once, but not more than three times. Do you have any questions before we being?

[Answer questions accordingly]

You can now press the first button to view the movie that demonstrates a gesture.

[Wait for video to end]

You can now press the first button to try and solve the task, or you can press the second button to view the movie again. [Do not let participant watch the video more than three times]

[Present each of the five tasks one at a time to each participant]

POST-SESSION SCRIPT

Before we finnish, do you have any questions or comments? [Wait and answer accordingly]. I would like you thank you for participating in this study. Your contribution has been of great importance to our work. Thank you.

A.3 TEST SCRIPT: PHASE THREE OF TESTING WITH USERS

PRE-SESSION SCRIPT

First of all, thank you for agreeing to take part in this study. My name is Roxanne, and I am finishing my Master's degree at the faculty of engineering, here in Porto. My work is aimed at understanding how mobile phones can be better made to meet the needs of people over sixty-five years of age. For this reason, you contribution is extremely important.

During this session I am going to ask you to play two games on this mobile phone [hand mobile phone to participant]. The whole session will take about 10 minutes. I would also like you to know that you are not being tested. There is no right or wrong way of playing the games. We are testing the games themselves, and are not testing you.

Please fell comfortable to interrupt the session at any moment, whether you need a break, have a question, or do not want to continue the session.

Before the session starts, do you have any questions or comments? [Wait for questions and answer accordingly].

SESSION SCRIPT

I will now explain how the session is going to work. I am going to ask you to play two different games. For each of these games, you will first watch a short movie demonstrating how the game is played, you will then have the opportunity to practice how to play a training level, after which you can play the actual game.

May we begin?

[Read instructions either for tap or swipe game according to which game each participant will play first].

TAP GAME

Let's start with the Insect Game. In this game, the objective is to smash the middle insect with your finger.

You can now press the first button so watch a short movie that demonstrates how the game is played.

[Wait for end of tutorial]

If you did not understand, or feel that you need to view the tutorial again, please feel free to do so.

[Wait for participant's reaction]

Ok, now to play the training level, please press the second button. You can now practice how to play before beginning the actual game.

[Wait until end of training level]

We have reached the end of the practice level. Would you like to play the "real" game? [Wait for answer]. Now you can press the third button to start playing.

SWIPE GAME

Now I am going to ask you to play the second game. The objective of this game is to drag the red/middle helicopter to the loop found on the opposite side of the screen.

Please press the first button to view the short movie that demonstrates how the game is played.

[Wait for video to end]

Now, press the second button to start playing the training level. In this level you can practice how to play before playing the "real" game.

[Wait for participant to finnish the practice level]

We have reached the end of the practice level. Would you like to play the "real" game?

[Wait for participant's answer]

To play the game, please press the third button.

[Wait until participant finishes the game]

POST-SESSION QUESTIONNAIRE

[Ask participants to fill in the post-session questionnaire].

Before we finish, do you have any comments or questions? [Wait and answer questions accordingly]. I would like to thank you for your time and interest in participating in this study. Your contribution os extremely valuable to our work. Thank you.

A.4 TEST SCRIPT: PHASE FOUR OF TESTING WITH USERS

PRE-SESSION SCRIPT

First of all, I would like to thank you for agreeing to participate in this study. My name is Roxanne and the what we are going to do in today's session if part of the work I am doing to finalise my degree at the faculty of engineering, here in Porto.

I am here to learn how existing mobile phones can be made easier to use for persons over sixty-five years of age. During the session, I am going to ask you to play two different games. The games will not take longer than 10 minutes to finnish. You can play the games on this mobile phone [hand phone to participant].

Your participation in this study is a valuable contribute to our work. I would like to remind you that you are not being tested, there is no wrong way of playing these games. We are here to understand in which ways we can make mobile phones simpler to use.

Please fell comfortable to interrupt the session at any moment, whether you need a break, have a question, or do not want to continue the session.

Before we begin, do you have any questions?

SESSION SCRIPT

I will now explain how this session is going to work. Firstly, we are going to teach you how to play the games by showing you a short animated movie. Then you will have the opportunity to practice before the "real" game starts. Once the practice phase has finished, we will then ask you to play the "real" game.

May we begin?

[Read instructions either for tap or swipe game according to which game each participant will play first].

TAP GAME

To learn how to play, please press the first button. Now a short animated video will demonstrate how the game is played.

[Let participant watch tutorial]

In this game, the objective is to use your finger to smash the mole. The mole will consecutively reappear at several locations on the screen. If you did not understand, and need to view the tutorial again, please feel free to do so.

[Wait and show tutorial again of necessary]

Now, you can play the training level, where you will get an opportunity to practice before playing the real game.

[Let participant play training level]

We have reached the end of the training level. Do you wish to start playing the game? You can now press the third button to start playing.

SWIPE GAME

The objective of this game is to find which animal can be dragged onto the red target without passing over any barriers. Only one animal, per screen, can be dragged to the target.

Firstly, we will show you how to play through the use of a short animated movie. Then you will have a chance to practice how to play a training level before playing the actual game.

May we begin?

To watch the short movie and learn how to play please press the first button.

[Let participant watch tutorial]

If you did not understand, and need to view the tutorial again, please feel free to do so.

[Wait and show tutorial again if necessary]

Now, to play the training level please press the second button. You can now practice before playing the "real" game.

[Wait for practice level to end]

Finally, to play the "real" game, please press the third button.

POST-SESSION SCRIPT

[Ask participants to fill in the post-session questionnaire].

Before we finish, do you have any comments or questions? [Wait and answer questions accordingly]. I would like to thank you for your time and interest in participating in this study. Your contribution was extremely valuable to our work. Thank you.

APPENDIX B: POST-SESSION QUESTIONNAIRE FOR RESEARCH PHASE THREE

B.1 QUESTIONNAIRE: PHASE THREE OF TESTING WITH USERS

1. Age: ___ || Gender: M / F

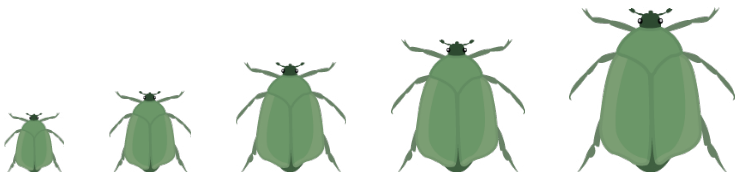
2. Did you prefer any of the games?

   a. Game
   b. Helicopter Game

3. Did any one of the games seem more difficult than the other?

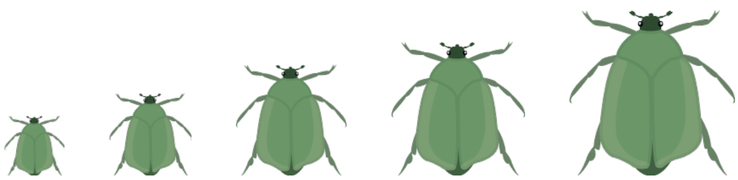
   a. Insect Game
   b. Helicopter Game

4. Imagine that the insects shown below are in fact buttons on the display of a mobile phone like the one you just used. In your opinion, which sizes do think are the <u>most adequate</u> for buttons on a phone? (Please draw a circle around the ones you find <u>most adequate</u>)



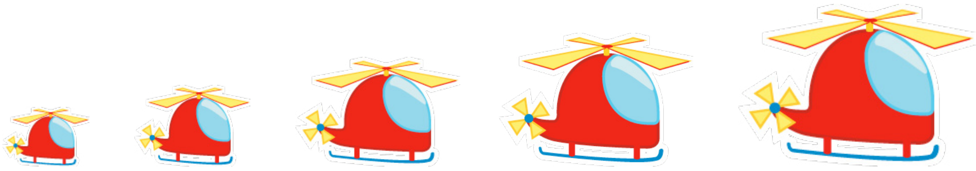
1 2 3 4 5

5. Again, Imagine that the insects shown below are in fact buttons on the display of a mobile phone like the one you just used. In your opinion, which sizes do think are the <u>least adequate</u> for buttons on this phone? (Please draw a circle around the ones you find <u>least adequate</u>)



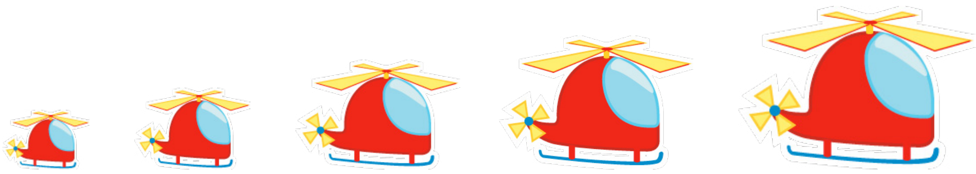
1 2 3 4 5

6. Imagine that the helicopters shown below are in fact buttons on the display of the mobile phone you just used, and that you have to drag them from one side of the screen to the other, like you did in one of the games. In your opinion, which sizes do think are the most adequate for draggable buttons on this phone? (Please draw a circle around the ones you find most adequate)



1 2 3 4 5

7. Imagine that the helicopters shown below are in fact buttons on the display of the mobile phone you just used, and that you have to drag them from one side of the screen to the other, like you did in one of the games. In your opinion, which sizes do think are the least adequate for draggable buttons on this phone? (Please draw a circle around the ones you find least adequate)



1 2 3 4 5

8. Which gesture did you find to be more fun while playing the games?

   a. Tapping the screen
   b. Dragging your finger along the screen

9. Which was harder to do?

   a. Tapping the screen
   b. Dragging your finger along the screen

10. Did you feel any kind of fatigue in your arm, hand, or fingers after finishing the games?

   a. Yes
   b. No

11. Which game do you feel was more tiring?
    - Insect game
    - Helicopter game

APPENDIX C

In this appendix is a paper that was accepted for publication at PLOP'2012 (Conference on Pattern Languages of Programs 2012).

TARGET AND SPACING SIZES FOR SMARTPHONE USER INTERFACES FOR OLDER ADULTS: DESIGN PATTERNS BASED ON AN EVALUATION WITH USERS

ROXANNE LEITÃO, FRAUNHOFER PORTUGAL – AICOS, AND FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
PAULA ALEXANDRA SILVA, FRAUNHOFER PORTUGAL - AICOS

The use of smartphones is becoming widespread among all sectors of the population. However, developers and designers do not have access to guidance in designing for specific audiences such as older adults. This study investigated optimal target sizes, and spacing sizes between targets, for smartphones user interfaces intended for older adults. Two independent variables were studied — target sizes and spacing between targets — for two common smartphone gestures — *tap* and *swipe.* Dependent variables were accuracy rates, task completion times, and participants' subjective preferences. 40 older adults recruited from several daycare centers participated in both tasks and a post-session questionnaire. The recommendations drawn from the authors' research support two interaction design patterns relative to touch target sizes for older adults, and are presented in this paper.

Keywords: Design patterns, older adult, touchscreen, smartphone, target size; tap gesture, swipe gesture, user study, interaction design

1. INTRODUCTION AND CONTEXT

There has never been such a high percentage of older adults in industrialized countries as there is nowadays and this trend is going to keep increasing (Cavanaugh & Blanchard-Fields, 2006)Datasets indicate that the percentage of older people (defined as over 65 years of age) in 2010 was 13% in the United States (Department of Health & Human Services, 2011) and 17.4% in the European Union (European Commission & Economic Policy Committee, 2011). By 2030-2035 the percentage of older adults is expected to reach 19.3% in the U.S (Department of Health & Human Services, 2011) and 23.8% in the EU (European Commission & Economic Policy Committee, 2011)

In addition, according to the International Telecommunication Union (2012), it is estimated that mobile phone subscriptions in Europe are around 119.5 per 100 people, meaning that there are more mobile phone subscriptions than individual persons and, on a larger scale, 86.7% of the world's population is estimated to own a subscription (International Telecommunication Union, 2012).

However, current design and development of mobile telecommunication devices has not been taking into account older adults specific needs and expectations (Czaja & Sharit, 1998; Zaphiris, Kurniawan, & Ellis, 2008; Ziefle, 2010)

More recently and given the proliferation of touchscreen devices, a few studies have been conducted to investigate optimal touch target sizes for the general population (Henze, Rukzio, & Boll, 2011; Lee & Zhai, 2009; Parhi, Karlson, & Bederson, 2006; Park, Han, Park, & Cho, 2008; Perry & Hourcade, 2008; Sears, Revis, Swatski, Crittenden, & Shneiderman, 1993) but very few have concentrated on touch target sizes for older adults (Jin, Plocher, & Kiff, 2007). In fact, current smartphone Operating System (OS) guidelines, such as Apple's "iOS Human Interface Guidelines"[1] Google's "Android Design"[2], and Microsoft's

1 http://developer.apple.com/library/ios/#DOCUMENTATION/UserExperience/Conceptual/MobileHIG/Introduction/Introduction.html
2 http://developer.android.com/design/index.html

"User Experience Design Guidelines"[3], do not offer guidance in designing for specific user groups, such as older adults.

Furthermore, it is well accepted that as a result of ageing several alterations occur to the sensory, cognitive and motor systems and that these changes might cause many products to be less adequate for, or even unusable by, older adults.

Modifications such as the yellowing of the eye lens and the shrinking of the retina result in issues such as reduced visual acuity, color-blindness, less contrast sensitivity, and diminished visual search abilities. Making it harder to perform tasks that involve small font-sizes, colors with similar hues or low-contrast levels, or user interfaces (UIs) with too many visual items presented at once (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Kurniawan, 2008).

Additionally, losses in muscle tissue and bone density occur, which contribute to the reduction of capabilities such as strength and endurance (Cavanaugh & Blanchard-Fields, 2006). In addition, common conditions among older adults such as osteoarthritis, rheumatoid arthritis, and osteoporosis, or malnutrition (Carmeli, Patish, & Coleman, 2003), declining physical activity and sedentary lives are also common conditions affecting their muscular and skeletal systems (Vandervoort, 2002). Accompanying physical changes in muscle tissue and bone density, cognitive and sensory modifications also cause older adults to conduct movement efforts in a different form than their younger counterparts (Ketcham, Seidler, Van Gemmert, & Stelmach, 2002). These alterations are related to poorer perceptual feedback, deteriorating motor pathways, and strategic differences in task resolution (Fisk et al., 2009; Goodman, Brewster, & Gray, 2005; Pak & McLaughlin, 2010). Research has shown that older adults take 30% to 70% longer than their younger counterparts to perform certain motor-related tasks, but that they are not necessarily less accurate than younger adults in accomplishing the end goal of a movement (Ketcham et al., 2002).

Likewise, age-related changes to the central and peripheral nervous systems affect the sensation of touch (Wickremaratchi & Llewelyn, 2006). Older adults have been found to sustain reduced ability in detecting vibrotactile stimulation, perceiving differences in temperature (Nusbaum, 1999), and noticing light pressure touches. Tactile acuity also suffers significant declines with the ageing process, with bodily extremities (e.g., finger-tips, toes) being the most affected (Wickremaratchi & Llewelyn, 2006).

However, to our knowledge research regarding touch target sizes on smartphones for older adults has not yet been extensively explored. Kobayashi, Hiyama, Miura, et al., (2011) investigated target sizes for *tap* gestures on mobile touchscreen devices but considered only three different targets sizes for individual targets with no neighbors. Jin, Plocher and Kiff (2007) also conducted a study to evaluate touch target sizes for older adults, considering six different target sizes for both adjacent and non-adjacent targets, as well as five spacing sizes for adjacent targets. Although their study investigates *tap* gestures and target dimensions for older adults, it was conducted using a 17-inch touchscreen tablet fixed on a stand and

3 http://msdn.microsoft.com/en-us/library/hh202915(v=vs.92).aspx presented at a 45º angle to the participants. Therefore, these results are not applicable to mobile devices such as smartphones.

Our research aims to extend existing knowledge regarding older adults and touch targets on small touchscreen hand-held devices, namely regarding target sizes and spacing for *tap* and *swipe* gestures. In order to do so, the authors tested target sizes, and spacing sizes between targets with older adults for both adjacent and non-adjacent targets on a smartphone. Furthermore, the authors wanted to investigate if any difference exists between ideal target sizes according to two different types of common touchscreen gestures — *tap* and *swipe*. The outcome of this research was then compiled in the form of design patterns.

Design patterns have been found to be an efficient form of compiling and sharing HCI knowledge, both within multidisciplinary teams (Borchers, 2001; Dearden & Finlay, 2006; Erickson, 2000) and pedagogical environments (Borchers, 2002; Carvalhais, 2008; Koukouletsos, Khazaei, Dearden, & Ozcan, 2009; Laakso, 2003). For these reasons, the authors decided that design patterns would be the best form of sharing their findings with the community.

This paper introduces two patterns:

1. LARGE SIZE *TAP* TARGETS
2. LARGE SIZE *SWIPE* TARGETS

In the future, these patterns are intended to be part of a larger pattern language for designing user interfaces that are usable by older adults.

2. DISCOVERING TARGET SIZES AND SPACING BETWEEN TARGETS FOR SMARTPHONE USER INTERFACES (UIs) TARGETED AT OLDER ADULTS

The patterns presented in this paper are supported by tests conducted with older adults participants. Although large target sizes are generally used in interfaces targeted specifically at older adults, our own research aimed to assess the actual effectiveness of larger target sizes on older adults performance when interacting with smartphones. Accordingly, in order to investigate *tap* and *swipe* target sizes, we conducted a study with 40 older adults. The study consisted of two individual tasks — one for *tap* gestures and another for *swipe* gestures.

Given the necessary repetition of each gesture throughout both tasks, we decided to conduct the study by using two games that we thought would better motivate older adults to participate. Games have been found to provide enjoyable experiences, while motivating players to achieve a defined goal even when certain actions need to be extensively repeated (Lazzaro, 2008). Likewise, games have been found to benefit older adults by contributing to the improvement of reaction times, visuo-motor coordination, and quality of life (Torres, 2011).

Firstly, the *Tap* Game or *Insect Game* was played by smashing a target insect while avoiding other neighboring insects. Neighboring targets could be present or the target insect could appear alone. This intends to simulate occasions where only one button (non-adjacent target) occupies most of the interface (e.g., application login), or others where a set of targets (adjacent targets) is closely placed together (e.g., soft keyboard).

Next, the *Swipe* Game or *Helicopter Game* consisted of dragging a helicopter from one side of the screen toward a target located on the opposite side. Once again, the game simulated the existence of adjacent and non-adjacent targets, as would occur in the regular usage of a smartphone.

The following section provides further detail regarding participants, apparatus used, test procedure, and finally our main findings.

2.1 Participants

40 older adults (30 female and 10 male) aged from 65 to 95 (*Mean* = 76.88) years old were recruited from several day care centers within the city of Porto, Portugal. All participants completed the *tap* and *swipe* tasks, as well as filling out the post-session questionnaire.

2.2 Apparatus

All tests were performed on a *Samsung Nexus S* with a 52.32 mm by 87.12 mm display at 233 PPI. All participant data was logged on the smartphone itself, therefore there was no need to collect any audio or video during any of the sessions while also avoiding peripheral equipment that could hinder the participants' interaction with the smartphone.

2.3 Procedure

A within-subject design was used, in which two within-subject variables were included — touch target size and spacing between targets.

Based on the average size of a human fingerpad, which is about 10mm to 14mm (Dandekar, Raju, & Srinivasan, 2003), five levels of touch target size where used: 21mm, 17.5mm, 14mm, 10.5mm and 7mm. That is, target sizes considered the higher bound of the average human finger, which is 14mm and then added or subtracted 14/4 = 3.5mm in order to obtain the remaining sizes, e.g., 14 + 3.5 = 17.5 mm and 17.5 + 3.5 = 21 mm for the bigger sizes; the same procedure was used to find the smaller sizes.

Spacing between targets obeyed the same criteria and included another 5 levels: 0 mm, 3.5 mm, 7 mm, and10.5 mm, plus an additional level for non-adjacent targets (a single target with no neighbors).

Each factor was measured three times per participant. Resulting in 5 (sizes) x 5 (spacing sizes) x 3 (repetitions) = 75 *taps* for the first task and 75 *swipes* for the second task, per participant.

There were three dependent variables: accuracy, task completion time and number of errors per task. Accuracy was measured as the number of times a target was missed before correctly acquiring it, so if a participant tried to hit a target twice but only managed to do so on the third try, then accuracy would be 1 (accurate hit)/3 (tries) = 0.33%. Task completion time was considered as the average amount of time participants took to accurately complete a task, and finally, the error rate was only accounted for in the *swipe* task, and represents the number of times a target was dragged and released before reaching the destination mark.

All users completed both tasks. Each task consisted of a game which we thought would better motivate users to participate, given the high levels of gesture repetition that the tasks required.

Finally, each game assessed target sizes and spacing dimensions for one of two types of common gestures performed on existing smartphones — *tap* and *swipe.*

3. RESULTS

The following section presents individual results for the *Tap* Game, then for the *Swipe* Game, and finally we compare results for both tasks. Charts 1, 2, 3 and 4 provide an overview of our findings.

In general, target sizes were found to have had a significant effect on participants' performance, both regarding accuracy rates and task completion times. On the other hand, spacing between targets did not seem to influence participants' performance.

3.1 *Tap* game

A repeated measures Analysis of Variance (ANOVA) with a Greenhouse-Geisser correction showed that the mean accuracy measures for different button sizes was significant ($F(1.184, 46.160) = 46.914$, $P < 0.001$). Participants' mean accuracy decreased as target sizes got smaller. Mean accuracy was significantly lower for button sizes below 14 mm, although no significant differences where found for targets larger than 14 mm square. Our finding that older adults' accuracy decreases as targets get smaller is consistent with other studies conducted by Jin, Plocher and Kiff (2007) and Kobayashi, Hiyama, Miura et al., (2011). In addition, task completion time was also influenced by *tap* target sizes ($F(1.456, 56.770) = 24.895$, $P < 0.001$). Mean task completion times were higher for targets smaller than 14 mm square. A significant difference was also found between 17.5 mm and 14 mm size targets, where the bigger target resulted in longer task completion times.

Chart 1 Mean accuracy rates for the *Tap Game* according to target size and spacing size between targets

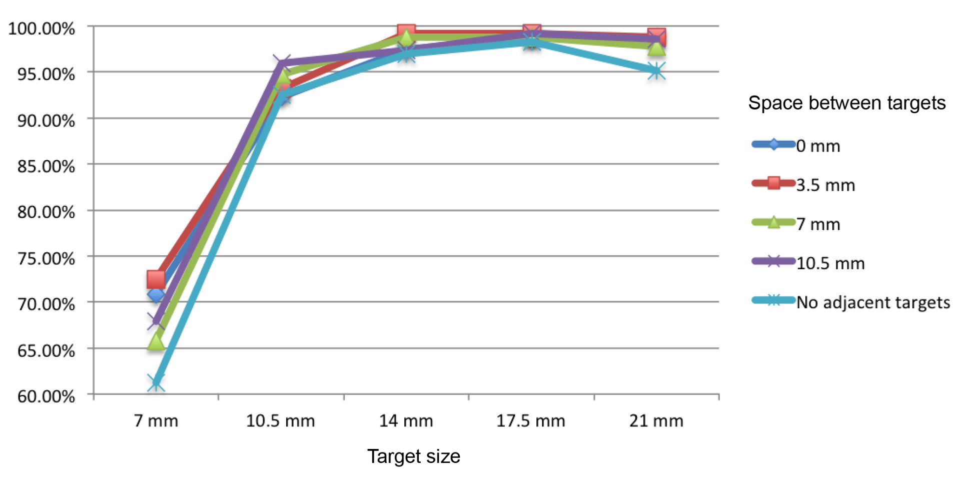
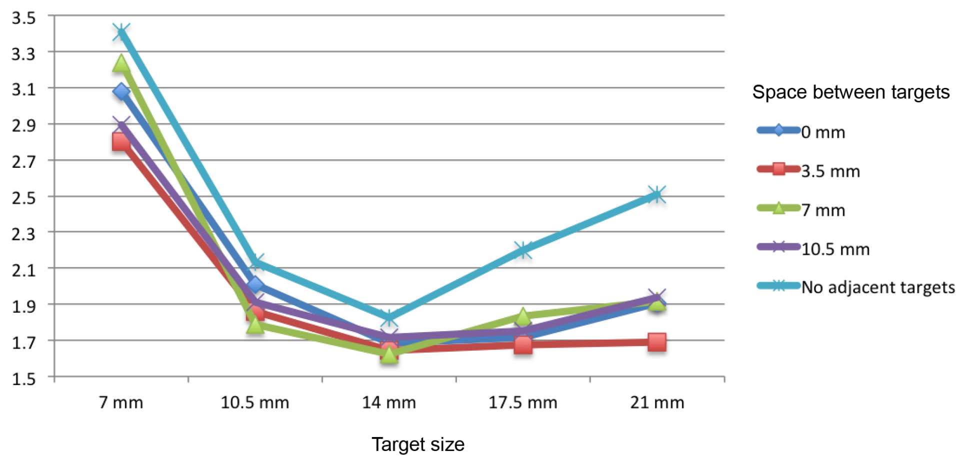


Chart 2 Mean task completion times for the *Tap Game* according to target size and spacing size between targets



3.2 *Swipe* Game

A repeated measures ANOVA with a Greenhouse-Geisser correction showed that the mean accuracy measures for different *swipe* target sizes was significant ($F(2.083, 81.247) = 16.809$, $P < 0.0001$). Mean accuracy measures decreased as target dimensions became smaller. Accuracy was significantly lower for *swipe* target sizes below 10.5 mm, but no significant differences were found for targets larger than this.

Contrary to the *Tap* Game, target sizes did not have a significant effect on the time it took participants to complete *swipe* tasks.

Chart 3 Mean accuracy rates for the *Swipe Game* according to target size and spacing size between targets

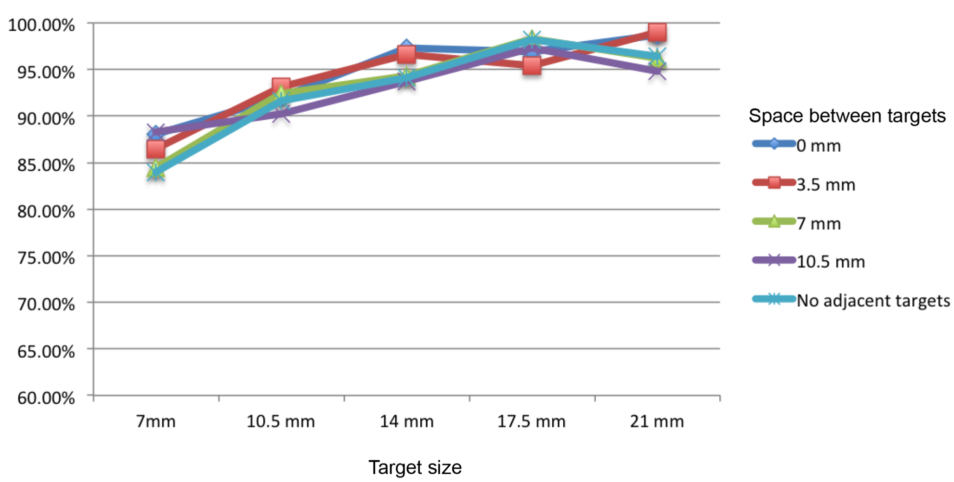
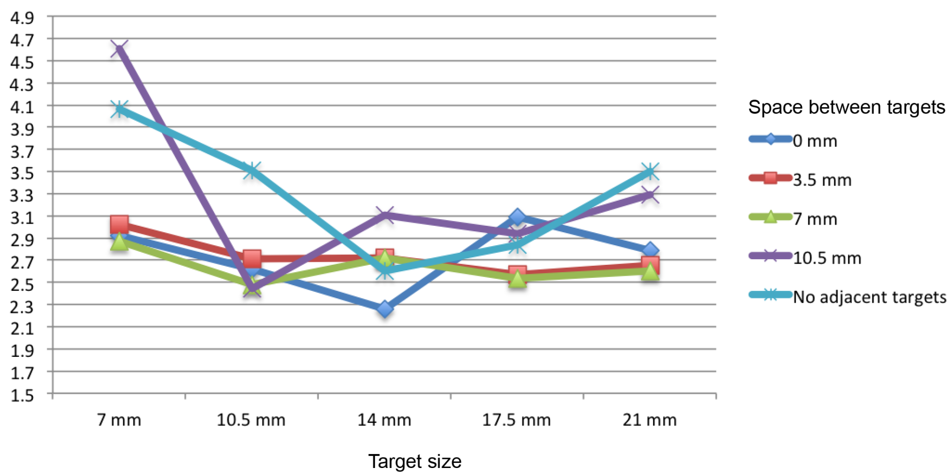


Chart 4 Mean task completion times for the *Swipe Game* according to target size and spacing size between targets



3.3 Comparison of *Tap* and *Swipe* results

For the purpose of developing patterns to guide UI designers in constructing more usable interfaces for older adults, satisfactory target sizes where considered as those with a mean accuracy rate over 97%. Consequently, for *tap* gestures that would include target sizes larger than 14mm square and for *swipe* gestures this value is slightly higher at 17.5 mm square. Lastly, spacing between targets did not show significant effects in either of the tasks.

4. PATTERN FORMAT

Our patterns largely follow the structure presented by Christopher Alexander *in A Pattern Language: Towns, Buildings, Construction* (1977), and that was later reused by Jan Borchers in *A Pattern Approach to Interaction Design* (2001).

Each pattern starts with its name written in small caps. An individual ranking is attributed to each pattern, representing the level of confidence that the authors deposit in it. This ranking can range from zero to two asterisks, where zero represents the lowest level of confidence and two represents the highest.

The pattern identification elements are followed by the context that describes the reader's current situation, as well as the goal of the pattern and the environment within which it is located. The title and context will give the reader an immediate perception whether the pattern is applicable, or not, to their particular problem.

After context is set, the problem statement is presented in bold and is followed by a longer problem description. It is in the problem description that contradicting forces are explained and the problem's empirical background is presented.

Next, the solution appears in bold. Then, examples of the solution applied in real-world interfaces close off the central body of the pattern, and aim to make the solution more understandable by providing a simple illustration of its real-world applicability. However, given the nature of our patterns, which focus on touch target sizes, the examples provided do not intend to be general examples of good interface design for older adults, but rather examples of interfaces that make use of large touch targets as a form of compensating for sensory and psychomotor age-related declines that impact the usability of a given interface.

5. DESIGN PATTERNS FOR CONSTRUCTING SMARTPHONE USER INTERFACES FOR OLDER ADULTS

5.1 LARGE SIZE *TAP* TARGETS **

… you are developing a smartphone user-interface (UI) targeted at older adults. This may be the first time you are designing for this specific audience, or you might already have some experience and have chosen to review the design decisions made in previous projects. You are now in a phase of the project where decisions need to be made regarding target sizes for *tap* gestures. Choosing target sizes for a particular gesture is an important decision as it will determine whether your intended users will, or not, be able to complete necessary actions and tasks throughout the flow of your UI.

+++

As a result of the ageing process, sensory and psychomotor capabilities undergo several declines and these alterations may render conventional *tap* target sizes as inadequate for older adults. In addition, existing smartphone OS guidelines[4] do not provide guidance concerning specific audiences, such as older adults.

Previous research has explored adequate target sizes for *tap* gestures on large touch-surfaces (Colle & Hiszem, 2004), PDAs (Parhi et al., 2006; Park et al., 2008; Perry & Hourcade, 2008; Sears & Zha, 2003) , or more recently on tablets (Jin et al., 2007) and smartphones (Henze et al., 2011), but very few have explored target sizes for older adults on smartphones. Consequently, most guidelines currently available guidelines[4] do not aid designers in creating a smartphone UIs that adequately responds to older adults' specific characteristics.

It is commonly accepted that visual acuity, contrast sensitivity, visual search capabilities (Fisk et al., 2009), fine-motor skills, hand dexterity (Carmeli et al., 2003) and touch sensitivity (Carmeli et al., 2003; Fisk et al., 2009; Nusbaum, 1999; Wickremaratchi & Llewelyn, 2006) suffer considerable losses with age. Additionally, natural age-related declines of the sensory and psychomotor systems can be further aggravated by diseases

4 Android: http://developer.android.com/design/style/metrics-grids.html
iPhone: https://developer.apple.com/library/ios/#documentation/UserExperience/Conceptual/MobileHIG/Characteristics/Characteristics.html
Windows Phone: http://msdn.microsoft.com/en-us/library/hh202889(v=VS.92).aspx

such as Age-related Macular Degeneration, cataracts, presbyopia and glaucoma — relative to visual abilities, and multiple sclerosis, arthritis, osteoporosis, stroke and Parkinson's disease — related to psychomotor issues (Kurniawan, 2008). Movement can be severely affected by these diseases, causing symptoms such as weakness, numbness, loss of muscle coordination, pain, stiffness, tremors, rigidity and slow movement. Therefore, one cannot safely assume that target sizes that have been found to be adequate for younger adults will also provide a comfortable user experience for the elderly.

It is clear that special considerations need to be taken into account when designing UIs for older adults. Targets for all gestures should be resized to fit the elderly population's particular characteristics. *Tap* target sizes are no exception. Our own research conducted with older adults revealed that their performance is best with targets between 14 and 17.5 mm square. While, official guidelines recommend targets between 7 and 9 mm square for *tap* gestures, which are considerably smaller than our own findings for older adults.

In accordance, many interfaces developed specifically for older adults make use of large *tap* targets. Below are examples of "Big Launcher"[5], "AlzNav"[6], "Smart Companion"[7], "Dance! Don't Fall"[8], "Phonotto"[9] — for Android, "WP for Senior Citizens"[10], "Big Button Dialer"[11] — for Windows Phone, and "Eye Read"[12] — for the iPhone. The authors do not intend to provide these applications as examples of effective interface design for older adults, but rather as examples of the usage of large *tap* targets with the objective of compensating for the previously mentioned sensory, and psychomotor age-related declines, that unfold with the ageing process. The use of large *tap* targets makes it easier for older adults to see targets, to distinguish between adjacent targets, as well as allowing them to more accurately acquire *tap* targets, as larger touchable areas compensate for issues related to movement control and hand dexterity.

In addition, as demonstrated by the examples below, although targets are larger than usual in interfaces designed specifically for older adults, they still may vary in size depending on the amount of targets that need to be displayed, on the available screen real estate to do so, as well as according to the relative importance of each target. For example, the targets shown in the dial-pads of "Phonotto" and "Big Button Dialer" are smaller than those presented in the home screens of "BIG Launcher" or "WP for Senior Citizens", as the amount of screen real estate available for such a large number of targets is limited; and as seen in "Smart Companion" and "AlzNav", although all targets are considerably large, information hierarchy also determines the relative size of each target, where more relevant targets tend to be larger. Accordingly, our own research showed that although

5 https://play.google.com/store/apps/details?id=name.kunes.android.launcher.activity&hl=en
6 https://play.google.com/store/apps/details?id=pt.fraunhofer.navigator&hl=en
7 http://smartcompanion.projects.fraunhofer.pt/
8 https://play.google.com/store/apps/details?id=pt.fraunhofer.dancedontfall&feature=search_result#?t=W251bGwsMSwxLDEsInB0LmZyYXVuaG9mZXIuZGFuY2Vkb250ZmFsbCJd
9 https://play.google.com/store/apps/details?id=com.gammapps.SimplePhone&feature=search_result#?t=W251bGwsMSwyLDEsImNvbS5nYW1tYXBwcy5TaW1wbGVQaG9uZSJd
10 http://www.windowsphone.com/en-GB/apps/b51b275f-3417-4b10-87fe-5db8717bf76f
11 http://www.windowsphone.com/en-US/apps/278ae89c-8d11-489b-8c98-517e6dd2b66b
12 http://itunes.apple.com/us/app/eyeread/id345271596?mt=8

accuracy rates decrease and task completion times increase as targets get smaller, older adults' performance measures still maintain themselves within acceptable levels for targets larger than 10.5 mm square.

Still, the relatively large size of these *tap* targets could raise issues related to the number of targets that need to be displayed and the available screen real estate to do so, which in turn could lead to the need to make certain compromises. One of these compromises could be to place all UI elements in a large scrollable VERTICAL LIST (Hoober & Berkman, 2011), or to divide the content into several pages — PAGINATION (Hoober & Berkman, 2011; Tidwell, 2010). However, opting for any of these solutions would either result in an increased number of necessary *swipes* to navigate a long list, or in a larger amount of navigation layers. In both cases, the complexity of the navigation system would increase and could in fact become an issue for older adult users, who have been found to have more difficulty in operating complex navigation systems (Ziefle, 2010; Ziefle & Bay, 2004). On the other hand, an alternative solution could be to reduce the number of functionalities and/or options included in your interface, thus avoiding the need for long list of items, or for an excessive amount of pages. However, while a reduced set of functionalities could be effective for your target older adult population — whom are likely to have low levels of technology proficiency, it might not be suitable for younger users who could be expecting a broader range of services from your interface.

Therefore...

If screen real estate is not an issue and the task requires high performance levels, use *tap* targets that are significantly larger than those found on conventional smartphone interfaces. However, in particular cases throughout the screen flow of your UI, where screen real estate is limited, and a decrease in older adults' performance measures is acceptable, it might be necessary to (a) use targets that are slightly smaller than the ones employed throughout the remainder of your UI, or (b) redistribute your content through PAGINATION (Hoober & Berkman, 2011; Tidwell, 2010), or into scrollable VERTICAL LISTs (Hoober & Berkman, 2011), or finally, (c) reduce the number of available funcionalties and options displayed on your interface.

+++

Tap targets can be BUTTONs (Hoober & Berkman, 2011), TABS (Hoober & Berkman, 2011), LINKs (Hoober & Berkman, 2011), INDICATORs (Hoober & Berkman, 2011) or KEYBOARDS & KEYPADAS (Hoober & Berkman, 2011). Whatever their particular form, these targets should appear to be "clickable" or actionable — ACTION BUTTON (Van Welie, 2008) — as to inform users of their specific functionality, as opposed to other static UI elements. In addition, when such targets are manipulated they should make use of HAPTIC OUTPUT (Hoober & Berkman, 2011) and/or auditory TONES (Hoober & Berkman, 2011) as the appropriate feedback to confirm interaction. Finally, when many related targets are necessary, consider making use of BUTTON GROUPS (Tidwell, 2010) to arrange clusters of similar targets in a logical way.

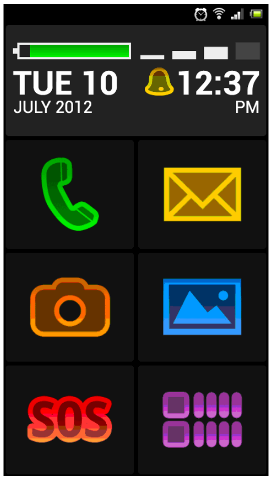


Fig. 1. *Big Launcher* for Android

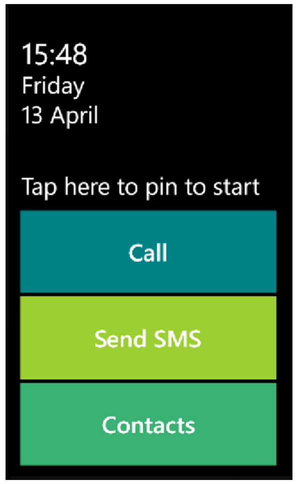


Fig. 2. *WP for Senior Citizens* for Windows Phone

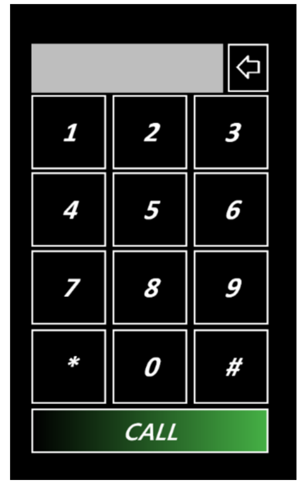


Fig. 3. *Big Button Dialer* for Windows Phone

Fig. 4. *AlzNav* for Android

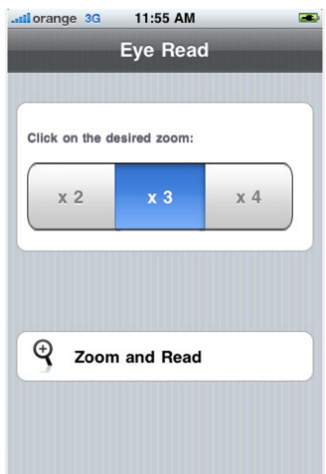


Fig. 5. *Eye Read* for iPhone

Fig. 6. *Smart Companion* for Android

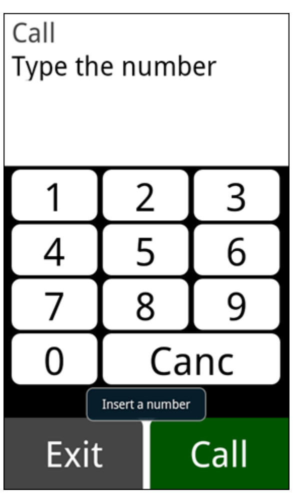


Fig. 7. *Phnotto* for Android

5.2 LARGE SIZE *SWIPE* TARGETS **

… Consider you have recently started prototyping the visual layout of a UI targeted at older adults. This might be a new audience, with which you have never worked before, or it is also possible that you already have considerable experience in designing for this user group but want to review strategies used in previous projects. You are now in a position where you need to decide on specific target sizes for *swipe* gestures. They are an important issue, as they will determine if your users will, or not, be able to complete many actions and tasks throughout the flow of your UI.

Selecting a range of target sizes that are most adequate for a given group of users requires a thorough understanding of their particular characteristics, expectations and preferences. Official smartphone OS guidelines such as, Window's "User Experience Design Guidelines"[13], Google's "Android Design"[14], and Apple's "iOS Human Interface Guidelines"[15] do not provide guidance in designing *swipe* targets for specific groups of users such as older adults.

These official guidelines recommend target sizes that are smaller than the average human finger (10 to 14mm) (Dandekar et al., 2003), raising issues such as target occlusion while performing a gesture and/or accidentally touching neighboring targets.

It is well accepted that visual acuity (Fisk et al., 2009), movement control, hand-eye coordination, hand dexterity (Carmeli et al., 2003) and touch sensitivity (Carmeli et al., 2003; Fisk et al., 2009; Nusbaum, 1999; Wickremaratchi & Llewelyn, 2006) suffer considerable losses during the aging process. Thus making it harder to see small targets and to perform the necessary movements in order to accurately acquire them.

Additionally, vision and psychomotor capabilities can be further compromised by common diseases among older adults such as Age-related Macular Degeneration, cataracts, presbyopia glaucoma — relative to visual abilities; and multiple sclerosis, arthritis, osteoporosis, stroke and Parkinson's disease — related to psychomotor issues. Movement can be severely affected by these diseases, causing symptoms such as weakness, numbness, loss of muscle coordination, pain, stiffness, tremors, rigidity and slow movement (Kurniawan, 2008).

Inevitably, accurately acquiring small targets becomes increasingly difficult as age progresses. Providing targets that are too small makes a UI more difficult to use and could result in frustration and anxiety among older adults (Czaja & Sharit, 1998; Laguna & Babcock, 1997; Turner, Turner, & Van De Walle, 2007) and should therefore be avoided.

Our own research conducted with older adults revealed that performance was best for *swipe* targets larger than 17.5 mm square. When compared with the findings for *tap* targets, where

13 http://msdn.microsoft.com/en-us/library/hh202915(v=vs.92).aspx
14 http://developer.android.com/design/index.html
15 http://developer.apple.com/library/ios/#DOCUMENTATION/UserExperience/Conceptual/MobileHIG/Introduction/Introduction.html

best performance was found for targets larger than 14 mm square, it seems that the end intention of a movement — whether to finalize in a *tap* or in a *swipe* — influences older adults accuracy and the time they take to correctly acquire touch targets.

Accordingly, many interfaces specifically designed for older adults make use of large *swipe* targets. Below are examples of "iDown"[16], "Guardly"[17], and "Pillboxie"[18]. Although the authors do not intend that these be examples of effective interface design for older adults, their use of large *swipe* targets makes it easier for older adults to see targets, to distinguish between them, as well as to correctly acquire them. The larger touchable areas compensate for movement control and hand dexterity issues that occur with age. Therefore, allowing for easier interaction with, and manipulation of a touch interface.

However, the use of large *swipe* targets throughout an interface might not always be possible due to screen real estate limitations, which are often an issue on mobile UIs. For example, in cases where many targets are needed on a particular screen, it might be necessary to recur to techniques such as PAGINATION (Hoober & Berkman, 2011; Tidwell, 2010), or a VERTICAL LIST (Hoober & Berkman, 2011), as forms of accommodating all the information that needs to be displayed. In turn, these solutions force the user to either perform more *taps* to select a page, or more *swipes* to scroll a long list. Thus, in any of these situations, navigating the content might become frustrating for users in general, and for older adults in particular (Ziefle, 2010; Ziefle & Bay, 2004) as many actions are needed to access several layers of hidden content. In this context, as an alternative to creating overly complex navigations mechanisms, it might be necessary to restrict the number of options and/or functionalities provided, as a form of reducing the number of targets that need to be displayed. However, when restricting the available functionalities, UI designers should be aware of potentially excluding younger, and more technology proficient users, who could be expecting a broader set of functionalities. On the other hand, as previously mentioned, if the complex navigation mechanisms needed to accommodate a larger number of targets are indeed implemented, the UI might exclude older adult users (Ziefle, 2010; Ziefle & Bay, 2004).

Therefore...

In cases where available screen space for *swipe* targets is not an issue and the task requires high performance measures, use large *swipe* target sizes. Otherwise, you might need to (a) redistribute the UI content through PAGINATION, or a VERTICAL LIST, or (b) limit the provided functionalities, in order to accommodate *swipe* targets that are sufficiently large for older adult users.

+++

Swipe targets can be of many different kinds — CAROUSELs (Tidwell, 2010;Hoober & Berkman, 2011), FILM STRIPs (Hoober & Berkman, 2011; Tidwell, 2010), SLIDESHOWs (Hoober & Berkman, 2011), SCROLL (Hoober & Berkman, 2011) bars, ALPHABET SCROLLERs

16 http://itunes.apple.com/us/app/idown/id374806701?mt=8
17 http://itunes.apple.com/us/app/guardly/id400742014?mt=8
18 http://itunes.apple.com/ca/app/pillboxie/id417367089?mt=8

(Tidwell, 2010), and MECHANICAL STYLE CONTROLS (Hoober & Berkman, 2011) such as sliders, and spinners. Whatever their form, consider implementing these targets in addition with HAPTIC OUTPUT (Hoober & Berkman, 2011) and/or auditory TONES (Hoober & Berkman, 2011), as forms of providing the appropriate feedback to users. Finally, when many related target are necessary consider using BUTTON GROUPS (Tidwell, 2010) in order to logically group sets of similar targets.

Fig. 8. *iDown* for the iPhone

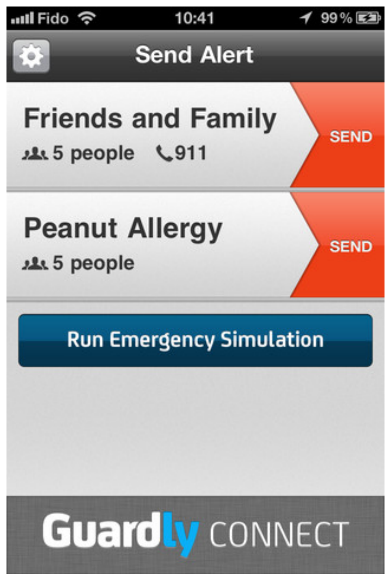


Fig. 9. *Guardly* for the iPhone

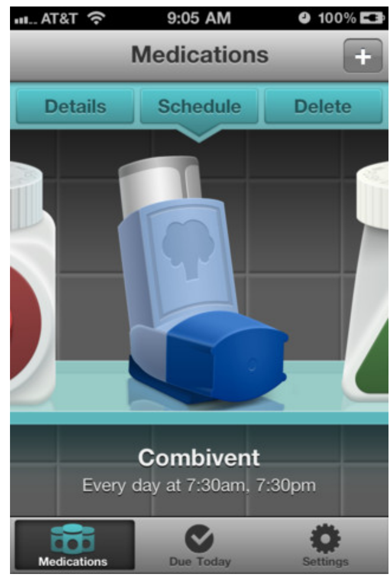


Fig.10. *Pillboxie* for the iPhone

6. CONCLUSIONS AND FUTURE WORK

The two patterns here presented explore the use of large size *tap* and *swipe* targets as a means for compensating for visual and motor issues that occur with ageing. The smartphone UI examples presented in these patterns intend to demonstrate the use of large touch target sizes in UIs specifically developed for older adults, however, the authors do not intend that these examples be understood as general good UI design for older adults. In the future, the authors aim is that these patterns be the starting point of a larger pattern language, that will be aimed at UI developers and designers, as well as teachers and students interested in learning about or designing smartphone user interfaces for older adults.

It is the authors' intention to extend our research by conducting further tests with users. Accordingly, the next step of this research will be to evaluate screen comfort zones for both *tap* and *swipe* gestures for older adults using smartphones. Additionally, the authors plan to assess performance rates for both direction and orientation of *swipe* gestures in order to provide a set of comprehensive patterns regarding gesture performance, target sizes, target spacing sizes, and comfortable activity zones, on small mobile touchscreens for older adults.

7. ACKNOWLEDGEMENTS

This work was funded by Fraunhofer Portugal – AICOS. A special thank you to all the participants who willingly agreed to take part of our study, and to Sílvia Rêgo who helped recruiting tests' participants.

REFERENCES

Alexander, C., Ishikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., & Angel, S. (1977). A Pattern Language: Towns, Buildings, Construction. 1171.

Borchers, J. (2001). *A Pattern Approach to Interaction Design*: John Wiley & Sons.

Borchers, J. (2002). Teaching HCI design patterns: Experience from two university courses. *Patterns in Practice A Workshop for UI Designers at CHI 2002 International Conference on Human Factors of Computing Systems*: Citeseer.

Carmeli, E., Patish, H., & Coleman, R. (2003). The Aging Hand. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58*, M146-M152. doi: 10.1093/gerona/58.2.M146

Carvalhais, M. (2008). Learning and studying interaction design through design patterns. *Proceedings of the 15th Conference on Pattern Languages of Programs - PLoP '08*. New York, New York, USA: ACM Press.

Cavanaugh, J. C., & Blanchard-Fields, F. (2006). *Adult Development And Aging*: Wadsworth/Thomson Learning.

Colle, H. A., & Hiszem, K. J. (2004). Standing at a kiosk: Effects of key size and spacing on touch screen numeric keypad performance and user preference. *Ergonomics, 47*(13), 1406-1423. doi: 10.1080/00140130410001724228

Czaja, S. J., & Sharit, J. (1998). Age Differences in Attitudes Toward Computers. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 53B*, P329-P340. doi: 10.1093/geronb/53B.5.P329

Dandekar, K., Raju, B. I., & Srinivasan, M. A. (2003). 3-D Finite-Element Models of Human and Monkey Fingertips to Investigate the Mechanics of Tactile Sense. *Journal of Biomechanical Engineering, 125*, 682. doi: 10.1115/1.1613673

Dearden, A. M., & Finlay, J. (2006). Pattern languages in HCI: a critical review. *Human-Computer Interaction, 21*, 49-102.

Department of Health & Human Services. (2011). AoA (Administration on Aging) Retrieved 05 December 2011, from http://www.aoa.gov/aoaroot/aging_statistics/index.aspx

Erickson, T. (2000). *Lingua Francas for design: sacred places and pattern languages*. Paper presented at the Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York City, New York, United States.

European Commission, & Economic Policy Committee. (2011). The 2012 Ageing Report: Underlying Assumptions and Projection Methodologies (pp. 294).

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). *Designing for Older Adults: Principles and Creative Human Factors Approaches, Second Edition (Human Factors & Aging)*: CRC Press.

Goodman, J., Brewster, S., & Gray, P. (2005). How Can We Best Use Landmarks to Support Older People in Navigation. *Journal of Behaviour and Information Technology, 24*, 3-20.

Henze, N., Rukzio, E., & Boll, S. (2011). 100,000,000 taps: analysis and improvement of touch performance in the large. *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services - MobileHCI '11*. New York, New York, USA: ACM Press.

Hoober, S., & Berkman, E. (2011). Designing Mobile Interfaces. *2011*, 581.

International Telecommunication Union. (2012). ICT Data and Statistics (IDS). Retrieved 15 May 2012 http://www.itu.int/ITU-D/ict/statistics/

Jin, Z. X., Plocher, T., & Kiff, L. (2007). Touch screen user interfaces for older adults: button size and spacing. *Universal Acess in Human Computer Interaction Coping with Diversity, 4554*, 933-941.

Ketcham, C. J., Seidler, R. D., Van Gemmert, A. W. A., & Stelmach, G. E. (2002). Age-Related Kinematic Differences as Influenced by Task Difficulty, Target Size, and Movement Amplitude. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57*, P54-P64. doi: 10.1093/geronb/57.1.P54

Koukouletsos, K., Khazaei, B., Dearden, A., & Ozcan, M. (2009). Teaching Usability Principles with Patterns and Guidelines (Vol. 289, pp. 159-174): Springer US.

Kurniawan, S. H. (2008). Web Accessibility: A Foundation for Research. In S.-V. London (Ed.), *Human-Computer Interaction Series* (pp. 47-58).

Laakso, S. A. (2003). User Interface Design Patterns Retrieved 15 June 2012, 2012, from http://www.cs.helsinki.fi/u/salaakso/patterns/

Laguna, K., & Babcock, R. L. (1997). Computer anxiety in young and older adults: Implications for human-computer interactions in older populations. *Computers in Human Behavior, 13*, 317-326. doi: 10.1016/S0747-5632(97)00012-5

Lazzaro, N. (2008). Why we Play: Affect And The Fun of Games. In A. Sears & J. A. Jacko (Eds.), *The Human-computer interaction handbook: Fundamentals, Evolving Technologies and Emerging Applications, Second Edition* (pp. 679–700): Lawrence Erlbaum Associates.

Lee, S., & Zhai, S. (2009). The performance of touch screen soft buttons. *Proceedings of the 27th international conference on Human factors in computing systems - CHI '09*. New York, New York, USA: ACM Press.

Nusbaum, N. (1999). Aging and sensory senescence. *Southern medical journal*.

Pak, R., & McLaughlin, A. (2010). *Designing Displays for Older Adults*: Taylor & Francis US.

Parhi, P., Karlson, A. K., & Bederson, B. B. (2006). Target size study for one-handed thumb use on small touchscreen devices. *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services - MobileHCI '06*. New York, New York, USA: ACM Press.

Park, Y. S., Han, S. H., Park, J., & Cho, Y. (2008). Touch key design for target selection on a mobile phone. *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services - MobileHCI '08*. New York, New York, USA: ACM Press.

Perry, K., & Hourcade, J. P. (2008). Evaluating one handed thumb tapping on mobile touchscreen devices. *Proceedings of graphics interface 2008*, 57-64.

Sears, A., Revis, D., Swatski, J., Crittenden, R., & Shneiderman, B. (1993). Investigating touchscreen typing: the effect of keyboard size on typing speed. *Behaviour & Information Technology, 12*, 17-22. doi: 10.1080/01449299308924362

Sears, A., & Zha, Y. (2003). Data entry for mobile devices using soft keyboards: Understanding the effects of keyboard size and user tasks. *International Journal of Human-Computer, 16*, 163-184. doi: 10.1207/S15327590IJHC1602_03

Tidwell, J. (2010). *Designing Interfaces, 2nd Edition* (Second Edition ed.): O'Reilly Media.

Torres, A. C. S. (2011). Cognitive effects of video games on old people. *International Journal on Disability and Human Development, 10*, 55-58. doi: 10.1515/IJDHD.2011.003

Turner, P., Turner, S., & Van De Walle, G. (2007). How older people account for their experiences with interactive technology. *Behaviour & Information Technology, 26*, 287-296. doi: 10.1080/01449290601173499

Van Welie, M. (2008). Patterns in Interaction Design, from http://www.welie.com/patterns/

Vandervoort, A. A. (2002). Aging of the human neuromuscular system. *Muscle & Nerve, 25*, 17-25. doi: 10.1002/mus.1215

Wickremaratchi, M. M., & Llewelyn, J. G. (2006). Effects of ageing on touch. *Postgraduate medical journal, 82*, 301-304. doi: 10.1136/pgmj.2005.039651

Zaphiris, P., Kurniawan, S., & Ellis, R. D. (2008). Older people and mobile phones: A multi-method investigation. *International Journal of Human-Computer Studies, 66*, 889-901. doi: 10.1016/j.ijhcs.2008.03.002

Ziefle, M. (2010). Information presentation in small screen devices: the trade-off between visual density and menu foresight. *Applied Ergonomics, 41*, 719-730.

Ziefle, M., & Bay, S. (2004). *Mental Models of a Cellular Phone Menu. Comparing Older and Younger Novice Users*. Paper presented at the Mobile Human-Computer Interaction – MobileHCI 2004.