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Study of the interaction of older adults with touchscreen

Lilian Genaro Motti

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Université Fédérale



Toulouse Midi-Pyrénées

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Étude de l'interaction de personnes âgées avec des écrans tactiles

Résumé

Utiliser une tablette ou un smartphone est désormais courant. Cependant, les effets de l'âge sur les capacités motrices nécessaires pour l'exécution des gestes d'interaction tactile n'ont pas été suffisamment pris en compte lors de la conception et de l'évaluation des systèmes interactifs, une des raisons qui a empêché l'inclusion numérique de ce groupe d'utilisateurs. L'objectif de cette thèse est d'étudier l'interaction des personnes âgées avec les écrans tactiles afin d'identifier des problèmes d'utilisabilité sur des supports variés (smartphone et tablette, doigt et stylet). Pour cette étude, nous avons conçu un système interactif constitué de jeux de type puzzle numérique tactiles, où le geste d'interaction drag-and-drop (glisser-déposer) est employé pour positionner les cibles. Dans ce contexte, une attention particulière a été portée à l'analyse des mouvements de l'utilisateur. L'analyse des postures du poignet durant l'interaction a permis d'élucider la relation entre les caractéristiques des mouvements des personnes âgées avec leurs performances, à savoir, des temps plus longs et une augmentation du nombre d'erreurs par rapport aux utilisateurs adultes plus jeunes. Prendre en compte la variabilité des capacités motrices des utilisateurs lors des phases de conception et d'évaluation des systèmes interactifs est nécessaire pour comprendre leurs difficultés et améliorer l'ergonomie et utilisabilité de l'interaction tactile.

Mots clés : *interaction homme-machine, interaction tactile, personnes âgées, utilisabilité, analyse du mouvement, drag-and-drop.*

Abstract

Tablets and smartphones have become mainstream technologies. However, the aging effects on the motor skills implied on tactile interaction haven't been enough considered during the design and evaluation of tactile interactive systems, what prevent this group of older adult users to be digitally included successfully. This thesis aims to study the interaction of older adults with touchscreens in order to identify usability issues on different devices and input modalities (smartphone and tablet, finger and stylus). To this study, we designed an interactive system consisted of tactile puzzle games and using drag-and-drop interaction for positioning the puzzle pieces into their corresponding targets. In this framework, a special attention was given to the analysis of the movements of the user. The analysis of the postures of the users' wrists during interaction allowed to elucidate the relationship between the characteristics of the movements of older adults and their performances, particularly concerning the longer times needed for executing the gestures of interaction as well as the increased error rates of this group of users when compared to younger adults. Taking into account the variability of users' motor skills during the design and evaluation of interactive systems is necessary to better understand their difficulties as well as to improve the ergonomics and the usability levels of tactile interaction.

Keywords: human-computer interaction, tactile interaction, older adults, usability, movement analysis, drag-and-drop.

Table of contents

I.	Introduction	15
I.1.	Framework	16
I.2.	Context.....	19
I.2.1.	The digital gap across generations	19
I.3.	Thesis statement and Research Questions	24
I.3.1.	Research Question 1	24
I.3.2.	Research Question 2	25
I.3.3.	Research Question 3	25
I.3.4.	Research Question 4.....	26
I.4.	Methodology	26
I.5.	Organization.....	27
II.	Theoretical basis	33
II.1.	Factors of acceptance and adoption of technologies by older adults.....	34
II.1.1.	Predictors related to the user’s profiles	37
II.1.2.	Predictors related to the user’s context	38
II.1.3.	Predictors related to the users’ subjective evaluation	39
II.1.4.	Predictors related to systems and technologies	40
II.1.5.	Summary	42
II.2.	Designing for older adults.....	44
II.2.1.	Summary	46
II.3.	Tactile interaction for older adults.....	48
II.3.1.	Design and evaluation of interactive systems and interaction techniques.....	48
II.3.2.	Summary	67
II.4.	Study of movements during interaction with touchscreen.....	71
II.4.1.	Age effects on the movements of users’ upper limbs	71
II.4.2.	Movements of the user during interaction with touchscreen	74
II.4.3.	Summary	83
II.5.	Conclusion	86
III.	Design of the tactile interactive system Puzzle Touch	93
III.1.	Understanding and specifying the context of use	94
III.1.1.	Design specification for the context of use	95
III.2.	Specifying the user requirements.....	96

III.2.1.	Design specification for the user requirements	98
III.3.	Producing design solution: Puzzle Touch.....	99
III.3.1.	Description of the game play	101
III.4.	Design evaluation	102
III.4.1.	Methods.....	102
III.4.2.	Results	104
III.4.3.	Discussion	111
III.5.	Application of results and new design	112
III.6.	Conclusion	114
IV.	Study of the drag-and-drop interaction on touchscreen for older adults	121
IV.1.	Experimental design and methods	122
IV.1.1.	Hypotheses	122
IV.1.2.	Settings of the interactive system for interaction evaluation	122
IV.1.3.	Task	124
IV.1.4.	Touchscreen devices and input modalities.....	124
IV.1.5.	Procedures	125
IV.1.6.	Measures.....	126
IV.1.7.	Data analysis	128
IV.2.	Results.....	128
IV.2.1.	Participants	129
IV.2.2.	Effects of screen sizes and input modalities.....	131
IV.2.3.	Effects of lowering the accuracy requirements on interaction performances.....	132
IV.2.4.	Effects of aging	135
IV.2.5.	Effects of experience of using interactive technologies.....	136
IV.2.6.	Effects of the constraints of accuracy for different age groups.....	137
IV.2.7.	Effects of constraint of accuracy for participants with different experience of using interactive technologies.....	138
IV.2.8.	Unintentional touches.....	139
IV.3.	Discussion.....	141
IV.3.1.	Drag-and-drop interaction and tactile puzzle games for older adults .	142
IV.3.2.	Bigger screen sizes and pen interaction allow more accurate interaction	142
IV.3.3.	Lowering constraints of accuracy for improving accessibility	143
IV.3.4.	Age as a predictor of performances.....	144
IV.3.5.	Previous experience with technologies as predictor of performances	145
IV.3.6.	Accessibility of drag-and-drop interaction for older users without experience with technologies.....	146

IV.3.7.	Ease of use of tactile interaction	146
IV.3.8.	Delimitating interaction zones for preventing errors related to unintentional touches on the screen.....	147
IV.3.9.	Limitations	148
IV.3.10.	Perspectives	148
IV.4.	Conclusion and future work.....	149
V.	Differences in postures and movements of the wrist between older adults and adults and their consequences on interaction performances	155
V.1.	Experimental design and methods	157
V.1.1.	Hypotheses	157
V.1.2.	Settings of the interactive system Puzzle Touch.....	157
V.1.3.	Task	159
V.1.4.	Apparatus and equipment.....	159
V.1.5.	Procedures	169
V.1.6.	Measures.....	172
V.1.7.	Data analysis	173
V.2.	Results.....	180
V.2.1.	Participants	180
V.2.2.	Effects of morphologies	183
V.2.3.	Effects of aging	184
V.2.4.	Effects of screen sizes, targets sizes and input modalities	189
V.3.	Discussion.....	198
V.3.1.	Characterization of postures and movements of the wrist during interaction with touchscreen.....	199
V.3.2.	Differences in performances between older adults and adults.....	201
V.3.3.	Differences in postures and movements of the wrist between older adults and adults	202
V.3.4.	Relationship between performances and postures of the wrist	203
V.3.5.	Bigger screen sizes and pen interaction for accurate interaction	204
V.3.6.	Bigger targets facilitates drag-and-drop interaction.....	206
V.3.7.	Assessing postures and movements of the users during interaction with touchscreen	206
V.3.8.	Limitations	208
V.3.9.	Perspectives	208
V.4.	Conclusion and future work.....	209
VI.	Conclusion.....	216
VI.1.	Thesis summary	216
VI.1.1.	Thesis statement	218

VI.1.2.	Research Questions	219
VI.1.3.	Contributions	221
VI.2.	Perspectives and future work	223
VI.2.1.	New Research Questions	224
VII.	Appendices	226
VII.1.	Summary of the incidence of age-related disabilities in France	226
VII.2.	Tools for empirical observation	227
VII.2.1.	Observation grid	227
VII.2.2.	Initial questionnaire	228
VII.2.3.	Final questionnaire	230
VII.3.	Evaluation of users' profiles	231
VII.3.1.	Eye-sight tests	231
VII.3.2.	Questionnaire for assessing motor control profile	233
VII.3.3.	Questionnaire for assessing cognitive profile	234
VII.4.	Appendix for Chapter IV	237
VII.4.1.	Images used to generate the tactile puzzle games	237
VII.4.2.	Effects of different user' profiles on performances	238
VII.5.	Appendix for Chapter V	240
VII.5.1.	Preliminary study: Analysis of movements of the users during interaction with touchscreen:	240
VII.6.	Procedures for filtering and clipping data	245
VII.6.1.	Procedures for filtering and clipping data with Matlab	245
VII.6.2.	Procedures for clipping data and normalizing with R	246
VII.7.	Complementary results for the experimental study described in Chapter V	247
VII.7.1.	Differences in performances and postures and movements of the wrist for the two groups of subjects in the eight situations of the study	247
VII.7.2.	Effects of the iterations	257
References.....		262
Index of figures.....		273
Index of tables.....		280
Attachment: Technical documentation of the system Puzzle Touch.....		285

Chapitre 1 : Introduction

Résumé

Le premier chapitre présente le contexte et la méthodologie de cette thèse en Interaction Homme-Machine (IHM), avec une approche multidisciplinaire intégrant l'analyse des aspects sociologiques de l'utilisation des technologies et la contribution de l'étude de la biomécanique du mouvement pour caractériser l'interaction des utilisateurs avec des écrans tactiles.

Contexte

Le vieillissement de la population est un phénomène mondial et les technologies mobiles apportent de nombreuses possibilités d'amélioration de la qualité de vie des personnes âgées. Cependant, les difficultés d'utilisation et d'interaction avec les écrans tactiles demeurent une barrière pour l'acceptation et l'adoption de ces nouvelles technologies par ce groupe d'utilisateurs. Afin d'atténuer ce problème, il est important d'appréhender les effets d'âge sur les habiletés nécessaires pour accomplir le geste d'interaction sur différents supports (smartphone, tablette) ainsi que leur conséquence sur les performances d'interaction (temps et taux d'erreurs). Pour ce faire, les spécificités des utilisateurs âgés doivent être prises en compte lors de la conception et de l'évaluation des techniques et systèmes d'interaction tactiles.

Pertinence

Les technologies mobiles sont majoritairement équipées d'écrans tactiles et l'interaction directe sur l'écran a été recommandée pour les personnes âgées. L'amélioration de l'utilisabilité de l'interaction tactile est importante pour intégrer les personnes âgées dans l'évolution numérique ainsi que pour prévenir leur exclusion. Ceci permettrait de réduire l'écart de taux d'utilisation de technologies mobiles entre les générations. De plus, l'évaluation des interactions avec les écrans tactiles d'un point de vue ergonomique pourrait assurer leur bon usage par les jeunes utilisateurs.

Objectif

*Notre objectif principal est de **comprendre et d'expliquer les difficultés que les personnes âgées rencontrent lors de l'interaction tactile afin d'en améliorer son utilisabilité** par la mise en œuvre de méthodes de conception et de protocoles expérimentaux. Ceux-ci devront tenir compte des différents profils utilisateurs, des diverses situations d'usage des technologies mobiles et des différentes habiletés motrices des personnes âgées pour l'exécution des gestes d'interaction.*

Questions de recherche

Cette thèse s'est construite autour de quatre questions principales de recherche :

- 1) Quels sont les facteurs qui empêchent les personnes âgées d'utiliser les technologies mobiles ?*
- 2) Quelles démarches doivent être mises en œuvre pour la conception de systèmes d'interaction tactile pour les personnes âgées ?*
- 3) Quels aspects d'utilisation des écrans tactiles influencent les performances d'interaction (temps et taux d'erreurs) des utilisateurs âgés ?*
- 4) Quelles sont les différences de mouvements d'interaction entre les personnes âgées et les adultes qui pourraient expliquer les difficultés rencontrées par les personnes âgées en termes de performance (plus de temps et plus d'erreurs) sur différents supports d'interaction (smartphone et tablette, doigt et stylet) ?*

I. Introduction

The continuous evolution and popularization of smartphones and tablets has led to these devices becoming mainstream technologies. In 2012, about one third of the European population accessed the Internet on mobile devices (Seybert, 2012) and, in France, 88% of people aged 15 to 29 and 79% of people aged 30 to 44 have used mobile Internet (Gombault, 2013). With the aging of the population, researchers and developers have become interested in the applications and possibilities of use of these new technologies to improve the quality of life of older people, helping them to maintain a social life, and ensuring medical assistance and security services for aging in place (Barros et al., 2014; Nischelwitzer et al., 2007; Peek et al., 2014; Vasconcelos et al., 2012; Wilkowska and Ziefle, 2009). However, only a small proportion of older populations are actually using mobile devices. In France, people older than 60 years old represented 24% of the population in 2012 (INSEE, 2012) but only 16% of people aged 60 to 74 had already used mobile devices to access Internet (Gombault, 2013); this number drops to 3% for people older than 75.

Mobile devices are often equipped with touchscreens, and the direct interaction on the display screen has been considered intuitive and easy to learn and use, especially for older adults (Caprani et al., 2012). So, why older adults are not using mobile devices as much as younger populations? Do they find difficulties using touchscreen devices? If so, how to design tactile interactive systems to facilitate interaction for this group of users? What kind of devices and input modalities would be more suitable for them? And why do older people find more difficult than younger users to interact with touchscreen? Addressing these questions is fundamental to reduce the digital gap and allow older populations to take full advantage of the interaction with mobile technologies.

This thesis in Human-Computer Interaction (HCI) aims to shed light in to the usability issues of tactile interaction of older adults in order to propose appropriate solutions and recommendations, aiming to improve the use of touchscreen and mobile devices for this group of users. By tactile interaction, we designate the actions the user executes through gestures of interaction on touchscreen. Older users are a heterogeneous group because of the different possible evolutions on the sensorial and psychomotor systems with aging and also because of their different experiences with information and communication technologies (ICTs) (Caprani et al., 2012; Östlund, 2002). In order to better understand the specificities of this particular group of users, we will take a broad

approach to consider the sociological aspects influencing technology adoption. Furthermore, we will try to understand the difficulties older adults may find in executing the gestures of interaction from an ergonomic point of view, through the analysis of the Biomechanics of the movements.

Although older adults represent the target group of users for this work, our results have implications on a broader scope too, especially regarding interactive systems and interaction techniques for users with different skills or disabilities. Finally, this work has implications for interaction designers, scientific communities, industrial practitioners and also digital content producers, not only concerning the procedures of design and evaluation of interactive systems but also the experimental design and analysis presented on the following chapters.

I.1. Framework

This thesis research is built upon seven keywords described below: tactile interaction, touchscreen, older-aged users, older adults, usability, mobile web accessibility and errors of interaction.

The tactile interaction designates the actions the user executes through gestures of interaction detected by the touchscreen. Tactile is defined as “discernible by touch”¹, and interaction as “reciprocal action, effect, or influence”².

Touchscreen is a display screen (output) of a computer or other electronic device that is sensitive to contact and pressure. The screen can detect touch information (input) and send it to the information processing system. With such an approach, the user is though able to interact with the display screen by touching the graphical elements displayed or by executing pre-defined patterns of gestures, which can be executed by means of special pens or the user’s fingers.

Figure I.1 and Figure I.2 give examples of tactile interaction on mobile devices equipped with touchscreen.

¹ The American Heritage® Roget's Thesaurus. Copyright © 2013, 2014 by Houghton Mifflin Harcourt Publishing Company. Available at <http://www.thefreedictionary.com/tactile>

² Random House Kernerman Webster's College Dictionary, © 2010 K Dictionaries Ltd. Copyright 2005, 1997, 1991 by Random House, Inc. Available at <http://www.thefreedictionary.com/interaction>

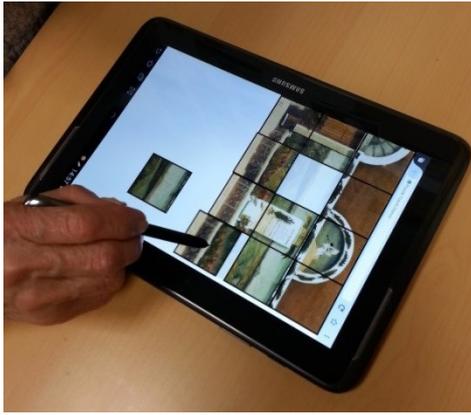


Figure I.1 Example of tactile interaction on touchscreen: user interacting with pen on a tablet



Figure I.2 Example of tactile interaction on touchscreen: user interacting with finger on a smartphone

Older-aged users, or older users, refer to the characteristics of older adults using information and communication technologies: their skills, their needs and their expectations are considered to define the requirements of interactive systems and interaction techniques. In the literature, older users have also been referred as elderly users (Hwangbo et al., 2013; Stöbel, 2009) or senior users (Abrahão et al., 2013; Dahn et al., 2014) to represent group of subjects aged 50 to 85 (see Chapter II, II.4.2.1) (Motti et al., 2013).

Older populations have been defined mainly by chronological age, because 65 years old is the common age of retirement on many western countries (Östlund, 2002). In developing countries, older populations usually designates adults older than 59 (Lara, 2012). Indeed, being excluded of the labor market implies social changings. Moreover, age-related changings on sensorial, cognitive and physiological systems can imply decrease of autonomy and lower health conditions. For an overview of the effects of aging, Geronimi (2008) presents a detailed description of the functional limitations related to the aging (Geronimi, 2008); Lepicard (2011) discuss how these limitations can interfere on interaction with technologies (Lepicard, 2011); and Reerink-Boulanger (2012) discuss the evolution of the representation of the aging in western societies (Reerink-Boulanger, 2012). A summary of the incidence of age-related disabilities in France can be found in Appendix VII.1 (p. 226). Age-related disabilities and special needs can prevent older people to access and use mobile technologies while these technologies offer extended possibilities for improving their well-being and quality of life.

Usability, according to J. Nielsen's definition (1993), is a multi-dimensional property of user interfaces, including five elements: *Learnability*, *Efficiency*, *Memorability*, *Few and Non catastrophic errors* (facilitating error recovery and feedback) and *Subjective Satisfaction* (Nielsen, 1993). From ISO 9241-11 (Guidance on usability), usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". Effectiveness meaning "accuracy and completeness with which users achieve specified goals", efficiency as "resources spent in relation to the accuracy and completeness with which users achieve goals", satisfaction meaning "freedom from discomfort and positive attitudes towards the use of the product" and the context of use being defined as "users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used" (ISO 9241-210, 2010). Improving the usability of tactile interaction means designing interaction that older users can easily learn and successfully use.

Accessibility is defined on ISO 9241-171 as the "usability of a product, service, environment or facility by people with the widest range of capabilities" (ISO 9241-210, 2010). Web accessibility, according to the World Wide Web Consortium (W3C), refers to "designing Web sites and software that are flexible to meet different user needs, preferences, and situations"³. Concerning the widespread availability of web-enabled mobile devices, W3C also provides specific authoring guidelines for mobile web applications. The Mobile Web Accessibility Guidelines tries to embrace "the challenges posed by network costs and delays, memory and CPU (central processing unit) limitations, keyboard and pointing devices differences. As importantly, they (web-enabled mobile devices) feature a growing set of advantages with their personal and always-available nature, and their increasingly context-aware capabilities."⁴

By errors of interaction, or human errors, we designate the problems that can occur during interaction because of the actions of the users on the interactive systems, indicating the user do not understand the interaction or inappropriate design. Errors can be described and counted to assess usability. According to Fisk *et al.* (2010), distinguishing the kinds of errors is fundamental to understand the difficulties older users find during interaction in order to propose appropriate design (Fisk et al., 2009). They

³ Available online at <http://www.w3.org/WAI/intro/accessibility.php>

⁴ Available online at <http://www.w3.org/standards/webdesign/mobilweb.html>

outline the distinction between slips and mistakes: the first occur when the user unintentionally activates a control; the second when the user intendedly make the inappropriate action.

In this thesis, we describe the design of a tactile interactive system conceived as a web mobile application for older users. In this context, improving the usability of tactile interactive systems means enhancing interaction performances, by means of preventing errors of interaction. Moreover, improving usability and accessibility of tactile interactive systems refers to ensuring that older users with different abilities will be able to accomplish interaction on touchscreen devices, with different screen sizes and input modalities, in different situations of use.

I.2. Context

The context of this thesis work is the crossing between the widely spreading of web-enabled mobile devices equipped with touchscreens and the aging of worldwide populations. We describe how the low usage rates of new technologies among older populations generate a digital gap across generations.

I.2.1. The digital gap across generations

The increase of life expectancy and the falling fertility rates have led to a demographic aging - a worldwide phenomenon, as represented in Figure I.3.

In Europe in 2015, 17% of the human population is older than 65 years old (INSEE, 2015). The current trends in population aging estimate that this population will reach 30% by 2060, representing more than 128,770 thousand people: 17% of Europeans will be aged 65 to 79 and 10% of Europeans will be older than 80 years old (European Commission, 2012). In France, 18% of the population is older than 65 in 2015 and the estimative for 2060 is that more than 26 % of the population will be older than 65, representing about 19,360 thousand people (INSEE, 2015). In Brazil, 8% of the population is older than 65 in 2015 and the estimative for 2060 is also that more than 26 % of the population will be older than 65 (European Commission, 2012), where this number will represent about 59,926 thousand people. The growth in older populations in these two countries along time is represented in Figure I.4.

As the populations of older adults increase, we would expect that the number of users of mobile devices among this population would to increase too. However, the usage rates of these technologies among older adults are low. Only 16% of people aged 60 to 74

years old have used mobile devices to access Internet in France in 2012 (Gombault, 2013). Among people older than 74 years old, users of mobile Internet were 3%. On the other hand, among younger generations the usage rates of mobile web were impressive: 88% of people aged 15 to 29 and 79% of people aged 30 to 44 have used mobile devices to connect to the Internet in France in 2012.

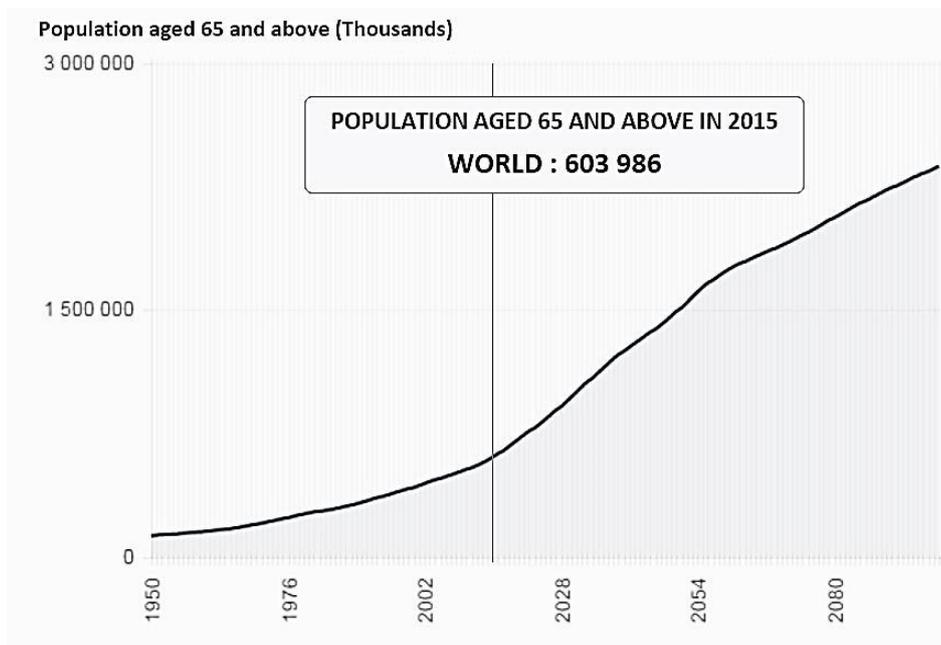


Figure I.3 World population aged 65 or older between 1950 and 2015 and estimative by 2060. In 2015, older population represents approximately 603,986 thousand people and this number is expected to increase in the next years.

Source of graphic: http://www.ined.fr/en/everything_about_population/graphs-maps/population_graphs/, UN, 2012

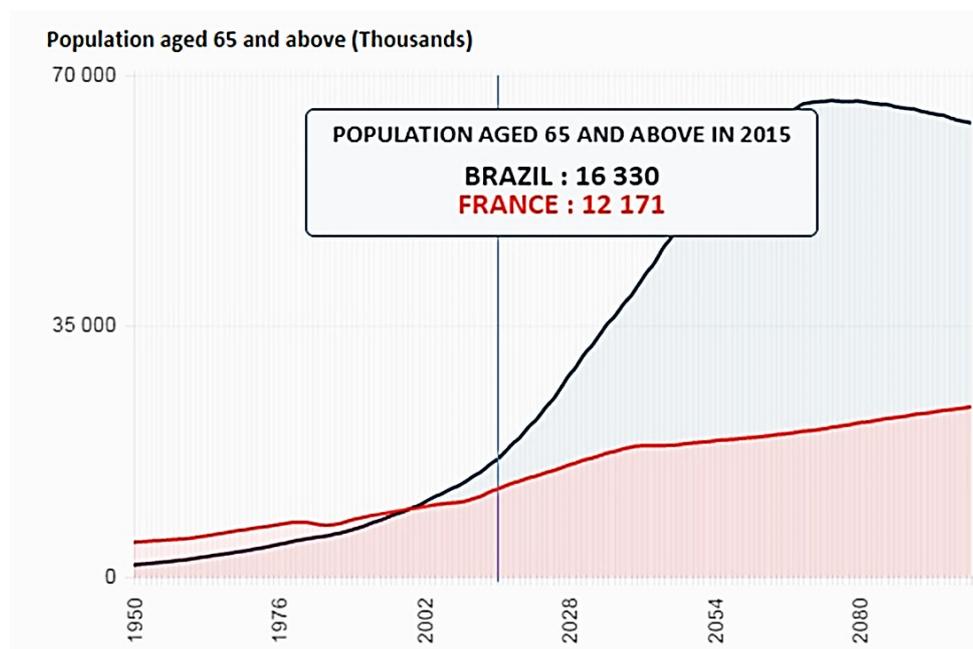


Figure I.4 Populations aged 65 or older in France (red) and in Brazil (black) between 1950 and 2015 and estimative until 2060. In 2015, populations older than 64 represent approximately 12,171 thousand people in France and 16,330 thousand people in Brazil.

Source of graphic: http://www.ined.fr/en/everything_about_population/graphs-maps/population_graphs/, UN, 2012

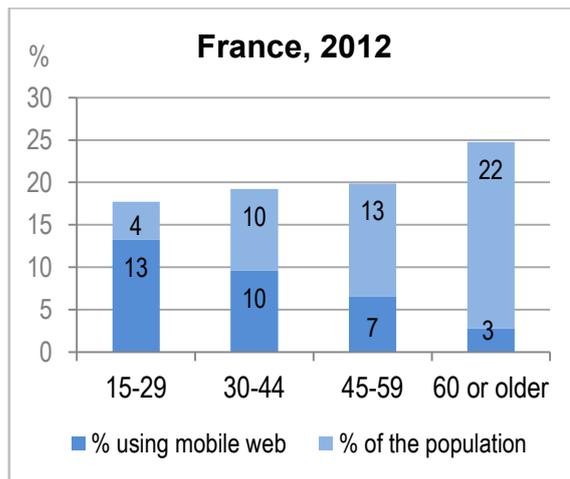


Figure I.5 Percentage of French population according to four specific age groups (15 to 29, 30 to 44, 45 to 59 and 60 or older) and, for each group, percentage of people that had used mobile web in 2012 in France.

Source of data: <http://www.insee.fr>

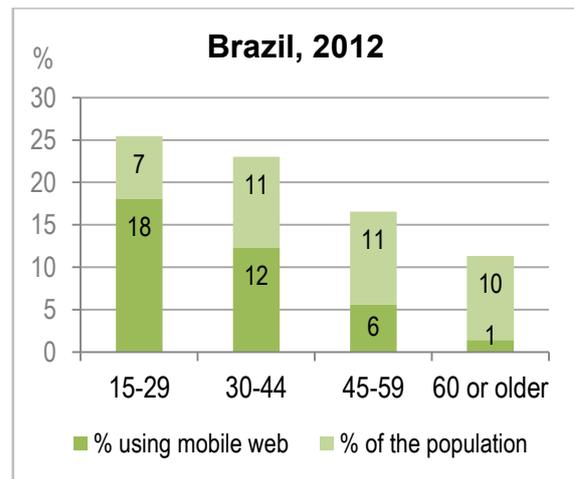


Figure I.6 Percentage of Brazilian population according to four specific age groups (15 to 29, 30 to 44, 45 to 59 and 60 or older) and, for each group, percentage of people that had used mobile web in 2012.

Source of data <http://www.ibge.gov.br>

Figure I.5 represents the usage rates of mobile web according to the age groups in France in 2012, showing that the digital gap on technology use is prominent across four different generations (15 to 29, 30 to 44, 45 to 59 and 60 or older).

In Brazil, the Internet access has rapidly increased in the past ten years but as in France, there is a big difference in the use of mobile technologies across different age groups. Among people aged 60 years old or older, 11% of those had already accessed to Internet in 2011 and 44% of those owned a mobile phone (IBGE, 2011). Among the younger populations, 68% of people aged 15 to 29 and 48% of people aged 30 to 44 have accessed to Internet and 78% of people aged 15 to 29 and 81% of people aged 30 to 44 owned a mobile phone. Smartphones are spreading on the markets in this country and the telecommunication companies are investing in infrastructure and networks to provide mobile Internet for all. Despite of that, there is evidence on the difference of use and adoption of mobile technologies between younger and older adults, as represented on Figure I.6.

According to Barnard *et al.* (2013), people who do not work with computers during their paid occupations have more difficulty in engaging with digital products and services and are also more susceptible to be digitally excluded (Barnard et al., 2013). The rapid growth of mobile technologies has accelerated the lifecycle of mobile devices and applications. Younger generations using computers at school or at work find a favorable environment to get continuously informed about technologies, contrary to older

populations who have to find their own way through the digitalized world. In France, only 12% of the retired population have used mobile Internet in 2012 while 50% of the working adults or 78% of the students have used and benefited from it (Seybert, 2012). Economic situations, need of support and lack of previous experience also prevent older adults from benefitting from interactive technologies, in particular mobile devices (Barnard et al., 2013).

Moreover, existing studies about tactile interaction and usability tests report unappropriated interactive systems and interaction techniques for older users. Misunderstanding of functionalities, disorientation during navigation within menus and lack of control of on-screen interaction zones are some examples of the several barriers older adults find when interacting with touchscreens (Crabb and Hanson, 2014; Harada et al., 2013; Lepicard and Vigouroux, 2010a; Nischelwitzer et al., 2007; Wilkowska and Ziefle, 2009; Zhou et al., 2012). Age-related changings on working memory capabilities make it difficult for older people to identify relevant information and to deal with novel interfaces (Caprani et al., 2012; Wilkowska and Ziefle, 2009). Additionally, the aging effects on psychomotor system in humans decrease the accuracy their movements of the arms (Caprani et al., 2012; Cooke et al., 1989; Darling et al., 1989; Geronimi and Gorce, 2009, 2007), and executing the gestures of interaction (*e.g.*, tapping, sliding, pinching) on touchscreen and small devices demands high dexterity of users (Jin et al., 2007; Wacharamanotham, 2011; Wood et al., 2005).

As older populations are a sizable user-group, there is a considerable effort being directed towards developing technologies and interactive systems for older adults. For years, technologies have been developed for this group of users to compensate or prevent age-related disabilities and social losses (Östlund, 2002). However, there are design and evaluation methods that try to better respond to older users' needs. Prototyping, user centered design methods and user testing helps designers to identify and prevent usability problems, improving technologies acceptance, adoption and actual use (Apted et al., 2006; Peek et al., 2014; Piper and Hollan, 2013; Ting and Lewkowicz, 2015). Analyze and understand the difficulties older adults face during tactile interaction is necessary to propose interactive systems and interaction techniques appropriate to their capabilities and skills.

For these reasons, study and improve tactile interaction for older adults is important to increase the usage rates on mobile technologies, reducing the gap across generations on technology use, as well as preventing digital exclusion for aging users in the future.

1.3. Thesis statement and Research Questions

Our vision is that understanding the difficulties older adults find during tactile interaction and improving tactile interaction for older adults is fundamental in allowing older populations to benefit from mobile technologies and increase the adoption and usage rates of technologies among this population.

We suggest the following thesis statement:

Understanding the difficulties older adults face during interaction with touchscreen is necessary to design appropriate tactile interactive systems, taking into account their different users' profiles and abilities.

In order to address this thesis statement, we investigate the following four main Research Questions.

1.3.1. Research Question 1

The first Research Question concerns the delimitation of the problems that need to be addressed.

- What are the factors preventing older adults to use mobile technologies?

In the state-of-the-art (Chapter II, II.1), we review of the literature on Technology Acceptance and Adoption Models (TAMs) for older adults to highlight the factors preventing older adults in using mobile technologies. Then we define how these problems can be addressed through design and evaluation methods.

Additionally, during the design of our interactive system and the experiment for the evaluation of tactile interaction we observe and report errors and difficulties that discourage older adults to use mobile technologies and touchscreen. We classify the errors, identifying their causes, in order to define those that can be addressed by the adaptation of the settings of the interactive systems and those that need to be considered during experimental studies (Chapter III).

1.3.2. Research Question 2

We design a tactile interactive system to be used during the experimental evaluation of tactile interaction of older adults, assessing touch information. Our second Research Question is:

- How to design tactile interactive systems to older adults?

In the state-of-the-art (Chapter II, II.2), we review the main factors to facilitate the participation of older adults in design and evaluation studies. Then, a review of the literature on HCI studies about tactile interaction for older adults provides the basis for defining the design specifications and evaluation methods proposed in this thesis.

The design of the interactive system Puzzle Touch follows an iterative design method, consisted in four steps: understanding and specifying the context of use, specifying user requirements, producing the design solution and evaluating the design (ISO 9241-210, 2010). These procedures are described in Chapter III.

1.3.3. Research Question 3

Older users have different abilities and touchscreen devices are used in different situations. In order to improve the usability of tactile interaction it is necessary to evaluate the effects of different screen sizes and input modalities on interaction performances. Our third Research Question is:

- Which aspects of the use of touchscreen can affect tactile interaction for older users?

The state-of-the-art on the evaluation of tactile interaction for older adults, presented in Chapter II (II.3), identifies the situations of use of touchscreen that have been evaluated so far on HCI studies. We report the findings of these studies about the effects of screen sizes and input modalities and we outline the interaction techniques that were evaluated. We also discuss the methods that were employed to define the user's profiles and measure the interaction performances (time and error rates), according to the tasks that were evaluated. This review helps us to define the specifications for our experimental protocols and the situations of use of touchscreen where usability and accessibility issues should be addressed.

Then, in Chapter IV, we evaluate the effects of screen sizes and input modalities on the accuracy of drag-and-drop interaction for older adults with different profiles. This experimental protocol is implemented to verify which situation of use would be more

suitable for this group of users and which situations are needed to be improved by the design of support techniques.

1.3.4. Research Question 4

Previous studies comparing interaction performances of older adults and adults report that older adults take longer times and make more errors of interaction than adults (Findlater et al., 2011; Hourcade and Berkel, 2006; Kobayashi et al., 2011; N. Schneider et al., 2008). However, the causes of the gap of performances between these two groups of users are still unknown.

One of the reasons of the decrease of performances of older users might be related to the accuracy of the movements. Tactile interaction requires fine motor control and dexterity on the execution of the gestures of interaction (Jin et al., 2007; Wacharamanatham, 2011). In this thesis, we chose to investigate differences in the movements executed during interaction with touchscreen to try to explain the differences in interaction performances. Our fourth Research Question is:

- What are the differences in movements of interaction between older-aged adults and younger adults that are related to their performances?

To answer the question abovementioned, the analysis of the Biomechanics of the movements users execute during interaction with touchscreen should be associated to the HCI evaluation of interaction performances.

The state-of-the-art on Biomechanics, presented (Chapter II, II.4), brings some considerations about the effects of aging on the movements of the arms and provides information to help us to define the tools and specifications for an experimental protocol associating HCI and Biomechanics.

Then, this experimental protocol is implemented and described in Chapter V to evaluate the movements of older-aged adults and adults during the execution of drag-and-drop interaction on touchscreen.

1.4. Methodology

To address the Research Questions presented above, the methodology of this thesis is built in three parts.

First, a review of the literature provides the theoretical basis to conduct this work, delimitating the problems that will be addressed, justifying our methodological choices

such as the specifications for the interactive system, the design and evaluation methods as well as the parameters for the experimental protocols. We selected relevant work from HCI, Human Sciences and Biomechanics embracing all the specificities of older populations.

Secondly, the design of the interactive system Puzzle Touch follows one cycle of an iterative design method in four steps: we specify the context of use, the user's requirements, we produce a design solution and then we evaluate our interactive system. The purpose of this interactive system is to facilitate the inclusion of older adults as participants in the two experimental studies that we implemented thereafter.

Finally, two experimental protocols have been implemented to evaluate the tactile interaction of older adults. The first concerns the evaluation of the appropriateness of drag-and-drop interaction on touchscreen for older adults with different user' profiles (age and experience with technologies) on different situations of use (screen sizes and input modalities). We evaluate time and error rates as well as the accuracy of the gestures during drag-and-drop interaction. Then the second experiment associates HCI and Biomechanics to evaluate the movements of the users, in particular the wrist, during tactile interaction and their interaction performances (time and error rates). To do so, the data registered with the interactive system is synchronized to the data collected through motion tracking systems, registering the user's postures and movements during interaction.

1.5. Organization

The structure of this thesis follows the methodology described in the section I.4. The main steps are interlaced but each chapter has been constructed as a separate, complete section and does not necessarily need to be read in the order presented in this thesis.

Chapter II establishes the theoretical basis of this thesis. Through critical analysis of the state-of-the-art on HCI, Human Sciences and Biomechanics studies related to technology adoption, tactile interaction and analysis of the movements of older adults, we try to understand the reasons and motivations that lead to higher acceptance and adoption of mobile technologies by older adults. Then we present main considerations about the design of interactive systems and experimental protocols for this group of users. Finally, we identify factors that may influence their tactile interaction performances and should be further studied. The goal of this chapter is first, to determine the problems that need to be

addressed, then to define the specifications for an interactive system and, finally, to establish methods for evaluating the tactile interaction of older adults.

Chapter III describes the design of the tactile interactive system Puzzle Touch that is used for assessing touch information during the experiments in order to allow the study of tactile interaction of older adults. This interactive system is consisted of a series of tactile puzzle games.

Chapter IV presents an experimental protocol to study the appropriateness of drag-and-drop interaction on touchscreen for older adults with different user's profiles. The system Puzzle Touch is used to assess the accuracy of the movements of older users on smartphone and tablet, with pen and fingers. We also evaluate the effects of varying the constraints for positioning the targets on the interaction performances of drag-and-drop interaction.

Chapter V presents the second experimental protocol. We associated HCI and Biomechanics to evaluate the movements of the upper limbs of older adults, particularly the wrist, during interaction with touchscreen device. The purpose of this experiment is to try to understand the differences between older adults and adults during the execution of the gesture of interaction drag-and-drop and their consequences on interaction performances.

Chapter VI presents the general conclusion, thesis summary, with the answers provided to the Research Questions, future work and perspectives.

Chapitre 2 : Bases théoriques

Résumé

L'objectif de ce chapitre est d'établir les bases théoriques pour la conception et l'évaluation de l'interaction tactile pour les personnes âgées (système interactif et technique d'interaction). L'état de l'art s'étend sur trois domaines : Interaction Homme-Machine (IHM) pour les méthodes de conception et d'évaluation, Sciences Humaines pour une approche sociologique de l'usage des technologies par les personnes âgées et Biomécanique pour l'analyse des mouvements réalisés par l'utilisateur durant l'exécution des gestes d'interaction.

Dans un premier temps, nous présentons l'état de l'art sur les facteurs qui influencent l'acceptation et l'adoption des technologies par les personnes âgées. Six modèles ont été sélectionnés car ils prennent en compte les particularités des utilisateurs âgés (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Mallenius et al., 2007; Peek et al., 2014; Renaud and Biljon, 2008). Nous avons élaboré une classification des facteurs déterminant l'usage ou le rejet des technologies selon leur nature : les profils des utilisateurs, leur contexte, leur évaluation subjective et les facteurs liés aux propriétés des systèmes interactifs et technologies interactives. Ces derniers peuvent être directement considérés lors de la conception et de l'évaluation des systèmes interactifs afin de favoriser l'adoption des technologies.

Pour prévenir des problèmes d'utilisabilité et d'accessibilité, il est important d'identifier les difficultés d'interaction des utilisateurs âgés dès les premières étapes de conception. Dans cette deuxième section, nous présentons les principales recommandations pour faciliter la participation de personnes âgées lors des séances d'évaluation de systèmes interactifs et techniques d'interaction. Nous essayons de prendre en compte les facteurs liés au contexte et à l'évaluation subjective des utilisateurs afin d'avoir un impact positif sur l'acceptation des technologies.

Ensuite nous avons réalisé un état de l'art sur la conception et l'évaluation des systèmes interactifs et techniques d'interaction sur écran tactile pour des personnes âgées. 36 études publiées entre 2000 et 2013 ont été retenues. Suite à l'analyse des caractéristiques des populations étudiées, des tâches exécutées, du matériel utilisé, des modalités de saisie, des retours de l'interaction et des critères d'évaluation, nous déterminons les spécifications pour la conception d'un système interactif et les méthodes d'évaluation de l'interaction tactile. Ces études reportent des effets de taille d'écran

(Kobayashi et al., 2011), *de modalité d'interaction* (Hourcade and Berkel, 2006) *et de gestes d'interaction* (Harada et al., 2013; Leitao and Silva, 2013; Lopicard and Vigouroux, 2010a) *sur les performances des utilisateurs. Les études comparant les performances d'utilisateurs de différents groupes d'âge démontrent que les personnes âgées font souvent plus d'erreurs avec des temps d'interaction plus longs que les utilisateurs plus jeunes* (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006). *Cependant, un contact continu sur l'écran permet d'augmenter la précision du geste d'interaction* (Mertens and Jochems, 2010; Wacharamanotham, 2011) *et réduire les effets de l'âge sur les performances* (Stöbel et al., 2010). *Notre recherche portera sur la facilité d'apprentissage du drag-and-drop tactile (glisser et déposer).*

Les méthodes de conception et d'évaluation en IHM permettent d'analyser l'interaction tactile afin de proposer des systèmes interactifs plus appropriés aux utilisateurs âgés. Par contre, l'exécution des gestes d'interaction demande une dextérité fine (Jin et al., 2007; Nicolau and Jorge, 2012; Wacharamanotham, 2011) *et les effets d'âge sur les mouvements d'interaction ont été peu étudiés. Il est donc nécessaire de compléter l'évaluation des performances d'interaction par une analyse du mouvement lié au geste d'interaction.*

La quatrième section présente l'état de l'art des études en Biomécanique démontrant les effets de l'âge sur les mouvements des membres supérieurs (Cooke et al., 1989; Darling et al., 1989; Geronimi and Gorce, 2007) *et leur répercussion sur les mouvements d'interaction* (Lopicard and Vigouroux, 2012; Walker et al., 1997). *Ensuite, nous avons identifié dix études évaluant les postures et mouvements d'utilisateurs adultes durant l'utilisation d'écrans tactiles* (Irwin and Sesto, 2012; Irwin et al., 2011; Kim et al., 2014, 2013; Pereira et al., 2013; Sesto et al., 2012; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2013, 2012). *A partir de l'analyse des paramètres de ces études, nous avons identifié les articulations impliquées dans le geste d'interaction tactile et défini un protocole expérimental associant IHM et Biomécanique. Le poignet qui est particulièrement sollicité lors de l'interaction tactile* (Werth and Babski-Reeves, 2014; Young et al., 2013) *est affecté par des contraintes sensorimotrices liées au vieillissement humain* (Laursen et al., 2001; Wright et al., 2011). *Pour cette raison, cette articulation a été choisie en tant qu'objet d'analyse de notre étude afin d'élucider les causes des différentes performances d'interaction entre les personnes âgées et adultes.*

II. Theoretical basis

The aim of this chapter is to establish the theoretical basis for the design and evaluation of tactile interaction for older adults. The state-of-the-art includes studies from three main research fields: Human-Computer Interaction (HCI) for the design and evaluation methods, Human Sciences for a sociological approach of the factors influencing the use of technologies by older adults, and Biomechanics, for the analysis of the movements of the user during the execution of the gestures of interaction.

Aiming to give rise to fundamental concepts in our research and better understanding the state-of-the-art in the domain, we defined four main Research Questions that guide this thesis (I.3, p. 24). By eliciting current problems in the research domain, previous works drive the design requirements for interactive systems for older adults and experimental protocols for evaluating tactile interaction of this group of users. In this chapter, we present the review of the literature concerning:

- 1) Factors that influence the acceptance and adoption of technologies by older adults.
- 2) Recommendations that facilitate the design of interactive systems for older adults.
- 3) The design and evaluation of tactile interaction for older users from Human-Computer Interaction (HCI) studies.
- 4) Biomechanics studies that evaluates aging effects on the movements of the users hindering the execution of the gestures of interaction on touchscreen.

For each concern mentioned above, our goal to review the literature includes:

- 1) Identifying potential barriers that can hinder the use of touchscreen in mobile devices for older adults. These barriers must be addressed in the design of adapted interactive systems;
- 2) Defining the specifications of an interactive system to assess interaction information on touchscreen devices. Such specifications aim at facilitating the inclusion of older participants in the design evaluation sessions and usability testing with older users ;
- 3) Establishing the parameters and specifications for evaluating the usability levels of tactile interaction and the experimental protocols implemented during this thesis (Chapters III, IV and V);
- 4) Determining the parameters and methods to evaluate the effects of aging on tactile interaction performance.

II.1. *Factors of acceptance and adoption of technologies by older adults*

Acceptance, according to Chen and Chan (2011), is “an attitude towards a certain behavior, that is, the individual’s positive or negative feeling or appraisal about the behavior and the degree to which this affects the behavior, and the usage behavior itself” (Chen and Chan, 2011). Acceptance can be interpreted as a subjective evaluation of a person deciding about performing or not a behavior (in the context of this thesis work, using an interactive technology); or the intention before a given action. Renaud and Biljon (2008) define acceptance as an “attitude towards a technology” (Renaud and Biljon, 2008), referring to the beginning of the adoption process. Adoption is a process that starts “with the user becoming aware of the technology” and ends “with the user embracing the technology and making full use of it” (Renaud and Biljon, 2008).

Reerink-Boulangier (2010) described an exhaustive review of behavioral theories of use of technologies by older users (Reerink-Boulangier, 2012). Several authors evaluated factors that could predict acceptance and adoption of interactive technologies based on the Technology Acceptance Model (TAM) proposed by Davis (1989) (Davis, 1989). This TAM model defines two main factors of acceptance:

- **Perceived Usefulness** indicating “the degree to which a person believes that using a particular system would enhance his or her job performance”, and
- **Perceived Ease of Use** referring to “the degree to which a person believes that using a particular system would be free of effort”.

These two factors defined above are based on a subjective evaluation of a given individual user (*i.e.*, an individual approach). Regarding elderly populations, some authors extended the TAM model to also take into account the users’ individual characteristics, such as previous experience with technology and the users’ contexts, from a sociological perspective.

In our literature analysis, we reviewed six models regarding technology acceptance and adoption. These models define the use of technologies by older adults regarding potential factors that influence, predict or determine the use of interactive technologies by this population of older adults (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Mallenius et al., 2007; Peek et al., 2014; Renaud and Biljon, 2008). Among the studies we selected, three of them evaluated potential influencing factors that could aid to predict the use of mobile phones; interviews and questionnaires

were employed for data collection (Conci et al., 2009; Mallenius et al., 2007; Renaud and Biljon, 2008). Two of the studies we analyzed report the results of systematic reviews of TAM's for general purposes or interactive technologies for aging in place (Lee and Coughlin, 2014; Peek et al., 2014). Barnard *et al.* (2013) conducted two case studies to investigate the how older adults learn to use tablet devices. Their study proposes two complementary models of acceptance: one from the perspective of the users and another related to the features and characteristics of the system and technologies (Barnard et al., 2013).

The factors of acceptance and adoption of technologies by older adults presented in the six studies analyzed in our literature review concern different influencing aspects, which range from the characteristics of the users and technologies to the availability of technical support. We propose the following classification for the factors presented in the six reviewed models:

- users' profiles,
- users' context,
- users' subjective evaluation
- features and properties of systems and technologies.

Table II.1 summarizes the factors related to the acceptance and adoption of interactive technologies by older adults according to our proposed classification. All factors presented in Table II.1 are described on the sequence, followed by a discussion for each category.

Table II.1 Factors determining the use of technologies for older adults

	TAM factors	Mallenius <i>et al.</i> (2007)	Renaud & Biljon (2008)	Conci <i>et al.</i> (2009)	Barnard <i>et al.</i> (2013)	Lee & Coughlin (2014)	Peek <i>et al.</i> (2014)
Users' profiles	Attitude towards learning				✓		
	Experience of using interactive technologies	✓				✓	
	Personal characteristics		✓				✓
	Self-actualization			✓			
	Independence					✓	
	Affection					✓	
	Confidence					✓	
Users' context	Social influence	✓	✓	✓	✓	✓	✓
	Support	✓		✓	✓	✓	
	Lack of facilitating conditions	✓				✓	✓
	Alternative to technology						✓
Subjective evaluation	Perceived usefulness		✓	✓	✓	✓	✓
	Perceived ease of use			✓	✓		✓
	Perceived self-efficacy				✓		
	Perceived safety	✓		✓			
	Perceived need						✓
	Expected benefits	✓				✓	✓
	Enjoyment			✓			
	Intention of use		✓	✓			
Systems and technologies	Usability	✓				✓	
	Ease of learning and use		✓				
	Transparency				✓		
	Feedback				✓		
	Error recovery				✓		
	First impressions		✓				
	Learnability	✓					✓
	Confirmed usefulness		✓				
	Actual use		✓				✓

II.1.1. *Predictors related to the user's profiles*

In the models previously proposed and analyzed, the authors included different user's characteristics as predictors of acceptance and adoption of interactive technologies. According to our classification (Table II.1), seven main factors related to the user's profiles have been identified:

- **Attitude towards learning** is related to the users' prior experiences on learning and the subjective evaluation of their own ability to learn new things (Barnard et al., 2013).
- **Experience of using interactive technologies** refers to the previous knowledge of a system or technologies and the familiarity with the task (Lee and Coughlin, 2014). Mallenius *et al.* (2007) pointed out that unknown systems and activities tend to create anxiety (Mallenius et al., 2007).
- **Personal characteristics** as discussed by Peek *et al.* (2014) include users' age, gender, health conditions and level of education. In their proposed model, the personal characteristics are directly related to the desire of aging in place, their cultural background, familiarity with technologies and current living options (Peek et al., 2014). Renaud and Biljon (2008) regrouped demographic and personal characteristics in **User context**. In their study, they discuss the effects of aging on visual acuity and manual dexterity as well as the difficulties older adults have to learn how to use a new interactive technology (Renaud and Biljon, 2008).
- **Self-actualization** refers to the personal aptitude for learning new ideas and skills (Conci et al., 2009). **Self-actualization** has been defined as the highest level on Maslow's hierarchy of needs (Thielke et al., 2012), which means that once a person uses a technology for **Self-actualization needs** all the inferior levels needs are fulfilled and the user can reach a greater level of satisfaction. However, self-actualization needs are difficult to meet because they are highly personalized and depend on the individual's objectives. To address these needs, systems and technologies should be designed to go beyond functionality and elicit users' emotional responses as well (Barnard et al., 2013).
- **Independence** refers to the psychological need of feeling independent. Lee and Coughlin (2014) report the desire of older adults to keep their autonomy despite the aging effects on their physical skills and health conditions (Lee and Coughlin, 2014). For the same reason, technologies should prevent stigmatization (Lee and Coughlin, 2014).
- **Affection** or **Emotion** is related to the fear of loneliness and the decrease of interpersonal relationships. According to Lee and Coughlin (2014), older adults might try to compensate the decrease of mobility and lack of social activities by the use of interactive technologies that could aid them to keep in touch with other persons, besides sharing their memories and thoughts (Lee and Coughlin, 2014).
- **Confidence** is related to how the user feels when using interactive technologies. This factor is under influence of prior experiences and personal characteristics of a given user. Previous research shows that interactive systems that provide

navigation directions and error prevention can help to lower intimidation and anxiety in older users (Lee and Coughlin, 2014).

As previously mentioned, older adults consist of a heterogeneous population. Therefore, chronological age is not enough to describe the characteristics of older adults because Aging is also an individual process (Östlund, 2002), leading to diverse outcomes. In addition to the physical and cognitive declines related to age, early-life experiences affect older adults' perceptions of their own ability to use new interactive technologies. The studies we reviewed in this thesis take into account the individual changes related specifically to aging (**Personal characteristics**) as well as the users' individual needs (**Independence** and **Affection**), personalities (**Confidence**) and personal histories (**Experience of using interactive technologies**). As Barnard *et al.* (2013) discussed, older adults who did not learn how to use a computer during their professional carrier or education need more training to progress and feel confident when compared to younger adults (Barnard et al., 2013).

II.1.2. Predictors related to the user's context

According to the classification we propose (Table II.1), four main factors are related to the users' contexts and environments:

- **Social influence** generally refers to the influence of relatives and peers on the use of technologies, promoting the benefits of technologies inside a group of users (Barnard et al., 2013; Conci et al., 2009; Peek et al., 2014). Advice from medical professionals and home care workers are also valuable for older adults (Mallenius et al., 2007). These definitions can be presented as **User context** (Renaud and Biljon, 2008) or even **Social Support** (Lee and Coughlin, 2014).
- **Support** or **Technical support** refers to the help provided by other people so users can overcome barriers and difficulties for using technologies (*e.g.*, help for purchasing, installing, learning, operating and maintenance) (Conci et al., 2009; Lee and Coughlin, 2014). It can also be defined as **Training and Guidance** (Mallenius et al., 2007).
- **Lack of facilitating conditions** or **Barriers to use** include several concerns about technologies such as cost, affordability, awareness, availability in the market, difficulties during the registration to the services (*e.g.*, telecommunication operators), privacy implications and lack infra-structure (Lee and Coughlin, 2014; Mallenius et al., 2007; Peek et al., 2014). **Support** can be included as a factor of facilitating conditions (Barnard et al., 2013).
- **Alternative to technology** is related to the satisfaction with current technology or even the availability of help of other people, *e.g.*, spouse or caregivers (Peek et al., 2014).

Social influence is presented in all TAM models as a determining factor of use of technologies by older adults (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Mallenius et al., 2007; Peek et al., 2014; Renaud and Biljon, 2008). As Conci *et al.* (2009) pointed out, even if this factor is not directly related to the features of interactive systems and technologies (*i.e.*, extrinsic motivation), social influence can be remarkably motivating for older adults (Conci et al., 2009).

Technical support is presented as determining predictor in four models (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Mallenius et al., 2007). Help for users installing or operating interactive technologies can be provided by peers (Lee and Coughlin, 2014; Mallenius et al., 2007), written documentation (Barnard et al., 2013; Lee and Coughlin, 2014), call centers (Mallenius et al., 2007) or workshops (Conci et al., 2009). Authors did not mention the possibility of contextual help and guidance available on the system itself (*e.g.*, help button, illustrated help, videos) (Ribeiro and Barros, 2014).

II.1.3. Predictors related to the users' subjective evaluation

In the classification we propose (Table II.1), we consider eight factors related to the user's subjective evaluation:

- **Perceived usefulness**, as originally defined in the TAM proposed by Davis (1989), has been included in five models (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Peek et al., 2014; Renaud and Biljon, 2008).
- **Perceived ease of use** has been included in three models (Barnard et al., 2013; Conci et al., 2009; Peek et al., 2014). This factor is also referred as **Perceived difficulty** (Barnard et al., 2013).
- **Perceived self-efficacy** refers to how the user experiences learning new tasks and the users' subjective evaluation of their own ability of using a given technology without help (Barnard et al., 2013). According to Barnard *et al.* (2013), self-efficacy is based on individual experiences (**Experience of using interactive technologies**) (Barnard et al., 2013).
- **Perceived safety** refers to the human feeling of protection (Conci et al., 2009). This factor can be related to the possibility of asking for help (*e.g.*, through an emergency button) but Mallenius *et al.* (2007) report that older adults also appreciate being reachable (Mallenius et al., 2007), so communication features are valuable to this group of users.
- **Perceived need**, concerning mostly technologies for aging in place, is related to the subjective evaluation of the individual users about their own health status (Peek et al., 2014).
- **Expected benefits** is defined as the expected usefulness and utility of interactive technologies, including the increase in older adults' feelings of safety and

independence (Peek et al., 2014). Lee and Coughlin (2014) defined as **Emotion** the perception of emotional and psychological benefits and **Value** the perceived usefulness and potential benefits (Lee and Coughlin, 2014). Among the **Expected benefits**, users refers to communication features, access to services and medical assistance (Mallenius et al., 2007).

- **Enjoyment** is defined as an intrinsic motivation for older adults, referring to the perception of the use of technologies as pleasant. Conci *et al.* (2009) have demonstrated that enjoyment affects positively **Perceived usefulness** and **Perceived Ease of use** (Conci et al., 2009).
- **Intention of use** is under the influence of **Perceived Usefulness** and the **User context** according to Renaud and Biljon (2008) (Renaud and Biljon, 2008). In the model proposed by Conci *et al.* (2009), this factor is referred as **Behavioral Intention** and it is under the influence of intrinsic (*e.g.*, self-actualization) and extrinsic (*e.g.*, social influence) motivations for older adults (Conci et al., 2009).

These factors are closely linked and have mutual influences. For example, **Enjoyment** can have a positive impact on the **Perceived usefulness** and **Perceived ease of use** (Conci et al., 2009). Similarly, **Perceived usefulness** can positively influence the **Intention of use** (Renaud and Biljon, 2008).

Moreover, factors predicting the acceptance of interactive technologies that are related to the users' profiles or context influence users' subjective evaluation. Concerning the user's profiles, people with positive attitudes to learning will have a better perception of ease to use and usefulness (Barnard et al., 2013). Confidence positively affects perceived benefits (Lee and Coughlin, 2014). Analogously, health conditions can influence perceived needs and expected benefits (Mallenius et al., 2007; Peek et al., 2014). Concerning the user's context, social influence affects significantly the intention to use and the expected benefits (Conci et al., 2009; Lee and Coughlin, 2014; Peek et al., 2014). When purchasing and using interactive technologies, older adults may seek for the approval of their behavior by their entourage (Lee and Coughlin, 2014). Support and training can be designed to enhance user confidence (Lee and Coughlin, 2014), reducing anxiety during the first experiences of use of interactive systems and positively influencing users' subjective evaluation (Conci et al., 2009; Lee and Coughlin, 2014).

According to Peek *et al.* (2014), factors related to the users' subjective evaluation, their profiles and contexts can fluctuate during pre and post implementation phases (Peek et al., 2014).

II.1.4. Predictors related to systems and technologies

The following factors have been grouped because of their relation to the intrinsic features and properties of interactive technologies and systems. In the classification we propose (Table II.1), predictors related to systems and technologies include nine main factors, described as follows:

- **Usability** in the reviewed studies is related to the presence of features to satisfy basic user requirements and the adaptation of the available features to the users' needs (Mallenius et al., 2007). Usability comprises ease of use, intuitive interaction, simplified interfaces and error prevention (Lee and Coughlin, 2014).
- **Ease of learning and use** refers to how the users conclude their first experiences with an interactive technology. The first experiences can be decisive to the users because users confront their expectations concerning the characteristics of the systems and technologies (Renaud and Biljon, 2008).
- **Transparency** refers to the features that help the users to understand the interaction possibilities available in an interactive system (Barnard et al., 2013). Transparency is also important to facilitate the appropriation process, so users can optimize their actions to accomplish tasks more effectively (Dourish, 2003).
- **Feedback** is giving the users enough information so they can understand the effects of their actions in the interactive system, in order to optimize the users' performances (Barnard et al., 2013).
- **Error recovery** means the system is able to recover itself or to guide the user through the recovering steps (Barnard et al., 2013) (*e.g.*, dialog boxes informing the causes of the errors, menu options for undo or recover).
- **First impressions** refer to the perception of the ease of use and the features the users are able to use during their first experience with an interactive technology. This factor is also defined as **Experimentation and Exploration** (Renaud and Biljon, 2008).
- **Learnability** refers to what the user needs to learn before using the system. Barnard *et al.* (2013) referred to this factor as **Affordance** (Barnard et al., 2013). Changing functions, dynamic menus and lack of consistency can be troublesome for older adults because they need to learn new interactions, increasing the cognitive workload (Lee and Coughlin, 2014; Mallenius et al., 2007). Additionally, in case of casual use, the interaction should also be ease to remember (Peek et al., 2014). Learnability concerns one of the five attributes of **Usability** as defined by Nielsen (1993) (Nielsen, 1993).
- **Confirmed usefulness** refers to the features the user is able to learn and use (Renaud and Biljon, 2008).
- **Actual use** refers to the process of adoption, interaction with the system and even the users' adapting the system to better respond to their needs. Once the users are able to use the features they discovered, the technology will play a role in the users' lives (Renaud and Biljon, 2008). Actual use concerns the

appropriation of an interactive technology for long term use (Peek et al., 2014).

Regrouping and defining these factors is relevant because they demonstrate that the features of systems and technologies can influence acceptance and adoption of technologies.

Renaud and Biljon (2008) and Barnard *et al.* (2013) affirm that the ease of learn and use is determining during the first experiences with technologies (Barnard et al., 2013; Renaud and Biljon, 2008). According to Barnard *et al.* (2013), **Usability**, **Ease of learning and use** and **Error recovery** should be priority when designing interactive systems and technologies to older adults in order to positively influence acceptance and adoption of technologies (Barnard et al., 2013). Besides, **Learnability**, **Confirmed usefulness**, **Transparency**, **Feedback** and **Actual use** can be addressed to improve the use of technologies by older users for longer times (Peek et al., 2014).

II.1.5. *Summary*

Our analysis of the factors predicting the use or the rejection of technologies by older adults demonstrates that the acceptance and adoption are under the influence of the users' profiles, their contexts, their subjective evaluations and also the features of systems and technologies. The first goal of our proposed classification was to define the factors that can be taken into account for the design of interactive systems destined to older adults. When designing the tactile interactive system that we use for assessing touch information in our experimental studies, usability, ease of learning and use, error recovering are fundamental to enhance users acceptance of interactive technologies.

The main contribution of the proposed classification lays on regrouping the factors related to systems and technologies. Through this analysis, we partially addressed our Research Question 1. Indeed, among several factors influencing use of technologies, usability problems older adults find when interacting with tactile interactive systems may be preventing them to accept and adopt mobile technologies. Through this analysis, designers and developers can contribute to directly affect user's acceptance and adoption of mobile technologies by improving usability and ease of use of tactile interaction, appropriately adapting the parameters of the interactive systems to the users' skills and special needs.

We also discussed that the proposed categories of factors have mutual influence. Factors of acceptance and adoption related to the users' subjective evaluation are under

the influence of the users' personal characteristics (*e.g.*, their attitude towards learning, their experience of using interactive technologies, and their confidence), as well as their context (*e.g.*, social influence, support, facilitating conditions). Designing interactive systems that seem familiar (regarding their perceived ease of use) could lead to more positive attitudes towards learning interaction. Activities that encourage users to accomplish an interactive task (*e.g.*, a game) could improve the users' confidence (*i.e.*, perceived self-efficacy). Analogously, systems that are pleasant to learn and use (*i.e.*, enjoyment) could positively impact the perceived usefulness of interactive technologies. Additionally some factors of the users' context can be considered to positively influence technology use. Creating social interaction allows novices and experienced users to share their knowledges and impressions. Facilitating the access to devices and providing support for learning and operating interactive technologies is also helpful for older users.

As we discussed, older adults consist a heterogeneous group of users. When designing interactive systems and interaction techniques to older populations, the variability of user's profiles and personal characteristics should not be neglected. In the next section, we review and describe main concerns for designing and evaluating interaction addressing to the diversity of older adults special needs and expectations.

II.2. *Designing for older adults*

Fisk *et al.* (2009) affirms that when older people have difficulties interacting with systems and technologies, “more often than not the root of the problem lies in the design process rather than with the user.” (Fisk *et al.*, 2009)

As a matter of fact, older adults as a user-group have been commonly classified according to the formal age for retirement; however there is great diversity among this population in terms of effective skills, socio-economic situations and health conditions. For years, the needs of older people in terms of technology use have been generally interpreted as compensation for age-related functional limitations and social losses (Östlund, 2002). According to Lee and Coughlin (2014), one of the causes of the low technology acceptance by the elderly is “due to insufficient understanding or stereotyping of the target segment’s characteristics, expectations, and needs” (Lee and Coughlin, 2014).

In the first section of this chapter (II.1), we defined factors of acceptance and adoption of technologies by older adults that are related to features and properties of interactive systems. When designing for older users, the usability problems should be identified at the initial phases of design and development to allow adequate adaptations and solutions.

HCI provides methods and tools for designing and evaluating interaction and preventing usability problems. One possible solution is the participation of potential users since the early stages of the process, through design sessions, usability testing and experimental protocols. According to Nielsen (1993), user-centered design (UCD) evaluates users’ profiles in order to define “their behaviors of use of and preferences for various aspects of a given application, and using that information to then make design decisions” (Nielsen, 1993; Williams, 2009).

However, for our research, we would like to outline two particular characteristics of older adults as a user group. The first is the evolution of their characteristics through time. The second concern the difficulty for involving older adults in design and evaluation sessions.

Concerning their characteristics, older adults from different cultures and backgrounds have different experiences and attitudes towards technologies. Moreover, health conditions and special needs also evolve through time, they can be temporary or degenerative. For this reason, Gregor *et al.* (2002) discuss about the “dynamic diversity”

of older users and propose a “user sensitive inclusive design” as a method of design for better suiting the needs and requirements of older users. They affirm that in order to better address the usability issues of older adults it is important to involve representative users during the design process and evaluate interaction through experimental studies.

Fisk *et al.* (2009) highlight the enriching experience of including older adults as participants of the design process (Fisk et al., 2009). They describe the following four principles of design to take into consideration when designing to older people:

- 1) Early focus on the user and the tasks the user will be performing
- 2) Empirical measurement using questionnaires and surveys as well as usability testing studies that rely on observations and quantitative or qualitative data
- 3) Iterative design and testing
- 4) Integrated design, wherein all aspects of the usability design process evolve in parallel and are generally under the coordination of a single person.

Williams (2009) describes the process for designing web applications on three phases:

- **Design research:** when the designer assess the users’ profiles and their needs
- **Design:** the application of the research findings to build a version of the system
- **Design evaluation:** to test and revise the usability of the design with target users.

According to the ISO 9241-210, Human-centered development usually follows four steps (ISO 9241-210, 2010):

- a) Understanding and specifying the context of use
- b) Specifying the user requirements
- c) Producing design solutions
- d) Evaluating the design.

Concerning the difficulties to get older adults involved to the design and evaluation process, there are some recommendations previously proposed in the literature that aim to facilitate the participation of this group of users in design evaluation sessions and experimental protocols. Eisma *et al.* (2004) recommend social activities so participants can feel more comfortable (Eisma et al., 2004). Dickinson *et al.* (2007) also discuss about the difficulty of recruiting older adults and recommend clear written documentation, clear instructions for the task, flexible scheduling because older users can

take longer times and propose breaks to avoid fatigue (Dickinson et al., 2007). Problems of mobility and duration of the experiment can also be seen as barriers for involving older participants on experimental studies.

Fisk *et al.* (2009) pointed out that it is important to ensure the participants are representative of the target population (Fisk et al., 2009). To do so, they suggest defining inclusion criteria and protocols for assessing these criteria (*e.g.*, distinguishing groups of age, educational levels, assessing previous experience of using a particular interactive system or technology), choosing standardized instruments for aging populations (*e.g.*, tests for eye sight, cognitive or motor control) and pilot testing the protocols (*e.g.*, informal tests to verify the instructions and procedures). Besides this, they also recommend humanizing the evaluation session, *i.e.*, execute the tests in a stress-free environment, with optimal conditions (*i.e.*, easy to access, quiet place), use familiar vocabulary and materials and give sufficient time to the participants to respond.

For these reasons, authors agree that it is important to choose the recruitment strategies carefully (Dickinson et al., 2007; Eisma et al., 2004; Fisk et al., 2009).

II.2.1. *Summary*

In order to improve usability of interactive systems, it is important to take into account the variability of the users' profiles, previous experiences with technologies and special needs. Our analysis of this review partially addresses our Research Question 2 concerning the design of an interactive system for older adults. We reviewed design methods and recommendations for involving older users since the early stages of design and evaluation of interactive systems. These methods are fundamental to identify and prevent usability problems on interactive systems and technologies destined to this group of users.

However, recruiting older participants and engaging them to the activities can be challenging. To overcome this challenge, factors influencing acceptance of technologies related to the context of the users could be used to facilitate the participation of older adults during design and evaluation sessions. As discussed in the previous section (II.1), social influence, support and facilitating conditions could help to improve technology acceptance. Moreover, the nature of the activity proposed to the participants could also have a positive influence on their subjective evaluation: if they enjoy the interaction and are able to accomplish the task, this could influence the way they perceive the usefulness and the ease of use of technologies. By consequence, we argue that for promoting the use

of technologies among older populations it is necessary to consider the factors that are not directly related to the systems and technologies but can create a favorable environment and bring positive attitudes, especially during their first experiences of use.

In view of the foregoing analysis, we propose some recommendations for designers and researchers in order to facilitate the participation of older adults during design evaluation and experiment protocols. Table II.2 summarizes these recommendations according to our classification of factors influencing the use of technologies. We consider these recommendations for the design of our interactive system as well as during the experimental studies in order to promote a positive attitude of older adults towards touchscreen devices and tactile interaction.

Table II.2 Recommendations for including older participants during the design and evaluation of interactive systems, interaction techniques and experimental studies in order to promote the use of technologies

Factors	Recommendations
Users' profiles	<ol style="list-style-type: none"> 1. Respect differences in users' profiles, addressing novice and experienced users 2. Support interaction for users with special needs 3. Include representative users 4. Assess users' profiles through pre experiment tests and questionnaires
Users' context	<ol style="list-style-type: none"> 5. Design to the different situations of use and mobile devices 6. Promote social activities using touchscreen devices 7. Group sessions and demonstration meetings can facilitate the recruitment of participants 8. When possible, the experiment should take place in a familiar environment 9. Propose a short time activity, respect users' schedule
Subjective evaluation	<ol style="list-style-type: none"> 10. Interaction should be easy to learn and use 11. Enjoyment and pleasant activities influence perceived usefulness 12. Make clear to the participants that the system and the techniques are being evaluated, not their skills 13. Assess users' preferences and fatigue 14. Make instructions clear and easy to understand 15. Explain the procedures and the objectives of design and evaluation 16. Thank participants for their time and feedback
System and technologies	<ol style="list-style-type: none"> 17. Follow existing accessibility guidelines and recommendations 18. Follow usability requirements 19. Design intuitive interactions 20. Provide sufficient feedback 21. Identify errors and difficulties to propose adequate solution according to the users different skills and special needs 22. Adapt interaction to enhance ergonomics 23. Provide a support for interaction for users with different profiles

II.3. *Tactile interaction for older adults*

In section II.1.5, the analysis of factors influencing the use of technologies has showed that usability problems of interactive technologies can have a negative impact on acceptance and adoption of technologies by older adults. In order to improve the usability of interactive systems and interaction techniques on touchscreen, tactile interaction should be appropriately designed and evaluated. In order to find elements to address our Research Question 3, in this section, we review HCI studies on design and evaluation of tactile interaction for older adults.

II.3.1. *Design and evaluation of interactive systems and interaction techniques*

We made a systematic review on studies evaluating interaction of older adults with touchscreens. We selected 36 studies published between 2000 and 2013 on scientific journals and peer-reviewed conferences from HCI and also from ergonomics, healthcare and computer science research (such as ACM CHI, Int. Journal of HCI, BCS-HCI, INTERACT, Gestures Workshop, Universal Access on HCI, ACM Transactions on Accessible Computing, Universal Access on the Information Society, Journal of Applied Gerontology, Ergonomics, Human factors and Ergonomics Society, USAB, Engineering of Interaction on Computer Science).

In our review, we try to identify the characteristics of the studied populations, the procedures of the studies (touchscreen devices and tasks), the interaction techniques that were designed and investigated and the evaluation criteria employed in the studies analyzed. Additionally, we search for the aspects of the situations of the studies that could interfere on interaction performances, the errors of interaction that have been reported and the solutions that have been proposed by the studies' authors.

II.3.1.1 *Populations*

The studies reviewed included three to 85 older adults as participants aged from 50 to 94 years old.

14 studies only had older participants (Gonçalves and Ueyama, 2012; Harada et al., 2013; Hwangbo et al., 2013; Jin et al., 2007; Kobayashi et al., 2011; J. Lee et al., 2009; Leitao and Silva, 2013; Leonard et al., 2005; Mertens and Jochems, 2010; Nicolau and Jorge, 2012; Tsai and Lee, 2009; Umemuro, 2004; Wacharamanotham, 2011; Wood et al., 2005). The other studies compared different age groups.

According to the studies comparing older and younger users, age is a significant predictor of performance. Usually, older adults took longer times for completing the tasks and made more errors than younger participants (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006; Kobayashi et al., 2011). Authors who assessed participants' skills before the experiments demonstrated that manual dexterity (Jin et al., 2007), visual impairment (Leonard et al., 2005) or attention and concentration capabilities (Tsai and Lee, 2009) are also predictors of performance.

Users' skills have been measured by means of self-report or evaluation methods. Sometimes, these measures were used to determine inclusion or exclusion criteria (*e.g.*, users with low dexterity or visual impairments are not included as participants). Table II.3 summarizes subjects' skills assessed before the experiments, assessment tests and inclusion criteria.

The incidence of sensory, cognitive or motor impairments increases with ageing (Caprani et al., 2012). Even though, most of the studies we analyzed (18) included only able-bodied older adults.

Table II.3 HCI studies: Subjects' skills assessed for the experiments, assessment tests and inclusion criteria in the studies analyzed

Assessed skills	Pre-experiment tests	Inclusion criteria
Sensorial skills	Six studies assessed visual acuity. Eight studies assessed auditory skills; four of them provided audio feedback. Visual or hearing acuity were assessed through tests (Charness et al., 2004; Leonard et al., 2005) or participants were just questioned about it.	One included visually impaired subjects (age-related macular degeneration – AMD) (Leonard et al., 2005). Two studies included users wearing hearing aids
Cognitive skills	Ten studies assessed cognitive skills. Attention and concentration capabilities were assessed through computer assisted tests or standardized measures (Charness et al., 2004; Jastrzembski et al., 2005; Rogers et al., 2005; Tsai and Lee, 2009; Wood et al., 2005; Wright et al., 2000).	One study included users with low levels of attention and concentration (Tsai and Lee, 2009).
Dexterity or motor skills:	Fourteen studies assessed motor skills or manual dexterity. Different tests have been used: Purdue Pegboard test, Grooved Pegboard test or paper folding test for manual dexterity (Jin et al., 2007; Leonardi et al., 2010; Moffatt and McGrenere, 2007; Wood et al., 2005), Digit Symbol Substitution for speed (Moffatt and McGrenere,	Two studies included users with tremor (Mertens and Jochems, 2010; Wacharamanotham, 2011) and others three grouped users with lower manual dexterity according to the results of pre-experiment tests (Jin et al., 2007; Nicolau and Jorge, 2012; Wright et al., 2000).

	<p>2007), Operations on calculators were used to measure keyboard dexterity (Wright et al., 2000).</p> <p>Archimedes spiral drawing (Nicolau and Jorge, 2012; Wacharamanotham, 2011), accelerometers (Wacharamanotham, 2011) or Nine holes steadiness test were used to measure tremor (Moffatt and McGrenere, 2007; Wacharamanotham, 2011).</p>	
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The different performances of participants during interaction with technologies can also be related to the user’s background. Sixteen authors questioned the participants about their personal history, including attitudes towards technologies, health conditions, levels of education and reading skills.

Previous experience with computers, Internet, mobile phones or touchscreen devices was considered as a factor influencing the performances of older users for several studies (e.g., (M. K. Chung et al., 2010; Findlater et al., 2013; Kobayashi et al., 2011; Stöbel, 2009)). Table II.4 shows the studies in which users were questioned about their previous experience with information and communication technologies (ICTs) and interactive technologies. In five of these studies, previous experience with technologies was as criteria for inclusion or exclusion of participants (Kobayashi et al., 2011; Leonard et al., 2005; Nicole Schneider et al., 2008; Stöbel et al., 2010; Wood et al., 2005). This information was assessed by self-report, interview or standardized questionnaires (Nicole Schneider et al., 2008).

Table II.4 HCI studies: Users’ previous experience with ICTs and interactive technologies and the inclusion criteria adopted in the studies analyzed

Kind of technologies	Assessment of users’ previous experience with technologies	Experienced subjects included on the study
Computers	6 studies (Findlater et al., 2013; Kobayashi et al., 2011; Leonard et al., 2005; Nicole Schneider et al., 2008; Stöbel et al., 2010; Wood et al., 2005)	5 studies (Kobayashi et al., 2011; Leonard et al., 2005; Nicole Schneider et al., 2008; Stöbel et al., 2010; Wood et al., 2005)
Mobile phones	5 studies (Harada et al., 2013; Kobayashi et al., 2011; J. Lee et al., 2009; Leonard et al., 2005; Umemuro, 2004)	3 studies (Harada et al., 2013; Kobayashi et al., 2011; J. Lee et al., 2009)
Touchscreen	4 studies (M. K. Chung et al., 2010; Findlater et al., 2013; Harada et al., 2013; Kobayashi et al., 2011)	3 studies (Findlater et al., 2013; Harada et al., 2013; Kobayashi et al., 2011)

Discussion about the populations in the studies analyzed

The reviewed studies included older adults with different skills and experiences. For the design of interactive systems and evaluation studies, it is important to include representative users and consider the variability in their profiles. Older adults have different background, health conditions, levels of education, previous experience with technologies, as well as attitudes towards computers. Pre-experiment tests and questionnaires might be used to assess information that could be useful to further understand the participants' different performances.

Eight studies included users with previous experience in using computers, mobile phones or touchscreen devices (Findlater et al., 2013; Harada et al., 2013; Kobayashi et al., 2011; Leonard et al., 2005; Lepicard and Vigouroux, 2009; Nicole Schneider et al., 2008; Stöbel et al., 2010; Wood et al., 2005). The reason for the exclusion of participants with previous experience with ICTs of interactive technologies is that authors considered that the users' previous experiences might have some effect on interaction performances (M. K. Chung et al., 2010; Harada et al., 2013; Kobayashi et al., 2011). However, most of the studies do not include experienced participants. By consequence, the differences in interaction performances between novice and experienced users remain unknown. Following the popularization of touchscreen devices, more and more users will have previous experience with tactile interaction. It is necessary to investigate how users' previous experience with technologies could facilitate the learning and use of tactile interaction.

Studies comparing interaction between younger and older adults demonstrated a decrease in interaction performances for older users (*e.g.*, longer times of completion, more errors of interaction) (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006; Kobayashi et al., 2011). The causes of the difference in time and error rates have not been elucidated and require further investigation.

II.3.1.2 Touchscreen devices

The touchscreen devices chosen for the tasks described in section II.3.1.3 had many different screen sizes, ranging from 3.5 to 42 inches, with different screen resolutions and touchscreen technologies (*e.g.*, capacitive⁵ or resistive⁶).

Screen resolution and touchscreen technologies have been improved over the past 10 years, allowing higher image quality and better touch sensitivity. The variation on screen resolution affects the pixel sizes of the display, whereas the variation in touchscreen resolutions affects the required precision of contact. The resolution and the touchscreen technologies employed in the studies analyzed were not always specified by authors. Resistive touchscreens need constant pressure for dragging gestures, for example, therefore one studied reported that older users had difficulties to maintain pressure during the execution of gestures of interaction (Wood et al., 2005). Despite being highly sensitive to touch and contact, authors still reported unregistered and accidental touches of end users with capacitive touchscreens (Harada et al., 2013).

Two studies compared interaction performances between touchscreen devices with different screen sizes (Harada et al., 2013; Kobayashi et al., 2011).

The screen orientation (*i.e.*, landscape or portrait) and position (*i.e.*, horizontal, vertical, inclined, fixed or handheld) affects GUI. Landscape mode allows bigger key sizes on small portable devices, *i.e.*, during text entry tasks (Nicolau and Jorge, 2012), but portrait mode can be suitable for right and left handed users (Kobayashi et al., 2011). Horizontal positions are common for fixed devices or tabletops, but 30° inclination offers a better visual comfort for reading tasks (Piper et al., 2010).

Different screen sizes and orientation affect the layout of the content but also the way users hold and interact with touchscreen devices. Portable devices such as smartphones have small screen sizes, they are light-weighted and commonly used handheld (Nicolau and Jorge, 2012). However, to evaluate tactile interaction, three studies simulate small screen sizes on touchscreen monitors fixed on vertical position to evaluate target selection and digit input tasks (M. K. Chung et al., 2010; Jin et al., 2007; J. Lee et al., 2009). Surfaces and tabletops were fixed horizontally and employed for collaborative

⁵ A capacitive touchscreen is consisted of an insulator (*e.g.*, glass) coated with a transparent conductor. As the human body is also electrical conductor, touching the surface of the screen results on a distortion of the screen's electrostatic field and the positions of touch can be determined.

⁶ A resistive touchscreen is consisted of transparent electrically-resistive layers separated by a thin space. When the user presses down to the outer surface, the two layers become connected and the position of the pressure can be read.

Source: <https://en.wikipedia.org/wiki/Touchscreen#Technologies>, retrieved 01/10/2015

or multi-users tasks like photo albums and medical applications (Apted et al., 2006; Piper et al., 2010).

No problems were reported for older users with low manual dexterity to interact with large horizontal touchscreens (Apted et al., 2006; Piper et al., 2010)

Table II.5 summarizes the parameters and configuration of the apparatus for the analyzed studies.

Table II.5 HCI studies: Apparatus and configuration in the studies analyzed

Device characteristics	Configuration and number of studies
Screen size	Smartphone (3 to 5 inches), 12 studies Tablet (6 to 12 inches), 12 studies Monitor (15 to 19 inches), 10 studies Surface (24 to 42 inches), 3 studies (Apted et al., 2006; Piper et al., 2010; Vetter et al., 2011)
Screen resolution	Some examples of variability of display dimensions: 240x320 or 640x960 on 3.5 inches screen (Hourcade and Berkel, 2006; Kobayashi et al., 2011), 768x1024 or 870x1152 on 9.7 inches screen (Findlater et al., 2013; Kobayashi et al., 2011).
Touchscreen technology	3 studies used resistive touchscreens (Leonard et al., 2005; Wood et al., 2005; Wright et al., 2000). Most of studies after 2006 should have used capacitive touchscreens.
Screen orientation	Portrait, 13 studies Landscape, 13 studies Not-specified, 4 studies
Device orientation	Horizontal (0 to 30°), 11 studies, Vertical (75 to 90°), 10 studies, Not-specified or not applied, 9
Device position	Handheld, 5 studies Fixed, 17 studies Non-mentioned, 8

Discussion about the devices employed in the studies analyzed

The studies we analyzed have evaluated interaction on touchscreen devices with different touchscreen technologies, screen sizes, resolutions, touchscreen technologies, orientations and positions (*i.e.*, horizontal, vertical, fixed, handheld). Tactile interactive systems should be designed to be used on different situations and fit different screen sizes.

Only two of the studies analyzed compared the interaction between two screen sizes (smartphone and tablet) (Harada et al., 2013; Kobayashi et al., 2011). The study by Kobayashi *et al.* (2011) demonstrated that older adults' interaction on tablet outperformed the smaller screen size despite the longer traveling distances for executing the gestures of interaction (Kobayashi et al., 2011). In another study, Harada *et al.* (2013) also report older adults took longer times on tablet than on smartphone for dialing numbers, scrolling contact lists and looking for a location on a map (Harada et al., 2013). Further studies should investigate the causes of the different performances in these two devices in order to improve interaction for older adults, particularly on small screen sizes.

II.3.1.3 Tasks

In this section we describe the training tasks (practice trials, familiarization tasks) and evaluation tasks executed during the HCI studies for assessing tactile interaction performances and testing usability of interactive systems.

All the studies analyzed allowed subjects to conduct practice trials before the experiment started. Longer familiarization periods were proposed for users without previous experience with touchscreen devices (more practice trials or even one week period). The training tasks employed are detailed in the Table II.6.

Table II.6 HCI studies: Training tasks in the studies analyzed

Kind of training	Number of studies and details
Familiarization period	One study asked participants to practice the execution of gestures of interaction on the interactive system designed for the experiment at least once a day (Kobayashi et al., 2011).
Demonstration	One study evaluated the effects of animated tutorials, presented before participants executed the tasks, on the execution of the correct gestures of interaction (Leitao and Silva, 2013). In another study, experimenters debriefed the participants after the experiment demonstrating some techniques for improve the accuracy of the interaction (Harada et al., 2013).
Printed tutorial	One study presented a printed tutorial before the participants executed the task (Apted et al., 2006).
Practice trials	Ten studies allowed participants to execute some trials with the interactive system used for the experiment and discarded the data from these practice trials. (M. K. Chung et al., 2010; Hourcade and Berkel, 2006; Hwangbo et al., 2013; Jin et al., 2007; Leonard et al., 2005; Lepicard and Vigouroux, 2012, 2010a, 2010b; Nicolau and Jorge, 2012; Tsai and Lee, 2009)

Tutorials and training can be used to help older adults to improve their performances and positively influence their attitudes towards touchscreens (Leitao and Silva, 2013). Familiar user interfaces and simple tasks are helpful to start activities with novice users (Hwangbo et al., 2013). A week experience improved users' performances especially for dragging and pinching gestures (Kobayashi et al., 2011).

The studies we reviewed including novice and experienced users of touchscreen devices confirms that tactile interaction seems easy to use for older adults (Harada et al., 2013; Kobayashi et al., 2011; Nischelwitzer et al., 2007; Piper et al., 2010). Concerning the progress of interaction performances during the experiment, Mertens and Jochems (2010) report that older adults showed better performances and stabilization after the 20th trial for selecting targets with tapping tasks on touchscreen (Mertens and Jochems, 2010).

Subjects worked on groups during some studies (Apted et al., 2006; Gonçalves et al., 2011; Harada et al., 2013), which was helpful to generate more natural situations during the experiment. Working in pairs can be useful for older users because they can learn by observing their partners (Apted et al., 2006; Gonçalves et al., 2011; Harada et al., 2013).

The tasks executed during the evaluation procedure, assessing touch information for analysis, were elementary or complex. The elementary tasks were executed on interactive systems presenting a simple layout (few or no distractors) and users should do one single task at the time. Complex tasks, on the other hand, were consisted of several sub-tasks and represent more realistic situations (*e.g.*, creating a postcard (Apted et al., 2006), reading and sending emails (Holzinger et al., 2007), medical applications (Nischelwitzer et al., 2007)). Elementary and complex tasks executed during the experiments of the studies we analyzed are described in Table II.7 and Table II.8 respectively and discussed on the sequence.

Examples of elementary tasks are: reading, selecting targets, typing (text, digit or passwords) or executing patterns of gestures on the touchscreen. Some studies evaluated different elementary tasks, as described in the Table II.7.

Table II.7 HCI studies: Elementary tasks in the studies analyzed

Elementary tasks	Number of studies	References
Reading	3 studies	(Hollinworth, 2009; Nischelwitzer et al., 2007; Piper et al., 2010)
Target selection	10 studies	(Findlater et al., 2013; Hourcade and Berkel, 2006;

		Hwangbo et al., 2013; Jin et al., 2007; Lopicard and Vigouroux, 2012, 2010a; Moffatt and McGrenere, 2007; Nicole Schneider et al., 2008; Vetter et al., 2011; Wood et al., 2005)
Text or digit input	11 studies	(M. K. Chung et al., 2010; Harada et al., 2013; Hollinworth, 2009; Kobayashi et al., 2011; Lee et al., 2012; Nicolau and Jorge, 2012; Nischelwitzer et al., 2007; Piper et al., 2010; Tsai and Lee, 2009; Umemuro, 2004; Wright et al., 2000)
Patterns of gestures	9 studies	(Findlater et al., 2013; Harada et al., 2013; Kobayashi et al., 2011; Leitao and Silva, 2013; Lopicard and Vigouroux, 2012; Mertens and Jochems, 2010; Stöbel, 2009; Stöbel et al., 2010; Wacharamanotham, 2011)

Only three studies evaluated reading tasks with older users. Reading tasks consist of evaluation of text fonts and comfort aspects, but also the interaction technique for scrolling, passing through pages and resizing the text. While reading, participants appreciate when they can adjust font size (Hollinworth, 2009). However, older adults prefer graphical elements with clear functions, such as soft buttons for increasing the size of the text, instead of multi-touch gestures (*i.e.*, pinching) (Hollinworth, 2009). Authors recommended limiting the number of lines of text (Nischelwitzer et al., 2007) and avoid scrolling because certain users can lose orientation between lines (Apted et al., 2006), in this case, they suggest arrow' buttons to help users to navigate linearly going forward or backward analogously to book metaphor.

Target selection tasks and typing are affected by target' sizes, spacing and location, on small touchscreen devices (Hwangbo et al., 2013) and also on larger screen sizes (Lopicard and Vigouroux, 2010a). Results of the experiments show that it is better to reduce the number of targets and the number of interactions to facilitate the use of touchscreen for older adults (Hourcade and Berkel, 2006; Jin et al., 2007; Lopicard and Vigouroux, 2010a). Four or six targets are easier to identify and to interact than eight, especially for users older than 70 years old (Lopicard and Vigouroux, 2010b). Concerning the targets' locations on small screen devices, hand movements from top to bottom are easier to visually impaired older users according to Leonard *et al.* (2006) (Leonard et al., 2005). Hwangbo *et al.* (2013) reported that diagonal movements are slower to execute, so designers should consider positioning the targets to facilitate bottom-to-top, top-to-bottom or side-to-side movements (Hwangbo et al., 2013).

Concerning the graphical interfaces displayed on touchscreen, familiarity is an important aspect for interaction (Apted et al., 2006; Hollinworth, 2009; Piper et al., 2010). Digit input is easier for older adults with explicit displays, such as numeric keypads instead of cursors or sliders (Nischelwitzer et al., 2007). Sliders can be used only to present few positions for selection (*e.g.*, markers setting intervals), otherwise selecting a specific position requires highly accurate movements. For soft keyboards and numeric keypads, familiar arrangements (*e.g.*, placing the key zero above the eight) and labeling (*e.g.*, space bars, erase buttons) can help users to find the functionalities they need and prevent mistakes (*e.g.*, sending an email instead of erasing a character) (M. K. Chung et al., 2010; Harada et al., 2013; Nischelwitzer et al., 2007).

The familiarity with the gestures of interaction is also helpful to older users (Stöbel, 2009). When using patterns of interaction gestures with one finger on single touch devices, it is recommended to avoid complex patterns (Stöbel et al., 2010).

The execution of complex tasks, composed of multiple elementary tasks, allows the analysis of interaction as a whole on more realistic situations. The kinds of complex exercises analyzed on the reviewed studies are detailed on Table II.8.

Table II.8 HCI studies: Complex tasks in the studies analyzed

Complex exercises	Number of studies	References
Use a digital agenda	1 study	(Iglesias et al., 2009)
Email	2 studies	(Hollinworth, 2009; Umemuro, 2004)
Phone tasks	2 studies	(Gonçalves and Ueyama, 2012; Harada et al., 2013)
Photo manipulation	1 study	(Apted et al., 2006)
Health care systems	2 studies	(Nischelwitzer et al., 2007; Piper et al., 2010)
Map visualization	1 study	(Harada et al., 2013)

Discussion about the tasks executed in the studies analyzed

Learning how to interact with new technologies and using a new interaction technique can be demanding on time and practice for older adults (Harada et al., 2013; Kobayashi et al., 2011; Mertens and Jochems, 2010). In order to overcome this problem, proposing familiar interactions and interactive systems can be especially helpful for novice users, preventing errors (M. K. Chung et al., 2010; Tsai and Lee, 2009), improving performances (Stöbel et al., 2010) and reducing the anxiety (Conci et al., 2009).

Most of the reviewed studies (18) evaluate the user interaction during elementary tasks, in a controlled situation (*i.e.*, no distractors in the interactive system, specified positions of the devices). These tasks allow assessing interaction performances and comparing the influence of different input modalities such as pen or fingers (Hourcade and Berkel, 2006) or feedbacks, including visual effects (*e.g.*, targets sizes or colors (Tsai and Lee, 2009)) or multimodal effects (*e.g.*, audio or tactile (J. Lee et al., 2009)). However, elementary tasks and controlled situations can seem disconnected from the real situations of use of technologies, where graphical interfaces are usually encumbered by icons and errors of interaction can trigger unexpected actions of the interactive system. On the other hand, complex activities, composed of several sub-tasks, allow the observation of more usual situations, like users making errors and recovering from it, for identifying common difficulties on the execution of the gestures of interaction. Moreover, authors report positive evaluation from users when they accomplish a complex task, as dialing a phone number (Gonçalves et al., 2011) or manipulating a photo album (Apted et al., 2006). Complex activities can be used during the study of tactile interaction for observing more realistic situations of use of interactive systems.

One of the main advantages of touchscreens is the possibility of adapting the graphical user interface (GUI) or the interaction techniques (*i.e.*, acquisition criteria, number of touches detected simultaneously) to support the user for accomplishing the task. For example, it is possible to address gap between intended and actual touch location to prevent errors (Harada et al., 2013; Kobayashi et al., 2011; Nicolau and Jorge, 2012). Soft keyboards can be calibrated to adapt key sizes and touch sensitivity to users' needs, correcting drifting touches (Nicolau and Jorge, 2012) or providing support for slipping, a common error older users make (Hourcade and Berkel, 2006; Moffatt and McGrenere, 2007).

II.3.1.4 *Interaction techniques*

Different interaction techniques (such as: tapping, dragging, rotating, zooming) can be used to access information and to manipulate an interactive system on touchscreen devices. Different input modalities have been evaluated, with pen or fingers and single or multi-touch interaction. Several gestures for the user interaction have also been studied, the most common ones as “tapping” and “dragging” or new ways of typing as “swabbing”. In order to allow users understand interaction and follow the effects of their actions on the interactive systems, different kinds of feedback have been evaluated, including visual effects of multimodal output.

In our analysis of the interaction techniques for older adults using touchscreen devices, we describe the input and output modalities evaluated by the reviewed studies. The distinction between input and output interfaces in this section is merely for analytical purposes. During interaction, input and output are completely interlaced and they cannot be designed independently (Nigay and Coutaz, 1996).

Input modalities

The studies evaluated interaction performances (*i.e.*, accuracy, time of movements) for interaction with pen or finger, on single or multi touch systems. Seven studies investigated the use of pen based interaction by older users (Charness et al., 2004; Hourcade and Berkel, 2006; Jastrzembski et al., 2005; Leonard et al., 2005; Moffatt and McGrenere, 2007; Rogers et al., 2005; Wright et al., 2000). The others 27 studies evaluated tactile interaction with users’ fingers. Just one study compared interaction between pen and finger on touchscreen (Hourcade and Berkel, 2006).

Concerning finger interaction, it has been reported that most users used the index finger to point and target selection tasks, as well as text or digit entry tasks. In some studies, experimenters asked subjects to interact with one precise finger (*e.g.*, index) (Jin et al., 2007; Vetter et al., 2011).

Only seven studies evaluated multi-touch gestures of interaction (Apted et al., 2006; Findlater et al., 2013; Harada et al., 2013; Kobayashi et al., 2011; Leitao and Silva, 2013; Lepicard and Vigouroux, 2012; Piper et al., 2010). One study compared single or multi-touch interaction by older users (Lepicard and Vigouroux, 2012). Only two studies analyzed common gestures as scroll, pan, pinch or rotate (Harada et al., 2013; Leitao and Silva, 2013). Multi-touch gestures have only been studied with able-bodied participants.

During the evaluation of gestures for interaction, authors compared the trials' times and times of completion, as well as accuracy of the gestures (*e.g.*, position inside the target (Harada et al., 2013; Kobayashi et al., 2011), deviation curves (Stöbel et al., 2010)) and kinds of errors (*e.g.*, substitution or omission during typing tasks (Nicolau and Jorge, 2012; Wright et al., 2000)).

Table II.9 synthesizes the main gestures of interaction evaluated on the studies we analyzed. For analytical purposes, we divided the gestures identified into two kinds: *target selection*, one single touch on one specific target, and *displacement*, a continuous touch on the screen from an initial to a final position.

Table II.9 HCI studies: Main gestures of interaction in the studies analyzed

Touch modality	Kind of touch gesture	Examples	Input modality	Studies that used/evaluated this interaction technique by older adults
Single touch	Target selection	Tap, type	Pen or fingers	13 studies (M. K. Chung et al., 2010; Findlater et al., 2013; Gonçalves and Ueyama, 2012; Harada et al., 2013; Hollinworth, 2009; Hourcade and Berkel, 2006; Lee et al., 2012; J. Lee et al., 2009; Nicolau and Jorge, 2012; Nicole Schneider et al., 2008; Tsai and Lee, 2009; Umemuro, 2004; Wright et al., 2000)
Single touch	Displacement	Drag, move, draw, scroll, pan, swipe, swab, steer	Pen or fingers	10 studies (Apted et al., 2006; Findlater et al., 2013; Harada et al., 2013; Kobayashi et al., 2011; Leitao and Silva, 2013; Lopicard and Vigouroux, 2012; Mertens and Jochems, 2010; Stöbel et al., 2010; Wacharamanotham, 2011; Wood et al., 2005)
Multi touch	Target selection	-	Fingers	-
Multi touch	Displacement	Rotate, spread, pinch	Fingers	8 studies (Apted et al., 2006; Findlater et al., 2013; Harada et al., 2013; Hollinworth and Hwang, 2011; Kobayashi et al., 2011; Leitao and Silva, 2013; Lopicard and Vigouroux, 2012; Piper and Hollan, 2013)

Discussion about the input modalities in the studies analyzed

Concerning the input modalities identified in the studies we analyzed, most of studies evaluated finger interaction and single touch interaction.

Concerning pen interaction, the study that compared pen and finger describes that finger interaction was more accurate for older adults (aged 65 to 84) even if this group had 88% accuracy for tapping tasks on small targets (16 pixels) with the pen (Hourcade and Berkel, 2006). Indeed, pen-based interaction has been recommended for motor impaired young people because the contact of the pen on the screen seems to be easier to control (Cofre et al., 2012). Besides, contrary to pen, interaction with fingers imply a hidden surface of the screen by the users' hands (Moffatt and McGrenere, 2007). The accuracy of pen interaction should be investigated with different gestures of interaction (*e.g.*, drag-and-drop) to evaluate the appropriateness of this input modality as an alternative to finger to older users.

Multi-touch interaction is current used on several applications, such as mobile web browsers, photo managers, e-books, maps with different functions like zooming and selection. Although multi-touch interaction requires fine motor control, the seven studies that evaluated multi-touch gestures of interaction for older adults report that subjects were able to accomplish interaction but not without difficulties (Apted et al., 2006; Kobayashi et al., 2011; Leitao and Silva, 2013). Besides, the use of two fingers leads to the occlusion of a part of the screen. Lepicard and Vigouroux (2012) compared single or multi-touch interaction by older users and multi-touch for rotating and zooming tasks resulted in longer times when compared to single-touch (Lepicard and Vigouroux, 2012).

Among the interaction techniques evaluated in the analyzed studies, gestures of interaction based on continuous contact with the screen (*e.g.*, “swabbing” (Wacharamanatham, 2011), “trabing” (Mertens and Jochems, 2010)) have been designed to improve the accuracy of interaction on touchscreens. Drag-and-drop interaction for older adults has been evaluated only by four studies (Findlater et al., 2013; Kobayashi et al., 2011; Leitao and Silva, 2013; Wood et al., 2005). On resistive touchscreens, it has been considered difficult to execute because of the need of constant pressure between the finger and the screen (Wood et al., 2005). However, on capacitive touchscreens, the continuous contact of the finger with the screen reduces finger oscillation and it has shown effective results for older users with tremor (Mertens and Jochems, 2010; Wacharamanatham, 2011). Dragging has been preferred to tap for older users (Kobayashi

et al., 2011) even if this gesture is slower for this group of users when compared to tapping (Findlater et al., 2013).

The evaluation of input modalities and interaction techniques can provide recommendations of use for older adults as well as indicate the most suitable interaction technique regarding the needs of the users. On touchscreen devices, interactive systems can be adapted to support different interaction techniques according to the motor skills and special needs of the users. On the other hand, as users can choose between pen and finger as input modalities, interactive systems should be evaluated to allow interaction with pen or finger. More studies need to be done to further understand the difficulties older users find when they execute the gestures of interaction and outline the situations of interaction with touchscreen that might be further supported.

Output modalities

In all the studies we analyzed (except one, (Stöbel et al., 2010)), visual feedback was provided during touchscreen interaction. The only exception is a study about repeating patterns of gestures, where participants received no visual marks of the drawn trajectories to avoid corrective movements during the task (Stöbel et al., 2010).

One study evaluated the effects of providing different visual feedbacks during a digit entry task: three visual effects were applied on soft keys (magnifying, icon movement, changing color) and these effects were evaluated alone or combined (Tsai and Lee, 2009).

Table II.10 synthesizes the kind of feedback provided and evaluated in the analyzed studies. Five studies provided audio feedback. Three of them played a beep sound when the users miss the target (Moffatt and McGrenere, 2007), entry a wrong number (M. K. Chung et al., 2010) or to indicate a correct selection (Hwangbo et al., 2013). One provided audio aids when users selected the icons (Iglesias et al., 2009). The other played a message when the user accomplished the task (thanking for the participation) (Gonçalves and Ueyama, 2012).

Only two studies analyzed the bi-modality visual-tactile feedback or tri-modality visual-audio-tactile feedback for older users (Hwangbo et al., 2013; J. Lee et al., 2009).

Table II.10 HCI studies: Kind of provided feedback in the studies analyzed

Feedback modality	Number of studies and details
Visual	All studies provided visual feedback (except one (Stöbel et al., 2010)). One study evaluated different modalities of visual feedback (Tsai and Lee, 2009).
Visual + Audio	Five studies provided visual and audio feedback: Beep sound for errors (M. K. Chung et al., 2010; Hwangbo et al., 2013; Moffatt and McGrenere, 2007), beep sound for confirmation, a message for accomplishment (Gonçalves and Ueyama, 2012) or audio aids (Iglesias et al., 2009).
Visual + Tactile	Three studies provided visual and tactile feedback: Two studies evaluated interaction with or without tactile feedback (Hwangbo et al., 2013; J. Lee et al., 2009). One study had a vibration effect for accomplishment (Gonçalves and Ueyama, 2012)
Visual + Audio + Tactile	Two studies investigated tri-modality (Hwangbo et al., 2013; J. Lee et al., 2009)

Discussion about the output modalities in the studies analyzed

Output modalities consisted on visual, audio and/or tactile feedback during interaction with the tactile interactive systems designed for the studies we reviewed.

Visual feedback, such as magnification effects, helps users to verify the effects of their actions (*e.g.*, acquiring the desired target) (Tsai and Lee, 2009) and the current state of the interaction (Harada et al., 2013). Auditory feedback may be a valuable non-visual cue to support gestures of interaction (Leonard et al., 2005) and can improve pointing performances on touchscreen devices (Hwangbo et al., 2013). Tactile feedback has been considered distracting for novice older users (Hwangbo et al., 2013) or less effective than audio feedback (J. Lee et al., 2009), but more studies need to be done in order to evaluate different patterns and vibration intensity according to the user's sensitivity. Vibration should compensate the lack of tactile feedback on flat displays (Umemuro, 2004).

Only two studies (Hwangbo et al., 2013; J. Lee et al., 2009) have evaluated the effects of multimodal feedback during target selection and digit input tasks on small screens by older users without disabilities. Due to the age related changes on sensorial skills, multimodal feedback could provide alternatives and complementary feedback to support touchscreen interaction. Similarly, during the design evaluation of interactive systems for older adults, it should be verified if the users get enough feedback for their actions.

Feedback was used to indicate and prevent errors of interaction. However, when evaluating the execution of patterns of gestures (Stöbel et al., 2010) or text entry tasks (Mertens and Jochems, 2010; Wacharamanotham, 2011), participants did not get feedback about the travelling distances of their dragging paths on the screen. Feedback for gestures requiring continuous contact with the screen can be helpful for users to correct the positions of their touches.

II.3.1.5 *Evaluation criteria*

Most of the reviewed studies evaluated the efficiency and satisfaction of users for improving the design of interactive systems, interaction techniques or graphical interfaces. Only two studies reported situations where users were unable to achieve the tasks or understand the interaction (Apted et al., 2006; Iglesias et al., 2009).

For evaluating the usability of interactive systems and interaction techniques, efficiency has been commonly measured through time and number of errors. Satisfaction has been measured through debriefing and questionnaires assessing the users' subjective evaluation of the interaction. Table II.11 describes the main evaluation criteria (and measures) employed to evaluate subjects' performances and appreciation of interaction.

Table II.11 HCI studies: Evaluation criteria in the studies analyzed

Evaluation criteria	Number of studies and details
Time	32 studies
Error rate	31 studies
Subjective evaluation	12 studies
Other criteria	Position of touches on the screen: 6 studies (Harada et al., 2013; Hourcade and Berkel, 2006; Kobayashi et al., 2011; Moffatt and McGrenere, 2007; Nicolau and Jorge, 2012; Stöbel et al., 2010)

Different time criteria have been employed in 32 of the analyzed studies and these criteria are described in Table II.12. According to time being a criterion for evaluating efficiency or performance, different measures have been defined, such as time for completion, time of reaction, etc. Time for task completion usually includes reflection time (*e.g.*, when the user creates a strategy for accomplishing the task) and time for realizing and recovering from errors (*e.g.*, the users undo and try again their actions) (Apted et al., 2006; Gonçalves et al., 2011; Iglesias et al., 2009; Lepicard and Vigouroux, 2012; Nicole Schneider et al., 2008). For evaluating elementary tasks, the time per trial

has been measured. When designing a system for older adults, the time it takes for the user to figure out the actions to do in order to execute the task can also be evaluated (Piper and Hollan, 2013; Piper et al., 2010). Reaction time usually refers to the time the user takes to acquire the targets after the moment they appear in the GUI. Time of movement includes only the time participants spent effectively executing each gesture. The ratio between the global time of movement and the number of targets has been calculated, resulting on the mean time per target. Speed has also been included as the valuation criterion for the execution of gestures of interaction (Lepicard and Vigouroux, 2012; Stöbel et al., 2010; Wood et al., 2005).

Table II.12 HCI studies: Measures for time criteria in the studies analyzed

Measures	Number of studies	References
Time for task completion	9 studies	(Apted et al., 2006; Gonçalves et al., 2011; Hourcade and Berkel, 2006; Iglesias et al., 2009; Lepicard and Vigouroux, 2012, 2010a; Nicole Schneider et al., 2008; Tsai and Lee, 2009; Wright et al., 2000)
Time per trial	3 studies	(Harada et al., 2013; Leonard et al., 2005; Moffatt and McGrenere, 2007)
Time to figure out the action to do	2 studies	(Piper and Hollan, 2013; Piper et al., 2010)
Reaction time	5 studies	(Charness et al., 2004; Jin et al., 2007; J. Lee et al., 2009; Leonard et al., 2005; Lepicard and Vigouroux, 2012)
Time of movement	5 studies	(Findlater et al., 2013; Leonard et al., 2005; Lepicard and Vigouroux, 2012; Vetter et al., 2011; Wood et al., 2005)
Mean time per target	8 studies	(Charness et al., 2004; J. E. Chung et al., 2010; Hwangbo et al., 2013; Jastrzemski et al., 2005; Lepicard and Vigouroux, 2010a, 2010b; Mertens and Jochems, 2010; Nicolau and Jorge, 2012)
Speed	3 studies	(Lepicard and Vigouroux, 2012; Stöbel, 2009; Wood et al., 2005)

Concerning the error rates, only three studies did not evaluate interaction through the number of errors, at least not directly. Two studies analyze subjective evaluation (Holzinger et al., 2007; Umemuro, 2004) and do not use errors that occurred during tasks as evaluation criteria.

Table II.13 describes the different measures that have been used in the 31 studies analyzed to identify and characterize errors of interaction. Errors are commonly related to the difficulty users have to acquire a target. In six studies analyzed, the positions of the touches on the screen were evaluated (Harada et al., 2013; Hourcade and Berkel, 2006; Kobayashi et al., 2011; Moffatt and McGrenere, 2007; Nicolau and Jorge, 2012; Stöbel et al., 2010). This information was useful to evaluate the accuracy of the gestures (Harada et al., 2013; Kobayashi et al., 2011; Stöbel et al., 2010) or to understand the causes of the errors during text entry tasks (Moffatt and McGrenere, 2007; Nicolau and Jorge, 2012).

Table II.13 HCI studies: Measures for errors and typology in the studies analyzed

Measures	Number of studies	References
Not acquiring the right target	8 studies	(Charness et al., 2004; M. K. Chung et al., 2010; Hwangbo et al., 2013; Kobayashi et al., 2011; Lopicard and Vigouroux, 2012, 2010a; Vetter et al., 2011; Wacharamanotham, 2011)
Not achieving a task	5 studies	(Findlater et al., 2013; Iglesias et al., 2009; Lopicard and Vigouroux, 2010a; Piper et al., 2010; Stöbel et al., 2010)
Accuracy levels	6 studies	(Hourcade and Berkel, 2006; Jin et al., 2007; Kobayashi et al., 2011; J. Lee et al., 2009; Wood et al., 2005; Wright et al., 2000)
Reporting different kinds of errors	4 studies	(Harada et al., 2013; Moffatt and McGrenere, 2007; Nicolau and Jorge, 2012; Wright et al., 2000)

Users' subjective evaluation included measures of **Affection** (Apted et al., 2006), **Perceived difficulty** (Findlater et al., 2013), **Perceived Usefulness** (Piper and Hollan, 2013), **Usability** (Hwangbo et al., 2013), **Ease of use** (Charness et al., 2004; M. K. Chung et al., 2010), **Satisfaction** (Hwangbo et al., 2013) or even the users' attitudes towards technologies (*e.g.*, "I feel that computers are friendly" (Umemuro, 2004)) (Mertens and Jochems, 2010; Piper and Hollan, 2013; Umemuro, 2004; Wright et al., 2000). Subjective evaluations were assessed during debriefing with participants during or after the experiment (Hollinworth and Hwang, 2011; Holzinger et al., 2007; Kobayashi et al., 2011). Debriefing have also been complemented with questionnaires (M. K. Chung et al., 2010; Findlater et al., 2013; Piper and Hollan, 2013; Umemuro, 2004).

Discussion about the evaluation criteria employed in the studies analyzed

Measures for time as evaluation criteria were defined according to the tasks and the aims of the study. It has been reported that aging affects working memory what could influence the reaction time or reflection time that older adults take to start an action or develop a strategy for interacting with a system (Charness et al., 2004). It is not surprising though that studies that compared different age groups demonstrated that older adults take longer times to achieve a task or execute a gesture (Apted et al., 2006; Findlater et al., 2013; Hourcade and Berkel, 2006; Stöbel et al., 2010). However, Stöbel *et al.* (2010) evaluated paths for drawing patterns of gestures and they affirm that older adults do perform slower gestures but they are not less accurate (Stöbel et al., 2010). Indeed, older adults have a different strategy for interacting when compared to younger adults, who would adopt a trial-and-error approach (Barnard et al., 2013). Older users prefer to perform accurate gestures even if they are slower than younger users (Stöbel et al., 2010).

When comparing subjects across different age-groups, older adults usually make more errors than younger subjects (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006; Kobayashi et al., 2011). The causes of errors are usually related to non-adaptation of the layout or the interaction techniques to the user's abilities. Further studies need to be done to investigate the common kinds of problems that older users find when interacting with tactile interactive systems in order to design adequate solutions. As already discussed earlier, preventing errors, assisting for error recovery and supporting novice older adults since their first experiences with technologies is fundamental for improving acceptance and adoption (Barnard et al., 2013).

II.3.2. Summary

Several works concerning HCI for older adults and tactile interaction have been done; they reveal the importance researchers of different fields of knowledge have been giving to this subject.

Between 2000 and 2013, the studies concerning tactile interaction of older adults featured two main situations: the evaluation of the usability of different interaction techniques, for specific tasks or situations of use; or the evaluation of the usability of one particular interactive system. According to the aims of these studies, subjects executed isolated tasks or complex interaction exercises, on representation of different scenarios

and situations of use, and interaction performances were evaluated through different evaluation criteria.

After 2014, a new set of studies about older adults and tactile interaction emerged. The situations of use of tactile interaction and a series of gestures of interaction continued to be carefully evaluated but researchers got more interested in studying the variability of this population and their needs of usability, accessibility and ergonomics of the interaction with new technologies (Wulf et al., 2014). It has been demonstrated that experience of using interactive technologies and cognitive capabilities are more significant than age as predictors of use of interactive systems (Crabb and Hanson, 2014). Concerning tactile interaction, support techniques for novice older adults have been created and evaluated (Dahn et al., 2014). A special attention was given to the abilities of older users as producers of interaction and the way they conceive interactive systems and technologies (Rogers et al., 2014).

Yet, to improve the acceptance and adoption of touchscreen and mobile technologies among older adults, the usability of tactile interaction needs to be improved. Our analysis of the state-of-the-art on HCI studies about tactile interaction demonstrates that it is difficult to take into account the heterogeneity of older adults' profiles as well as the new situations of use of mobile devices and touchscreen. Even if the existing studies provide important recommendations, older adults' common errors and mistakes should be further investigated in order to provide relevant information in the development of adequate solutions.

Based on our analysis of the studies reviewed, we created a set of recommendations for improving the usability of tactile interaction for older adults. These recommendations are summarized in Table II.14, presenting the main considerations for the design and evaluation of an interactive system, described in Chapter III (p. 93). This interactive system is used for assessing touch information of older adults in the experiment presented in Chapter IV (p. 121).

Our analysis of the state-of-the-art on the evaluation of tactile interaction for older adults also identified the situations of use of touchscreen that have been evaluated so far. The studies reviewed discuss the effects of the situations of use, *e.g.*, screen sizes and input modalities, on interaction performances, which partially address our Research Question 3. However, factors influencing interaction performances of older adult should be further investigated in order to define the situations of use that need to be improved.

For this reason, the experiment presented in Chapter IV evaluates different situations of use of touchscreen devices (p. 121).

In summary, the methods employed in the reviewed studies for designing and evaluating tactile interaction can be used to identify problems in tactile interaction of older adults and propose adequate support for interaction such as the design of new interaction techniques (*e.g.*, “swabbing” (Wacharamanatham, 2011)). However, the analysis of the touch information assessed through interactive systems cannot help to understand the causes of the difficulties related to the user’s abilities to execute the gestures of interaction, such as the effects of aging on the accuracy of the movements. The analysis of the movements of the user, from an ergonomics perspective and through a biomechanical approach, would be particularly useful to provide information about the effects of aging on the movements employed during interaction with touchscreen devices and its consequences on interaction performances.

Table II.14 Specifications and recommendations for the design and evaluation of interactive systems in order to improve the usability of tactile interaction for older adults

Specifications	Recommendations
Screen sizes and orientation	<p>Touchscreen devices are available with different screen sizes and can be used on landscape or portrait orientation.</p> <p>Interactive systems should consider responsive layouts and the adaptation of the targets sizes.</p>
Input modalities	<p>Tactile interaction can be single-touch or multi-touch, users can interact with finger or pen.</p> <p>Interactive systems should be adapted to accept different input modalities and prevent errors of interaction.</p>
Output modalities	<p>Feedback is really important so older adults can see the results of their actions, follow the current state of the interaction and identify errors. Multimodality should be further studied. Visual feedback is the most used output and can support interaction when it is clear and well perceived.</p> <p>Visual feedback can be used for tactile interactive systems for older adults. It is important to verify if the users get enough feedback.</p>
Interaction technique	<p>Several gestures of interaction have been evaluated and can be used for tactile interaction. Tapping with pen or finger was widely evaluated while other gestures should be further studied. Gestures requiring continuous contact with the screen have been evaluated for users with tremor and could improve the accuracy of the gestures.</p> <p>Drag-and-drop interaction should be further studied to older users.</p>
Graphical parameters	<p>The reviewed studies evaluated different target sizes. According to the screen sizes, target widths between 13 to 35 mm seem to be more adapted to older adults.</p>
Evaluation criteria	<p>According to the aims of the studies, authors have measured usability of interactive systems through:</p> <ul style="list-style-type: none"> - Efficiency: time and task completion - Effectiveness: different measures of time for acquiring target, executing the gestures of interaction and the distinction of kinds of errors - Satisfaction: preferences and subjective evaluation <p>Older users can take longer times but they are not always less accurate than younger users (Stöbel et al., 2010). Time of movement can be used to evaluate interaction of older adults. The different kinds of errors and their causes should be further studied to provide solutions and adaptations, improving the accuracy.</p>
Task	<p>Familiar activities should facilitate interaction and the participation of novice users. Complex activities (composed of sub-tasks) allow the evaluation of more realistic situations of use and the observation of the main kinds of errors and difficulties. The accomplishment of the task should encourage users to carry on.</p>

II.4. *Study of movements during interaction with touchscreen*

Our analysis of the state-of-the-art on HCI studies of tactile interaction for older adults, presented in section II.3, demonstrates that tactile interaction has already been extensively designed and evaluated for older adults, but when comparing this group to younger users, older adults usually make more errors and take longer times to execute the gestures of interaction (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006). Indeed, human aging is related to changes in perceptual, psychomotor, cognitive and physical systems. Moreover, older adults have different psychological, social and cultural characteristics. It is though difficult to understand which factors related to the aging can be affecting interaction performances of older adults.

Contrary to traditional input devices used in desktop settings, where the users' arms are resting on the desk, the users' arms are usually floating when interacting with touchscreens. Consequently, the execution of the gestures of interaction on touchscreen requires fine dexterity of the user (Jin et al., 2007; Nicolau and Jorge, 2012; Wacharamanatham, 2011). The effects of aging on the movements the users executes during interaction with touchscreen devices need to be further studied in order to provide information to design tactile interactive systems and interaction techniques better adapted to the older users' motor skills.

In this section, we discuss our Research Question 4 concerning the evaluation of the effects of aging on movements of the users and their possible relationship with time of movement and accuracy of tactile interaction. First, due to the high implication of the users' arms and hands when using touchscreen devices, we describe main considerations about the differences in the movements of the upper limbs of older adults and adults. Then, we review the literature to establish the state-of-the-art on studies about the movements and postures of the users during interaction with touchscreens.

II.4.1. *Age effects on the movements of users' upper limbs*

To accomplish the gestures of interaction, movements of the user must be planned and executed with accuracy, which requires a good functioning and coordination of the central nervous system (CNS) and musculoskeletal system. According to Roy *et al.* (1996), the cognitive processing of movements of the user's body can be analyzed inside an information processing framework: "information from the environment that serves as input to the perceptual-motor system is processed through a number of stages resulting in an observable motor response" (Roy et al., 1996).

Previous studies on the movements of the arms of older adults have demonstrated the effects of lower muscle strength and decline on sensorimotor systems related to the aging on the trajectories of the arms (Cooke et al., 1989; Darling et al., 1989). Moreover, the age-related changes in proprioceptive acuity of the upper-limbs resulted on impaired detection of wrists' joint motions for older adults, negatively affecting goal-oriented arm movements (Wright et al., 2011). Indeed, the effects of age on the movements are related to the insufficient neural, perceptual or physiological information implying sensorimotor constraints to the movements of the arms (Roy et al., 1996) and these movement constraints limit the way in which movements are organized and controlled (Marteniuk et al., 1987).

According to Walker *et al.* (1997), there is a consistent documentation on age-related differences in movements of upper limbs of older adults and adults based on the analysis of ballistic movements (Walker et al., 1997). The aging effects on the execution of movements have been evaluated through time of movement (*i.e.*, the overall timing for executing one movement) and kinematics of the movement (*i.e.*, control processes of motor performances such as trajectories, articular angles, speed) (Roy et al., 1996). The analysis of the trajectories and speed of the movements of the arms of older adults and adults demonstrated that older subjects executed longer movement times, characterized by asymmetrical acceleration and deceleration curves (Cooke et al., 1989; Darling et al., 1989). This asymmetry is due to a longer deceleration phase, usually related to sub-corrective movements (Darling et al., 1989). Effectively, the same characteristics of movements have been observed on the trajectories of the cursor on the screen during the evaluation of age effects on pointing tasks with a computer mouse (Walker et al., 1997). Lepicard and Vigouroux (2012) demonstrated movements of older adults during tactile interaction are slower and characterized by irregular speed compared to younger adults (Lepicard and Vigouroux, 2012).

The analysis of the movements of the upper-limbs can be defined through the evaluation of the effects of movement constraints (Marteniuk et al., 1987; Roy et al., 1996), and their consequences on the strategies employed by the users to execute the gestures of interaction. Movement constraints are variables limiting the way in which movements are organized and controlled (Marteniuk et al., 1987). According to Roy *et al.* (1996), the evaluation of the age effects on the movements of older adults is defined by three kinds of constraints: sensorimotor, physical and high level constraints. Sensorimotor constraints refer to the temporal and spatial limitations of the central nervous system to

compensate age-related decreases on neural, perceptual or physiological information, necessities to effectuate the movement. These constraints are though centered in the characteristics of the performers: the users. Physical constraints refer to the biomechanical limitations of the performer (*e.g.* the ways a hand can be postured), the properties of the objects and the relationship between the objects and the environment (*e.g.* shape, location, distance). Finally, high levels constraints are informational, related to the knowledge the performers have about the context, as their previous experiences, motivational, related to their intentions for the movement they are executing, and functional, depending on the goals of the task being executed (Mackenzie and Iberall, 1994; Roy et al., 1996). Based on previous experience, for example, performers determine the forces, speeds and strategies for placing or throwing, lifting or transporting.

The constraints framework is suitable for analyzing how the effects of aging on cognitive processing and motor responses affect the movements of older users during interaction, and consequently their interaction performances. Indeed, aging leads to changes on psychomotor and physiological systems that hinder the execution of movements with accuracy (*e.g.*, reduce of proprioception sensibility, decrease of muscle strength, reduce of bone density, etc.).

The sensorimotor constraints define the movements of the users during the execution of the movements of interaction. For example, longer movement times and increased deceleration phases have been observed for trajectories of the arms of older adults (Cooke et al., 1989; Darling et al., 1989) as well on trajectories of cursor during mouse tasks (Ketcham et al., 2002; Walker et al., 1997) and tactile interaction (Lepicard and Vigouroux, 2012). Other studies have also demonstrated the effects of users' different motor skills on their interaction performances when interacting with touchscreen (Caprani et al., 2012; Irwin and Sesto, 2012; Jin et al., 2007). Users with motor disabilities made more errors of interaction and used more pressure than non-disabled users (Irwin and Sesto, 2012). Besides, older users with low dexterity skills (according to results of pre-experiment tests) take longer times and make more errors than older users with normal or high dexterity (Jin et al., 2007; Nicolau and Jorge, 2012).

Concerning the physical constraints, Geronimi and Gorce (2009) have demonstrated that the properties of the objects and obstacles influenced particularly the movements of older adults, with increased time of movement, range of motion and variability among users (Geronimi and Gorce, 2007). In regard to interaction with touchscreen devices, the properties of the devices (*e.g.*, screen size, orientation), the

parameters of tactile interactive systems (*e.g.*, targets sizes) and the input modalities (*e.g.*, pen, finger, multi-touch interaction) can be considered as physical constraints to the movements of the users. As discussed in section II.3.1.2 (p.51) and II.3.1.4 (p.59), the different situations of use of tactile interaction affect interaction performances. Indeed, the situations of use influence planning and execution of movements of the user during interaction.

Moreover, the high level constraints for the execution of movements of interaction would refer to the experience of the user using interactive technologies, executing the gesture of interaction or using the interactive system. The results presented and discussed by Darling *et al.* (1989) demonstrate that practice reduced the variability of movement trajectories of older subjects; this result showed that the ability of learning and improving performances in motor task is not affected by aging (Darling *et al.*, 1989). Concerning tactile interaction, it has also been demonstrated that older users get better times and stabilization after executing several trials (about 20) of tapping tasks (Vetter *et al.*, 2011). A week period for experiencing and executing gestures of interaction on touchscreen helped older users to enhance their interaction performances (Kobayashi *et al.*, 2011).

In the next section, we review of the literature on studies about the movements of the users during interaction with touchscreen. Through the analysis of the characteristics of the populations studied, the situations of use of touchscreen evaluated on the studies reviewed and the tasks that were executed, we try to identify which sensorimotor, physical and high level constraints could influence the movements of the users during interaction with touchscreen devices.

II.4.2. *Movements of the user during interaction with touchscreen*

In this section, we report the results of our literature review defining the state-of-the-art on evaluation of the movements and postures of the users during interaction with touchscreen. We try to identify the characteristics of the studied populations, the procedures (touchscreen devices and tasks), the methods and the equipment used for assessing movements during interaction. Additionally, we define the parameters and specifications for study of movements of interaction of older adults and adults that are employed on the experimental study described in Chapter V (p. 155).

As touchscreen mobile devices are new technologies, in our review we retrieved only ten studies (Irwin and Sesto, 2012; Irwin *et al.*, 2011; Kim *et al.*, 2014, 2013; Pereira *et al.*, 2013; Sesto *et al.*, 2012; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014;

Young et al., 2013, 2012). In these studies, authors evaluated the movements, position and postures of the human body during the execution of interaction tasks on touchscreen devices. The studies we selected were published between 2011 and 2014 on journals and peer reviewed conferences on Ergonomics, Human Modeling, Human Computer Interaction and Accessibility (such as Ergonomics, Applied Ergonomics, Proceedings of the Human Factors and Ergonomics Society Annual Meetings).

II.4.2.1 Population

Table II.15 describes the population included on these studies.

Table II.15 Biomechanics studies: Population in the studies analyzed

Population	Number of studies	References
Only able-bodied adults	7 studies	(Kim et al., 2014, 2013; Pereira et al., 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2013, 2012)
Able-bodied and Motor impaired adults	3 studies	(Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012)
Older adults	No study was found about the interaction of older adults and touchscreen on this research fields.	

Seven studies analyzed only able-bodied adults without any report of musculoskeletal disorder, motor difficulty or pain. Among these studies, four studies recruited expert typists for typing tasks (Kim et al., 2014, 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014). One study recruited subjects with limited or no experience of using touchscreen devices (Werth and Babski-Reeves, 2014) and two studies included experienced users (Young et al., 2013, 2012).

Authors assessed participants heights and weights (Shin and Zhu, 2011), sizes of the hands (Young et al., 2013, 2012). In one study, the size of the hands was an inclusion criteria (*i.e.*, authors recruited subjects with approximately the same size of hands and the participants were 15 female, with mean middle finger length of 7.58 cm or 1.84 cm for joint breath) (Pereira et al., 2013).

Three studies included subjects who reported disabilities affecting motor control of upper-extremity, classified by authors as gross motor disabilities (*e.g.*, Cerebral Palsy, Huntington's disease) or fine motor disabilities (*e.g.*, Multiple Sclerosis, Parkinson's

disease, Essential Tremor) (Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012). Including motor-impaired participants allowed the assessment of the effects of low motor control on interaction performances.

Discussion about the population in the studies analyzed

Most of the participants consisted of a homogeneous group of young adults without any musculoskeletal disorder. Comparing different groups of subjects could provide relevant information about the strategies used by the users to accomplish their interaction. The studies that included people with different motor abilities contributed to a rich analysis of the effects of their special needs during interaction.

No studies about the movements of interaction with touchscreen that included older adults as participants were found. As age affects the movements of the arms and hands, it is necessary to assess the biomechanics of movements of older adults and adults during interaction with touchscreen in order to analyze the consequences of the movements in their interaction performances.

II.4.2.2 *Touchscreen devices*

The touchscreen devices used during the studies analyzed and their display sizes are described in Table II.16. The situations of these studies representing the devices positions and orientations while subjects executed the gestures of interaction are described in this table (Table II.16).

Table II.16 Biomechanics studies: Apparatus and configuration in the studies analyzed

Devices characteristics	Configuration and number of studies
Large display (15 inches or larger)	6 studies, on which <ul style="list-style-type: none"> • 4 were fixed on vertical* position (desktop or kiosk settings) (Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012; Shin and Zhu, 2011) • 2 were fixed on horizontal** position (Kim et al., 2014, 2013)
Medium display (6 to 12 inches)	6 studies, on which <ul style="list-style-type: none"> • 2 was fixed on vertical* position (case) (Young et al., 2013, 2012) • 3 were fixed on horizontal** position (desk) (Kim et al., 2013; Werth and Babski-Reeves, 2014; Young et al., 2012) • 3 were on the lap (horizontal**) (Werth and Babski-Reeves, 2014; Young et al., 2013, 2012) • 1 was handheld (Pereira et al., 2013)
Small display (3 to 6 inches screen)	1 study, handheld (Pereira et al., 2013)

* Inclination angle superior to 60° or vertical support

**** Inclusion angle inferior to 50° or horizontal support**

Concerning the screen sizes, most of these studies evaluated large and medium displays, such as monitors or surfaces. Two studies compared two screen sizes: medium and large (Kim et al., 2013), medium and small (Pereira et al., 2013). Only one study evaluated small touchscreen devices and pen interaction (Pereira et al., 2013).

Concerning the positions of the touchscreen devices and the situations of use: two studies were interested in the effects of the devices positions *i.e.*, handheld (Pereira et al., 2013), fixed in portrait or landscape orientation (Young et al., 2012). Two studies compared different situations of use of touchscreen devices, including a tablet horizontally placed on the lap or over the desk or yet supported by a special case (Young et al., 2013, 2012).

Five studies collected information on the touchscreen devices to analyze the interaction performances of the participants (Irwin and Sesto, 2012; Kim et al., 2014, 2013; Sesto et al., 2012; Werth and Babski-Reeves, 2014). The other four studies only assessed the movements and postures of the users for an ergonomics analysis.

Four studies evaluated the effects of touchscreen configuration on user's performances. Kim *et al.* (2013) evaluated the effects of key sizes on virtual keyboards on time and accuracy for typing tasks (Kim et al., 2013) and then compared virtual and physical keyboards (Kim et al., 2014). Pereira *et al.* (2013) evaluated the effects of screen size and orientation and pen sizes on typing speed during simulated typing tasks (Pereira et al., 2013). Werth and Babski-Reeves (2014) evaluated the effects of different devices (desktop keyboard, laptop keyboard and virtual keyboard) and two postures (on a desk or on the lap when the user is seated) on time and errors (Werth and Babski-Reeves, 2014).

Discussion about the devices employed in the studies analyzed

Touchscreen equipment is available in different sizes and devices and used in different situations (*i.e.*, on a desk, handheld, in desktop settings). Our analysis of the studies reviewed show that authors were interested in the adaptation of the movements of the users for interacting with different screen sizes (Kim et al., 2013; Pereira et al., 2013), with different settings for the interactive systems (Kim et al., 2013) and diverse positions and orientations of the devices (Young et al., 2013, 2012).

Large displays can be fixed on vertical positions but they have been perceived as physically demanding for tapping and dragging tasks (Pedersen and Hornbæk, 2012). Studies evaluating tactile interaction of older adults reported arm fatigue for text entry on computers equipped with touchscreen (Umemuro, 2004). Three studies positioned the

touchscreen on vertical settings in order to assess force, impulse and dwell time of tactile interaction for motor impaired users (Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012).

Shin and Zhu (2011) demonstrated that using a touchscreen in desktop PC setting demands greater muscle activity than using traditional input devices, such as mouse and keyboard (Shin and Zhu, 2011). This configuration causes subjective discomfort of neck, shoulder and fingers. Horizontal positions should be more adapted to older adults for evaluating tactile interaction, to prevent arm fatigue. However, as the postures and movements of the users may be affected by the individual process of aging, the different situations of use of touchscreen devices by older adults should be analyzed to enhance ergonomics to this population.

It is important to note that the analysis of the movements of the users demonstrated effects of screen sizes and targets' sizes on postures and movements of the users' bodies as well as on interaction performances (Kim et al., 2013; Pereira et al., 2013). The review on HCI studies also demonstrated that different screen sizes can significantly affect users' interaction performances (Harada et al., 2013; Kobayashi et al., 2011).

II.4.2.3 *Tasks and interaction techniques*

The tasks subjects executed while their movements where registered on the reviewed studies are described in Table II.17.

Table II.17 Biomechanics studies: Tasks and interaction techniques in the studies analyzed

Task	Interaction techniques	Number of studies	References
Target selection	Tapping with finger (single-touch)	2 studies	(Irwin and Sesto, 2012; Irwin et al., 2011)
Text entry	Typing with finger and pen	5 studies	(Kim et al., 2014, 2013; Pereira et al., 2013; Sesto et al., 2012; Werth and Babski-Reeves, 2014)
Complex tasks (consisted of several sub-tasks)	Multiple gestures (e.g. tap, type and scroll) with finger	3 studies	(Shin and Zhu, 2011; Young et al., 2013, 2012)

Tapping and typing were the most frequent tasks executed. Tapping for selecting targets was executed on touchscreen devices mounted on force plates so the force motor-

impaired subjects used to touch the screen could be assessed (Irwin and Sesto, 2012; Irwin et al., 2011). One study assessed force during the evaluation of effects related to the targets' sizes effects during digit input entry (Sesto et al., 2012). One study simulated typing tasks on a cardboard (Pereira et al., 2013).

One study evaluated a complex computer task: subjects had to copy, paste and save an image using tap, typing and scrolling gestures (Shin and Zhu, 2011). These gestures of interaction are also common for the use of mobile devices as those executed during two studies (Young et al., 2013, 2012): Internet browsing, reading, receiving and answering an email message, playing a game and watching a movie.

Concerning the situations of use for the execution of the tasks described, complex computer tasks were executed on large display (Shin and Zhu, 2011) and multiple tasks on medium displays posed on a case (Young et al., 2012). Typing tasks were executed with a flat touchscreen computer horizontally placed on the lap of the users (Werth and Babski-Reeves, 2014). When horizontally placed, they were used for typing tasks on virtual keyboards (Kim et al., 2014, 2013; Werth and Babski-Reeves, 2014). On vertical positions, they were used for target selection or complex exercises. Vertical settings were used for target selection during two studies (Irwin and Sesto, 2012; Irwin et al., 2011) and digit input during one study (Sesto et al., 2012).

Discussion about the tasks and interaction techniques in the studies analyzed

When using a touchscreen, users have to perform different gestures of interaction, such as tap, drag, pinch, steer, swipe. These gestures demand different motor abilities and movements, by consequence, different adaptation of the body's postures and positions.

The studies evaluating different gestures of interaction as tap, type and scroll have demonstrated that the users adapts their bodies' movements to accomplish interaction. However, the diverse possibilities of the existing gestures of interaction on touchscreen are not fully represented in the studies reviewed.

II.4.2.4 Equipment

The equipment employed in the studies analyzed is detailed on Table II.18. This equipment assesses the postures and positions of the subjects and their movements during interaction with the touchscreen devices.

Table II.18 Biomechanics studies: Equipment employed in the studies analyzed

Equipment	Number of studies	References
Electromyograph (EMG)	6 studies	(Kim et al., 2014, 2013; Pereira et al., 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2013)
Motion capture system	3 studies	(Shin and Zhu, 2011; Young et al., 2012)
Force platforms	3 studies	(Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012)
Electrogoniometer	2 studies	(Werth and Babski-Reeves, 2014; Young et al., 2013)

Electromyograph records the electrical activity produced on the subjects' body during muscle activation. Electromyography was used to measure muscle activity on six studies analyzed to measure muscle activation and discomfort during tactile interaction (Kim et al., 2014, 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014) or holding touchscreen devices (Pereira et al., 2013; Young et al., 2013).

Motion capture systems record the movements and positions of objects or subjects. The most usual technique, optical-passive, is composed of cameras, usually infrared cameras, capable of tracking reflective markers placed in the subjects' bodies and the environment through a pre-determined sampling frequency. In the studies analyzed, motion capture systems were used to assess the subjects' postures, positions and movements in order to calculate articular deviations (*e.g.* angles between head and neck) (Young et al., 2012) as well as to measure the distance between the head and the devices (*e.g.* calculate the viewing angles) (Shin and Zhu, 2011; Young et al., 2012).

Force platforms, or force plates, are instruments to measure pressure through ground reaction forces. Force plates were used to measure the impulse and force the subjects applied to activate soft buttons on touchscreen and analyze interaction of motor impaired subjects (Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012).

Electrogoniometer is a flexible device placed on the body's articulations to measure articular angles and deviations through time. Electrogoniometer was used to measure the angles between wrist and elbow and the head position and rotation (Werth and Babski-Reeves, 2014).

Six studies assessed the positions of the subjects in relationship to the positions of the devices (Kim et al., 2014, 2013; Pereira et al., 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2012).

Three studies also assessed the subjective evaluation of the participants through questionnaires, reporting users' discomfort and fatigue (Pereira et al., 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014).

On the reviewed studies, equipment for collecting body's position and movements were non-intrusive. Table II.19 describes the parts of the body that are involved on the execution of gestures of interaction with touchscreen devices and details the equipment used for assessing the users' movements and positions.

Table II.19 Biomechanics studies: Subjects instrumentation for assessing bodies' postures and movements in the studies analyzed

Parts of the body	Number of studies and details
Head	3 studies with motion capture systems (Shin and Zhu, 2011; Young et al., 2013, 2012)
Neck	9 studies: 5 studies with electromyography (Kim et al., 2014, 2013; Pereira et al., 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2012), 3 studies with motion capture systems (Shin and Zhu, 2011; Young et al., 2013, 2012), 1 study with electrogoniometer (Werth and Babski-Reeves, 2014)
Shoulder	2 studies: 1 study through electromyography (Pereira et al., 2013), 1 study with motion capture system (Young et al., 2013)
Arm	1 study with electromyography (Young et al., 2013)
Elbow	1 study with electrogoniometer (Werth and Babski-Reeves, 2014)
Forearm	2 studies through electromyography (Kim et al., 2014, 2013; Pereira et al., 2013)
Wrist	2 studies with electrogoniometer (Werth and Babski-Reeves, 2014; Young et al., 2013)
Hand and fingers	4 studies through EMG (Kim et al., 2014, 2013; Pereira et al., 2013; Werth and Babski-Reeves, 2014)

Tracking the movements of the head was possible by the digitalization of the coordinates of markers placed on *bilateral outer canthi* (external palpebral commissures) and *bilateral tragi* (occiput cervical joint) (Young et al., 2012). For the neck, a reflective

marker was placed on the 7th Cervical vertebra (C7) (Shin and Zhu, 2011; Young et al., 2012). Electrodes were placed on the *trapezium* muscle (Kim et al., 2014, 2013; Pereira et al., 2013) or on the *sternocleidomastoid* (SCM). The elbow coordinates were tracked through a marker placed on the *lateral epicondyle* (Shin and Zhu, 2011).

Electrodes detecting muscle activity of the forearm were placed on the *extensor digitorum communis* (EDC) and *flexor digitorum superficialis* (FDS) (Kim et al., 2014, 2013; Pereira et al., 2013). For detecting muscle activation on wrist, hands and fingers, electrodes were placed on *extensor carpi radialis* (ECR) (Pereira et al., 2013; Werth and Babski-Reeves, 2014), *flexor carpi radialis* (FCR) (Pereira et al., 2013; Werth and Babski-Reeves, 2014) or *flexor pollicis brevis* (FPB) (thumb).

Only right side of the subjects' bodies was equipped during the study of Kim *et al.* (2014) (Kim et al., 2014).

Discussion about the equipment employed to assess the users' postures and movements in the studies analyzed

Whether the touchscreen device is fixed or handheld, the users adapt their movements and the bodies' position to accomplish the interaction. In the studies reviewed, different equipment has been used to assess articulatory angles, muscle activation, subjects' postures and positions around the devices. Movements of the head, neck, upper limbs and hands have been reported for the users during the execution of the gestures of interaction with touchscreen devices.

The muscle activity detected by electromyography in the users neck (Kim et al., 2014, 2013; Pereira et al., 2013; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2012), shoulder (Pereira et al., 2013), forearm (Kim et al., 2014, 2013; Pereira et al., 2013) and fingers (Kim et al., 2014, 2013; Pereira et al., 2013; Werth and Babski-Reeves, 2014) reflects the constraints of the postures for interacting with touchscreen devices. Increased muscle activation is related to increased angular deviations of the articulations and discomfort for the user (Shin and Zhu, 2011). Assessing and calculating articulatory angles is also possible through electrogoniometers (Werth and Babski-Reeves, 2014) and motion capture systems (Shin and Zhu, 2011; Young et al., 2013, 2012).

Motion capture systems have been used to assess the postures of the users in order to calculate angular deviations of the neck, shoulders and wrists (Shin and Zhu, 2011; Young et al., 2012). The advantage of motion capture systems is the possibility of

placing markers on the environment to assess information about the context and the situation of the study, such as the position of the touchscreen device.

The equipment used for assessing users' postures and movements required a controlled environment (*e.g.* university laboratory) and the markers are placed on the subjects' bodies. Concerning the evaluation of movements of older adults, these requirements can be a barrier for the acceptance of the experimental protocols. Even if they are non-invasive, older adults may be uncomfortable with the equipment, which can make difficult to include older adults as participants of experiments.

II.4.3. *Summary*

Our analysis of the selected studies about the users' movements during interaction with touchscreen devices shows that researchers have given a special attention to the ergonomics of the use of touchscreen devices. Users' upper-limbs are highly solicited for executing the gestures of interaction, not only for maintaining the arms floating and the hands moving during the interaction task, but also for holding the devices. As discussed in section II.4.1 (p. 71), age-related changes on psychomotor and physiological systems can decrease the accuracy of the gestures, which could affect interaction with touchscreen devices and explain the differences of performances when compared to younger adults, as reported in the studies analyzed in section II.3 (p.48). Indeed, studies comparing performances between users with different motor skills have demonstrated that motor impairment affected the users' movements (*i.e.* increased pressure) as well as interaction performances (*i.e.* more errors) (Irwin and Sesto, 2012; Irwin et al., 2011). For this reason, it is necessary to analyze the movements of older adults during interaction with touchscreen to try to understand the reasons of the decrease of performances commonly reported to this group of users (Findlater et al., 2013; Hourcade and Berkel, 2006).

The studies reviewed show that authors were interested in the adaptation of the movements of the users for interacting with different screen sizes (*e.g.* large screens, tablet, smartphone) (Kim et al., 2013; Pereira et al., 2013), with different settings for the interactive systems (*e.g.* targets sizes) (Kim et al., 2013) and diverse positions and orientations of the devices (*e.g.* landscape in the lap, portrait on a desk) (Young et al., 2013, 2012). Not only different tasks and interaction techniques have been evaluated (Shin and Zhu, 2011; Young et al., 2013, 2012), but also the postures of the users holding the devices (Pereira et al., 2013; Young et al., 2012). Comparing different situations of use of touchscreen devices can provide relevant information about the ergonomics of interaction.

Moreover, six of the studies we reviewed describe the relationship between the users' movements and the users' interaction performances (Irwin and Sesto, 2012; Irwin et al., 2011; Kim et al., 2013; Sesto et al., 2012; Werth and Babski-Reeves, 2014). Touchscreens offer great opportunities for enhancing the ergonomics of interaction not only for older adults but also for younger users. New touchscreen technologies are highly sensitive to touch, requiring less physical force than other input devices, such as physical keyboards (Kim et al., 2014). Previous studies have demonstrated the negative effects of key switch force (D. L. Lee et al., 2009), so improving the usability of soft keyboards could also enhance the ergonomics of typing tasks. Furthermore, GUI of tactile interactive systems can be adapted to facilitate interaction according to the user's needs and the situation of use. Different sizes of targets affects not only interaction performances, but also the movements of the users (Kim et al., 2013). Providing GUI adapted to the users' motor skills and hand span could prevent overuse of articulations and reduce the risk of musculoskeletal disorders (Sakai et al., 2006). As the studies analyzed demonstrated, the evaluation of postures and the movements of the users contribute to understand the relationship between the movements and the efficiency (Werth and Babski-Reeves, 2014) and the accuracy (Irwin and Sesto, 2012) of the interaction.

The equipment employed to assess users' postures and movements in the studies analyzed have been defined according to the objectives of the studies, more precisely, the parameters of a specific set of articulations of the users' bodies that were investigated: neck, shoulders, elbow, wrist, fingers. Motion capture systems allow recording the movements of the subjects within the context of use of the touchscreen devices, providing relevant information about the articular angles (*e.g.* neck (Young et al., 2012), shoulders (Young et al., 2013), wrist (Werth and Babski-Reeves, 2014)) as well as the positions of the user in relation to the touchscreen device (*e.g.* distance between head and screen and viewing angles (Shin and Zhu, 2011)).

Concerning the articulations involved on the movements of interaction, among the studies we reviewed, only two analyzed the postures and the movements of the users' wrists during tactile interaction (Werth and Babski-Reeves, 2014; Young et al., 2013). When compared to typing tasks on traditional keyboards, participants assumed a pronated wrist posture with increased flexion angle and increased ulnar deviation for typing on soft keyboards (*i.e.* displayed on touchscreen of a flat computer) (Werth and Babski-Reeves, 2014). Besides, holding a tablet inclined (*i.e.* handheld or resting on a case at 45° from

horizontal position) implies extreme wrist extension (greater than 27°) (Young et al., 2013). Young *et al.* (2013) explain that this uncomfortable posture of the wrist is due to the floating finger movements to avoid unintentional activation of onscreen commands or yet to avoid the occlusion of a part of the screen by the hands (Young et al., 2013). For this reason, evaluating the wrist postures and movements during the execution of gestures of interaction should provide relevant information for understanding the relationship between movements and interaction performances.

Based on our analysis of the state-of-the-art presented in this section, we propose a set of specifications and recommendations for the evaluation of the movements of older adults during the execution of the gestures of interaction with touchscreen devices. These recommendations are described in Table II.20 and they guide the experimental protocol described in Chapter V (p. 155), where we evaluate the differences between older adults and adults on postures and movements of the wrist during interaction and the consequences on time of movement and error rates.

Table II.20 Specification and recommendations for the Biomechanics evaluation of tactile interaction of older adults

Specifications	Recommendations
Posture	Subjects seated and devices horizontally placed on a desk can reduce arm fatigue. The evaluation of articulatory angles during the movements of shoulder, elbow and wrist is possible through the assessment of the angular deviation from a reference posture (neutral position).
Kinesthetic indexes	Head, neck, upper limb and hands are involved on the execution of the gestures of interaction. Additionally, compensatory movements of the trunk should also be verified. Shoulder, elbow and wrist articular motion angles and positions can be assessed to evaluate the user's strategies and the body's adaptation during tactile interaction. The wrist is very solicited during interaction with touchscreen (Werth and Babski-Reeves, 2014; Young et al., 2013). The positions and movements of the wrist can be used as a general indicator of the arrangement of upper limb movements and articulations during interaction with touchscreen.
Equipment	Motion capture system is non-intrusive equipment that can be used for assessing subjects' posture and movements as well as the positions of the touchscreen devices. Additionally, electromagnetic sensors and data glove can be used for assessing hands and fingers articular angles for complementary analysis.

II.5. *Conclusion*

The state-of-the-art presented in this chapter addresses each of our four Research Questions presented at the Introduction (Chapter I, I.3, p. 24) and defines the basis for our future design, evaluation and discussions.

In section II.1 (p. 34), we presented our analysis of the state-of-the-art on factors influencing acceptance and adoption of technologies by older adults. Six TAM models have been selected for their analysis of the specificities of this group of users (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Mallenius et al., 2007; Peek et al., 2014; Renaud and Biljon, 2008). We identified factors related to users' profiles, context, subjective evaluation and features of systems and technologies (Table II.1). Our analysis contributes to demonstrate that addressing usability issues of tactile interactive systems and touchscreen devices can facilitate the acceptance and adoption of these technologies by older users.

In order to prevent usability and accessibility issues, it is important to identify the difficulties users find during interaction since the early phases of design of interactive systems and interaction techniques. In section II.2 (p. 44), we reviewed some main recommendations to facilitate the inclusion of older adults as participants on design and evaluation sessions as well as in experimental protocols. We try to take into account factors related to the users' context and subjective evaluation to promote positive attitudes towards new technologies (Table II.2).

Then, in section II.3 (p. 48), we presented our state-of-the-art on studies of tactile interaction of older adults. We selected 36 studies on design and evaluation of tactile interactive system and interaction techniques for older adults. After the analysis of the populations included in the studies reviewed, the touchscreen devices employed, the tasks and interaction techniques evaluated as well as the evaluation criteria defined by these studies, we define the parameters and specifications for the design of the tactile interactive system (described in Chapter III, p. 93) and the methods to evaluate tactile interaction of older adults. The studies analyzed report effects of screen sizes (Kobayashi et al., 2011), input modalities (Hourcade and Berkel, 2006) and gestures of interaction on older users' interaction performances. The studies comparing performances of users from different age groups demonstrated that older users usually make more errors of interaction and take longer times but the causes of these differences should be further investigated. On the other hand, gestures of interaction requiring a continuous contact with the screen can improve the accuracy of the gesture (Mertens and Jochems, 2010;

Wacharamanotham, 2011) and reduce the effects of aging (Stöbel et al., 2010). Following the analysis presented in this chapter, our research focus on the ease of use of drag-and-drop interaction on touchscreen, the evaluation of its efficiency (time of movement and error rates) for older adults (Table II.14) and the effects of different situations of use through the experiment presented in Chapter IV (p. 121).

The methods of design and evaluation on HCI are essential to analyze tactile interaction in order to propose tactile interactive systems and interaction techniques usable and accessible to older users. However, the execution of the gestures of interaction require high dexterity and fine motor control (Jin et al., 2007; Nicolau and Jorge, 2012; Wacharamanotham, 2011) and the effects of aging on the movements of the user during interaction with touchscreen devices have been little studied. It is though necessary to complete the evaluation of interaction performances through the analysis of the movements related to the execution of the gestures of interaction through a Biomechanics study.

In section II.4 (p. 71), we presented our review of Biomechanics studies about the aging effects on postures and movements of upper limbs that could be related to the different performances of the users of touchscreen devices. First, we described main considerations about the sensorimotor, physical and high levels constraints on the movements of the upper limbs of older adults. Then, through the analysis of the parameters of ten studies (Irwin and Sesto, 2012; Irwin et al., 2011; Kim et al., 2014, 2013; Pereira et al., 2013; Sesto et al., 2012; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2013, 2012), we identified the articulations employed on the execution of the gestures of interaction, the equipment for assessing the users' movements and the specifications of an experimental protocol associating HCI and Biomechanics. The wrist being particularly solicited during tactile interaction (Werth and Babski-Reeves, 2014; Young et al., 2013), in the experiment described in Chapter V (p. 155) we focus on the analysis of this articulation to try to elucidate the reasons of the differences of performances of older adults and adults.

Chapitre 3 : Conception du système interactif tactile « Puzzle Touch »

Résumé

Dans ce chapitre, nous réalisons la conception du système interactif tactile « Puzzle Touch », qui sera utilisé lors des deux protocoles expérimentaux conduits avec des personnes âgées (Chapitres IV et V). Suite à une synthèse bibliographique des études existantes sur l'interaction tactile des personnes âgées et les recommandations présentées dans l'état de l'art, il était nécessaire concevoir un système interactif qui facilite la participation de personnes âgées de différents profils lors des protocoles expérimentaux. Des jeux de type puzzle permettent une activité familière notamment pour les personnes sans expérience préalable avec des technologies interactives (Abrahão et al., 2013; Pedell et al., 2013). De plus, le geste d'interaction choisi pour déplacer les pièces est le drag-and-drop, une technique appréciée des personnes âgées (Kobayashi et al., 2011), rapide à apprendre (Mertens and Jochems, 2010) et qui permet un geste plus précis grâce au contact continu avec l'écran (Mertens and Jochems, 2010; Wacharamanotham, 2011).

Ainsi, le système « Puzzle Touch » a été développé (HTML5, CSS3 et Javascript) en suivant les normes d'accessibilité pour les applications web (W3C) et les directives pour prendre en compte les besoins des utilisateurs âgés (Loureiro and Rodrigues, 2014).

Ce chapitre présente le premier cycle de conception et d'évaluation en suivant une méthode itérative (ISO 9241-210, 2010) en quatre étapes :

- Compréhension et spécification du contexte d'utilisation ;*
- Spécification des besoins de l'utilisateur ;*
- Production de la solution (système interactif) ;*
- Evaluation du système interactif.*

Une étude exploratoire a été conduite avec 17 sujets (58-85 ans) pour la vérification de l'appropriation du système interactif pour l'étude de l'interaction tactile des personnes âgées. Trois smartphones et quatre tablettes ont été mis à disposition des participants ; ces dispositifs acceptaient l'interaction avec le doigt ou le stylet. Les jeux de puzzle tactile avaient des pièces variant en taille et en nombre (16 petites, 12 moyennes ou 9 grandes), une seule pièce pouvait être déplacée à la fois (single touch) et le système était configuré pour que le positionnement des pièces dans leurs emplacements correspondants (cibles) soit aisé. Ainsi, la contrainte de précision des jeux a été définie

avec un niveau de 50% (à partir de ce seuil, si la pièce est positionnée sur sa cible correspondante, sa position est automatiquement ajustée).

Les résultats d'une observation empirique ont permis l'identification des postures et des mouvements des participants pour exécuter le drag-and-drop, la classification des difficultés rencontrées par les participants, des différents types d'erreurs qui en découlent ainsi que la proposition de solutions (Motti et al., 2014a). Nous avons identifié des erreurs liées aux caractéristiques des dispositifs, aux habiletés des utilisateurs, aux modalités d'interaction et aux paramètres du système interactif.

Suite à l'analyse des erreurs, des modifications ont été apportées au système interactif pour détecter et gérer plusieurs points de contact simultanés sur l'écran, afin de réduire les erreurs d'interaction. L'avantage du multi-touch est non seulement la possibilité de déplacer plus d'une pièce à la fois, mais aussi de pouvoir délimiter des zones d'interaction (les pièces du puzzle), ignorant les touches accidentelles ou les appuis de repos sur les zones en dehors des pièces, ce qui pourraient causer des erreurs. « Puzzle Touch » a ainsi été utilisé lors des protocoles expérimentaux conduits par la suite.

La principale contribution de cette étude est de démontrer que l'analyse et la classification des erreurs permettent d'identifier les problèmes à corriger lors du processus de conception d'un système interactif. De plus, et afin de tenir compte des erreurs liées aux dispositifs ou aux modalités d'interaction, il est important que les diverses situations d'usage des technologies mobiles soient considérées lors des séances d'évaluation et des protocoles expérimentaux. Nous avons démontré également comment les facteurs liés au contexte des utilisateurs (ex. l'interaction sociale) et à leur évaluation subjective des technologies (ex. divertissement) peuvent être pris en compte pour faciliter l'engagement de participants âgés lors des séances de conception ou d'évaluation ainsi que pour promouvoir l'usage des dispositifs mobiles équipés d'écran tactile auprès des personnes âgées.

III. Design of the tactile interactive system Puzzle Touch

In view of the shortcomings identified in the literature review and presented in the previous chapter, it is necessary to conduct experimental studies to evaluate interaction of older adults with touchscreen devices. In this chapter, we describe the design of the tactile interactive system that will be used for the evaluation of tactile interaction in the experiments implemented in the following chapters. Recruiting older participants and get them involved in design evaluation and experimental studies may be challenging due to the low acceptance of interactive technologies among older populations (Dickinson et al., 2007; Eisma et al., 2004). To overcome such challenge, we decided to design an interactive system that could facilitate the participation of older adults in our studies. As discussed in the state-of-the-art (Chapter II, II.2, p. 44), when designing for older users, the usability problems should be identified at the initial phases of design in order to propose appropriate solutions, suitable for the older users' needs and skills in order to improve interaction performances (Fisk et al., 2009; ISO 9241-210, 2010; Nielsen, 1993; Williams, 2009). Moreover, we based our study design on specific factors that could influence significantly the acceptance of technologies by older adults' users (Chapter II, II.1, p. 34).

Previous studies using games for older users discovering tactile interaction have described that users appreciate and get involved to the situations of the study (Abrahão et al., 2013; Barros et al., 2014; Ijsselsteijn et al., 2007; Pedell et al., 2013). When digital games are appropriately designed, facilitating the interaction for older adults with different users' profiles, expectations and needs, games can help to create a positive attitude towards technologies (Conci et al., 2009; Whitcomb, 1990), increase the users' self-esteem and enhance their overall well-being (Ijsselsteijn et al., 2007; Whitcomb, 1990). For these reasons, we decided to design an interactive system presenting tactile puzzle games. According to Pedell *et al.* (2013), puzzle games are perceived as a familiar activity, suitable for older adults with no experience of using interactive technologies (Pedell et al., 2013).

The interactive system Puzzle Touch is consisted of a series of tactile digital puzzle games. When playing the puzzle games displayed on touchscreen devices, users engage to two personal challenges: learning to execute the gestures of interaction and solving the puzzle. Accomplishing the game can be encouraging for users: being able to

play the game can make them feel like they are also able to learn and use tactile interaction and mobile technologies.

This chapter describes the first cycle of design following an iterative design method (based on the standard (ISO 9241-210, 2010)), consisting of four major steps:

- a) understanding and specifying the context of use;
- b) specifying the user requirements;
- c) producing design solutions;
- d) evaluating the design.

III.1. *Understanding and specifying the context of use*

As discussed in the state-of-the-art (sections II.1.1, p. 37, and II.3.1.1, p. 48), older adults have different skills and profiles. An interactive system targeted at such user population should be usable and accessible, allowing the inclusion of representative users during the experiments. Older adults have some reluctance on using technologies and this can also be a barrier for recruiting older participants (Dickinson et al., 2007; Eisma et al., 2004). In order to overcome this problem, we explored the four categories of factors, issued of our analysis (II.1, 34 and Table II.1, p. 36), that could influence the acceptance and adoption of technologies by older adults to generate positive attitudes towards touchscreen devices.

The interactive system Puzzle Touch that we design for the experimental studies evaluating tactile interaction of older adults might:

- Take into account the different users' profiles and help older users with different backgrounds, particularly older adults with no previous experience of using interactive technologies (Barnard et al., 2013; Lee and Coughlin, 2014; Mallenius et al., 2007);
- Take advantage of the users' context, creating social interaction and proposing support to interaction, in order to promote the use of touchscreen and mobile technologies (Barnard et al., 2013; Conci et al., 2009; Lee and Coughlin, 2014; Mallenius et al., 2007; Peek et al., 2014; Renaud and Biljon, 2008);
- Support users' subjective evaluation of touchscreen through enjoyable and pleasant activities because this kind of experiences can conduct a positive influence on the perceived usefulness and perceived ease of use of

touchscreen devices (Barnard et al., 2013; Conci et al., 2009; Peek et al., 2014);

- Focus on the characteristics of technologies and systems that can affect acceptance and adoption of technologies, especially ease of use and learnability for the first experiences of use (Mallenius et al., 2007; Peek et al., 2014; Renaud and Biljon, 2008).

Following this approach, the specification of the context of use of Puzzle Touch and the design evaluation session focuses mainly on factors from the users' context (*e.g.*, social interaction, facilitating conditions and support, described in section II.1.2, p. 38) and on factors from the users' subjective evaluation (*e.g.*, enjoyment, perceived ease of use, perceived self-efficacy, described in section II.1.3, p. 39).

Concerning the users' context, social activities have shown positive effects of group settings and familiar environments for technology acceptance (Pedell et al., 2013). Social interaction is helpful for older adults to discover interactive technologies. Another example is games developed for promoting exercising and cognitive stimulation, such as digital games to propose physical and reasoning exercises for older adults with early stage dementia (Ludlow et al., 2014). The social aspects including the ludic activities reinforce the perceived usefulness of the interactive systems for users and caregivers, these aspects can be considered to improve the use in a long-term.

Concerning the users' subjective evaluation, enjoyment can interfere on the perceived ease of use and usefulness (Conci et al., 2009) and familiarity with the interactions can lower users' anxiety levels (Barnard et al., 2013; Renaud and Biljon, 2008). Additionally, playing games can have a positive impact on users' self-esteem and self-confidence levels (Ijsselsteijn et al., 2007).

III.1.1. *Design specification for the context of use*

Indeed, considering factors of the users' context and their subjective evaluation is important to generate a positive attitude toward technologies. Social interaction, support of use and familiar activities, particularly during the first experiences with technologies, should influence the perceived usefulness and the perceived ease of use of tactile interaction and mobile devices. By consequence, design evaluation studies and recruitment meetings would take place during social activities.

The design and evaluation of the interactive system Puzzle Touch is based on the recommendations we formulated after our analysis of the state-of-the-art on tactile

interaction for older adults (II.3, p. 48). The tactile puzzle games could be played by users with different profiles (*e.g.* novice and experienced users) (Table II.2) and evaluate different situations of use, including diverse touchscreen devices (*e.g.* smartphones or tablets) and different input modalities (*e.g.* finger or pen) (Table II.14). The system Puzzle Touch can facilitate the recruitment process and allow the inclusion of older participants on design evaluation and experimental protocols.

III.2. *Specifying the user requirements*

Also discussed in the state-of-the-art (sections II.1.1, p. 37, and II.3.1.1, p. 48), the older adults are a heterogeneous population because of the individual differences in physical and cognitive declines related to age as well as their earlier experiences with interactive technologies and personal histories (Östlund, 2002). The variability of the characteristics of this population should be taken into account during the usability testing of the tactile puzzle games.

Loureiro and Rodrigues (2014) reviewed the existing usability and accessibility guidelines for web applications and they defined a set of recommendations for helping designers understanding and addressing multi-touch interaction for older adults⁷ (Loureiro and Rodrigues, 2014). In order to take into account older users' needs when interacting with touchscreen and multi-touch interfaces, Loureiro and Rodrigues proposed ten categories of design guidelines (Loureiro and Rodrigues, 2014). Based in the categories they proposed,

We defined the user requirements for the tactile puzzle games:

- 1) Target design: verify the users can identify interaction zones or adjust the size of the targets.
- 2) Use of graphics: verify the users can identify graphical elements; consider using high contrast and colors for the images.
- 3) Navigation and errors: propose simple interaction, prevent from errors and help users to recover from errors.
- 4) Content layout design: display simple design and explicit navigation cues.
- 5) User cognitive design: propose intuitive interactions, respect the older users special needs and decisions.

⁷ <https://eldermultitouchguidelines.wordpress.com/guidelines/>

- 6) Audio: if audio feedback is applied, make sure the audio information is clear.
- 7) Text design: consider participants with difficulties for reading or understanding textual information.
- 8) User feedback and support: make sure users get sufficient feedback and propose help during the first experiences of use.
- 9) Multi-touch interaction: propose gestures of interaction that are easy to understand and execute, search a comfortable position for the user and the touchscreen devices.
- 10) Interface testing: clearly inform the participants about the goals of the project and the experiment; keep the sessions short.

Since mobile devices are available in different screen sizes and operating systems, ensuring a responsive design and cross-platform development should be considered as an important accessibility requirement (Lara et al., 2010). Mobile operating systems and platforms also provide specific guidelines for improving accessibility, including the use of touch based gestures on mobile devices (Android Developers Center, 2015; iOS Developer Library, 2012; Windows Developer Center, 2015). In order to allow the use of the interactive system Puzzle Touch on different operating systems, so we choose to develop a web-based application that runs in mobile internet browsers⁸. Mobile browsers (e.g. Firefox Browser, Chrome Browser, etc.) are optimized to display content most effectively on mobile devices and support gestures of interaction with fingers or pen.

Concerning the variability of the situations of use, current web accessibility guidelines are continuously evolving to take into account the different situations of use of mobile devices. In addition to the guidelines of Loureiro and Rodrigues (2014) (Loureiro and Rodrigues, 2014), we reviewed the existing guidelines for the accessibility of mobile web-based applications for older adults from World Wide Web Consortium – W3C (e.g. Mobile Web Best Practices - MWPB, Mobile Web Application Best Practices - MWABP, Web Accessibility Initiative Accessible Rich Internet Applications Suite – WAI - ARIA). We selected the main design recommendations that should be applied for designing tactile interactive systems destined to older adults. The review of the accessibility guidelines and our analysis are presented in the Attachment (p. 285).

⁸ Web browsers are a software application for displaying web content and running client side scripting.

III.2.1. *Design specification for the user requirements*

The ten categories of guidelines as proposed by Loureiro and Rodrigues (2014) are useful to consider the main problems and difficulties faced by older adults when using touchscreen devices, embracing the main concerns about web accessibility as well as the specificities of tactile interaction. Based on these ten categories of guidelines, Table III.1 describes the user requirements for the interactive system Puzzle Touch. The user requirements extend the main specifications of design of tactile interactive systems for older adults presented in Chapter II (Table II.14, p. 70).

Table III.1 User requirements for the design of Puzzle Touch system

Set of guidelines according to Loureiro & Rodrigues (2014)	Specifications concerning the design of the Puzzle Touch system
1) Target design	The size of the targets will be defined according the literature. The results of usability tests should provide information about the most suitable sizes.
2) Use of graphics	Borders and feedback to indicate target selection. Display a watermark as a background to guide the users.
3) Navigation and errors	Feedback to show current location of targets positions, interaction zones and state of the game. Prevent from errors and help users to recovery from errors.
4) Content layout design	Concentrate all the information on the screen area and avoid scrolling. Avoid displaying distracting graphical elements.
5) User cognitive design	Consider intuitive interaction and familiar activities. Prefer illustrations to textual help.
6) Audio	If audio feedback is applied, make sure the audio information is legible, clear and without distractions.
7) Text Design	If textual information is displayed, give the users the possibility of adjust font size. Avoid scrolling for reading.
8) User Feedback and Support	Verify if participants get sufficient feedback for their actions. Propose help and support for initial learning (<i>e.g.</i> practice trials).
9) Multi-touch interaction	Tapping and dragging gestures should be easy to understand and execute for older adults. Search for a comfortable evaluation set (kind of touchscreen devices, position of devices and users postures).
10) Interface Testing	Keep the duration of the experiments short and propose breaks. Respect participants' opinions and profiles.

III.3. *Producing design solution: Puzzle Touch*

Following the specifications defined in user requirements (presented in the previous section, III.2, p.96), in this section we describe the development of the interactive system Puzzle Touch and we define the interaction settings available for the tactile puzzle games.

The images selected for the puzzle games are defined according to the goals of the experiment. The size of the game play zone, the grid of targets and the puzzle pieces are adapted to the screen size, fitting the entire screen (on portrait or landscape orientation) and preventing scrolling. In order to generate tactile puzzle games, the selected images are resized to and cropped to a 4:3 ratio; colors and contrast levels were homogenized.

A web page is designed to present the images the user can select for the tactile puzzle games. Once the user (or the experimenter) selects an image, the Puzzle Touch generates the puzzle pieces and the grid of targets according to pre-defined settings. The puzzle pieces are the same size of their corresponding targets, presented on the grid of targets. Then, the user can execute gestures of interaction for positioning the targets, solving the puzzle.

Figure III.1 illustrates a puzzle piece. Figure III.2 shows a screenshot of the initial state of the game, when the puzzle pieces are placed at the bottom and the grid of targets is presented on the top of the screen. Figure III.3 illustrates an instance of the game.



Figure III.1 One piece of the puzzle and the black border.

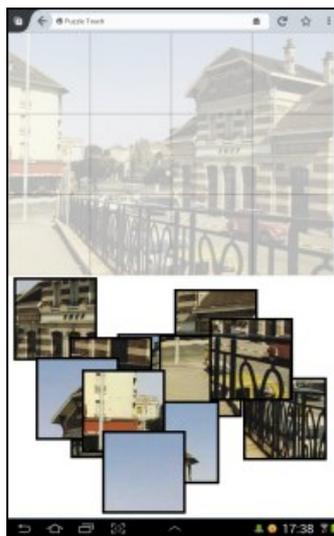


Figure III.2 Screenshot of the puzzle game at the initial state. The targets are randomly placed at the bottom and the grid with a watermark is displayed at the top.

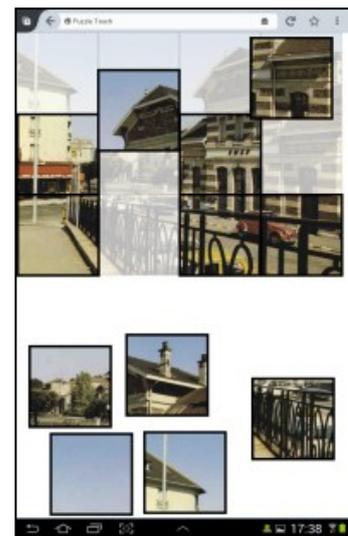


Figure III.3 Screenshot showing an instance of the game.

In order to engage the users to the puzzle solving activity, we have defined a constraint of accuracy that can be set to adapt the validation of target positioning, adjusting the challenge of the games. This parameter can be modified to facilitate (50%) or require higher accuracy (95%). The constraint of accuracy is verified once the user drops the puzzle piece over the correct emplacement on the grid (target). By default, the constraint of accuracy is set to 80%. It means that once the puzzle piece is covering 80% or more of its correspondent emplacement, its position is adjusted and its remains fixed. While the accuracy requirement is not met, the user should move the puzzle piece again.

The options for the games, or pre-defined settings, are summarized in Table III.2.

Table III.2 Options and default settings of the Puzzle Touch system

	Options of the game	Possibilities for implementation	Default settings
Target design	Target sizes	Large, medium or small	Depends on the size of the screen
	Target colors	Color or grayscale	Depends on the images selected for the game
	Targets number	Depends on the size of the targets: 9 large (grid 3x3), 12 medium (grid 4x3) or 16 small (grid 4x4)	12 pieces
	Constraint of accuracy	From 50% to 100%	80 %
Use of graphics	Spacing between targets or targets borders	Depends on the resolution of the screen	3 pixels dark border
	Shape of the pieces	Rectangular or jigsaw	Rectangular
	Background of the grid	Image on watermark, visibility can be set from 0% (invisible) to 100%.	30%
Content layout design	Position of the grid	Depend on the orientation of the screen. Top (portrait orientation) or aside	Top
User feedback and support	Feedback	Visual, tactile or sound	Visual (a flash effect)
Multi-touch interaction	Gesture of interaction	Tap or drag-and-drop	Drag-and-drop
	Number of pieces that can be dragged simultaneously	One piece (single touch) or many pieces (multi touch)	Single touch

The technical details of the development of Puzzle Touch can be found in the Attachment (p. 285). The next section describes the game play and the interaction.

III.3.1. *Description of the game play*

The main task for the user is moving each puzzle piece into its corresponding emplacement on the grid of targets, as illustrated in Figure III.2 (p. 99). When the user or the experimenter launches the game, by selecting an image, the image selected is displayed as a watermark on the background of the grid of targets, displayed on the top of the screen, and the puzzle pieces are displayed in the bottom (for touchscreen devices on portrait orientation).

When the user's finger or the pen touches a piece, the selected piece appears on the top of the others and it can be moved (dragged) inside the game zone (*i.e.* the screen space available inside the mobile web browser). As long as the contact with the screen is maintained, the puzzle piece follows the movement of the pen or the user's finger (visual feedback). When the finger or pen leaves the screen, the puzzle piece that was moving stops according to the last coordinates of the point of contact: the puzzle piece is dropped.

When the puzzle piece is dropped, the position of the piece is verified. If it is correctly placed on its corresponding emplacement of the grid, meeting the accuracy requirements set for the game, the puzzle piece is fixed. The position will be adjusted if necessary to match exactly the corresponding emplacement. There is a visual feedback (flash effect) to indicate to the user that the position is validated. The puzzle pieces correctly positioned cannot be moved anymore.

If the puzzle piece is dropped elsewhere, it should be moved again until it is dropped on its corresponding target on the grid. The game is over when all the pieces are correctly placed and a congratulations message appears on the screen.

When it is not possible to generate enough spacing between the puzzle pieces, for example when all the puzzle pieces are displayed in the bottom of the screen at the beginning of the game, they can overlay. In this situation, a black border (1 to 3 mm) is added to the puzzle pieces delimitating their interaction zone for selection and dragging. Besides, the piece selected by the user is placed on the top of the others (visual feedback).

The log files keep a track of all touch information on the screen. On each event detected, the system registers information about the game, its current state and the event itself.

III.4. *Design evaluation*

This section describes an exploratory study conducted to evaluate the Puzzle Touch as an interactive system for assessing touch information and allow us to study tactile interaction of older adults (Motti et al., 2014a).

III.4.1. *Methods*

The aim of the present study is to verify if the system Puzzle Touch can be used during our experimental protocols. The objective of this system is to allow older adults with different users' profiles (*e.g.* novice or experienced, different ages) to interact with different screen sizes of mobile devices (smartphones and tablets) and two kinds of input modalities (pen or finger). Additionally, the interactive system should help novice users to learn how to execute the gestures of interaction and promote the use of touchscreen and mobile technologies among the participants.

Following our analysis of the recommendations for including older participants on design evaluation activities, presented in Chapter II (Table II.2, p. 47), we organized an informal meeting in a local public room where people from the community can use computers and have internet access. Besides the different activities offered at this place (*i.e.* workshops about technologies, events), people can also take lessons to learn how to use a computer.

III.4.1.1 *Settings of the interactive system for design evaluation*

For the exploratory study we conducted to evaluate the design of Puzzle Touch, the users are free to select an image and the size of targets for the games on the touchscreen devices. We selected images of the city where participants live (postcards, old pictures and engraving reproductions) as well as pictures of historical places to generating the tactile puzzle games. These images we selected have different colors (grayscale, soft colors chart or color photography) and represented different subjects (landscapes, portraits, statues, objects, maps). According to the size of targets selected for the game, the puzzle games present different numbers of targets: 9 large, 12 medium or 16 small pieces.

Concerning the interaction, in the state-of-the-art presented in Chapter II (II.3, p. 48) we described several solutions that have been proposed to facilitate tactile interaction for older adults and improve the accuracy of the gestures of interaction. Following the recommendations of the studies we reviewed, drag-and-drop interaction is the main

gesture of interaction used for moving the puzzle pieces and positioning the targets (Findlater et al., 2013; Hourcade and Berkel, 2006; Kobayashi et al., 2011; Moffatt and McGrenere, 2007). The game is defined to be single-touch, one piece can be moved at a time. In order to facilitate the interaction for novice users, the constraints for positioning the targets have been initially set to 50%.

As described in the game play section (III.3.1, p. 101), the main task for the participants is to move the puzzle pieces into their corresponding emplacement on the grid. The parameters for this first cycle of evaluation and our development choices are described on Table III.3.

Table III.3 Settings of the interactive system for design evaluation

Parameter	Characteristics of the devices and development choices
Targets sizes	Large, medium and small. Depending on the screen sizes, targets will be 13 to 43 mm width
Targets number	9, 12 or 16
Targets border	1 to 3 mm dark border
Constraint of accuracy	50 %
Number of pieces that can be dragged simultaneously	One piece. This game is set to be single touch; only one piece can be moved at a time, with finger or pen.
Gesture of interaction	Drag-and-drop

III.4.1.2 *Touchscreen devices and input modalities*

The system was installed in seven touchscreen devices available for the design evaluation session. These devices had different screen sizes, allowing finger or pen interaction:

- Four tablets: three iPads with 9.7 inches screen and one Samsung Galaxy Note with a 10 inches screen,
- Three smartphones: one Samsung Galaxy Note II with a 5 inches screen, one Samsung S3 with a 4.7 inches screen and one iPhone with a 3.5 screen.

III.4.1.3 *Procedures*

The study was consisted of two sessions with two groups of users randomly assigned. It took place in a public place where the participants were used to take computer lessons at Meudon, France. One experimenter and two assistants were present in the room. The experimenter presented the procedures, interviewed the participants and took

notes. The assistants helped the participants to use the mobile devices and execute interaction.

Each section last about 90 minutes, including a presentation (20 minutes), playing time (60 minutes) and debriefing with the participants (10 minutes):

- 1) Presentation :
 - a. The experimenter presents the project and explains the design of the game.
 - b. The experimenter and the participants exchange about the touchscreen devices.
 - c. Participants gave their consent to be photographed and filmed.
 - d. The experimenter interviews the participants about their previous experiences with puzzle games, video games and use of interactive technologies (computers, mobile phones and touchscreen devices).
- 2) Playing time:
 - a. Participants were free to play, individually or in small groups (2 or 3). Participants were allowed to choose and try the different devices and input modalities. Participants were told to keep the devices on portrait mode.
 - b. After each game, an electronic questionnaire on the touchscreen devices assessed user appreciation.
 - c. The experimenter observed the activity, took notes and helped the participants to use the devices.
 - d. The assistants helped the participants to manipulate the devices, learn interaction and recover from errors.
- 3) Debriefing.

Data were collected through informal interviews, empirical observation and questionnaires. The interactive system recorded tactile interaction data on the touchscreen. After each session, the experimenter and the assistants debriefed about the interaction between participants, the interactive system and the touchscreen devices.

III.4.2. *Results*

In this section we describe the participants' profiles, their appreciation of the activity, the postures and the strategies users adopted to execute the tactile puzzle games and finally a typology of errors during the interaction with the interactive system, touchscreen and mobile devices.

III.4.2.1 *Participants*

The participants were divided into two groups so they can be followed during the learning process. The first group includes 6 older adults and 2 instructors lead the activity.

The second group includes 11 older adults and 3 instructors. We were also interested in analyzing the touchscreen devices as a support for intergenerational activity. For this reason, 5 children (9 years old) were invited to join the second group of older adults. In this thesis work, we focus on the older participants.

Seventeen older adults participated of the study. The first group was composed of six older users, two men (58 and 76 years old) and four women (66, 67, 75 and 85 years old). The second group was composed of eleven older adults, four men (74 to 83 years old) and seven women (70 to 87 years old). Two women did not want to tell their ages, but they had more than 65 years old and they were retired.

Table III.4 describes the users' profiles of the participants: gender, ages and frequency of use of puzzle games, electronic games, computer, touchscreen tablets, mobile phones or smartphone.

Table III.4 Subject's profiles

Id	Age	Gender	Plays puzzle games*	Plays video games*	Uses computer*	Uses tablet*	Uses mobile phone*	Uses smart-phone*
P1	58	M	1	1	5	1	5	1
P2	66	F	1	1	5	1	5	5
P3	67	F	1	5	5	1	5	5
P4	70	F	1	1	5	1	1	1
P5	73	F	1	1	5	1	1	1
P6	74	M	1	1	5	1	4	2
P7	75	F	1	4	5	5	5	5
P8	76	M	1	1	5	1	3	1
P9	78	F	2	4	5	1	1	0
P10	78	M	1	1	3	1	1	0
P11	79	F	5	5	5	1	1	0
P12	79	M	1	1	5	1	5	1
P13	83	M	1	1	5	1	1	1
P14	85	F	1	0	0	0	3	0
P15	87	F	2	3	3	1	3	1
P16	-	F	1	5	1	1	1	1
P17	-	F	5	5	1	1	3	1

Subject's profiles are sorted by age. *Frequency of use: 0) I do not know what it is, 1) never, 2) rarely, 3) once on a month but not every month, 4) once a week but not every week, 5) every day or almost everyday

According to previous studies about older user's interaction with computers and touchscreen, the age-related changes on cognitive (Tsai and Lee, 2009), motor (Nicolau and Jorge, 2012) and visual skills (Leonard et al., 2005) affect user's performances. Assessing the user's skills would be important to understand the difficulties they find during interaction and the variability of performances between users. However, the informal situation of this study did not allow us to measure the user's skills. Nevertheless some effects related to manual dexterity have been observed and reported.

Motor skills

Three women had some difficulty to use the devices.

- One had arthritis and complained of some pain on the arms. She did slow movements during the interaction.
- One had arthrosis and deformation on the index finger. She used the middle finger to interact.
- One woman had an injury and wore a splint on the right hand the day of the design evaluation session. She was right handed, she was not able to hold the devices but she could still uses her left hand or the right hands fingers to interact.

Vision skills

None of the participants reported visual impairments preventing them to interact with the system or the mobile devices. All of them were able to play puzzle games with small 16 pieces, even on the 3.5 inches screen device.

Previous experience with technologies and puzzle games

All the participants had already played puzzle games, mostly with jigsaw shapes on cardboard. Only one of older adult plays cardboard puzzle games regularly. Three older adults use to play electronic games almost every day (Facebook apps, online flash games, computer games with conventional input techniques as mouse and keyboard). Most of the older users present to this section uses a computer every day or almost every day.

Participants appreciation

As discussed by other studies about ludic activities and digital games, the benefits of a social activity for the design evaluation have been confirmed. All the participants were pleased to learn how to use tactile devices during this entertainment activity. They

said it was preferable to learn how to interact with an unknown technology during a ludic activity, without constraints or judgment. Playing games affected positively older users' attitudes towards technologies. They felt comfortable to ask the instructor or the more experienced users help when they had some difficulties during the activity. Working in pairs or in group help them learning from each other.

Participants were also able to discover solutions to common errors or difficulties together. For example, as the children had more experience with touchscreen devices, they were able to help the older users. Children helped the older ones to start interaction and also observed their main errors, providing solutions or correcting the gesture. Showing their interest in touchscreen devices, they encouraged older users to be more curious about it and try to discover new tips.

The situation of the study was a ludic, social and intergenerational activity for learning how to use new technologies. As the users were familiar to the images, they were pleased to play together and exchange about the activity, remembering the places and their history, but also learn how to use touchscreen devices together.

Report on observation of tactile interaction

During the exploratory study conducted for the design evaluation, we could observe the postures of the participants for holding and interacting with the devices as well as their main difficulties.

Participants used the devices handheld or placed on a desk, on their laps, over hand bags and handbooks.

Concerning the mobile devices handheld, some devices have small physical buttons on the sides and the front. When holding the devices with their hands, some users pushed the physical buttons accidentally and stopped the interaction (*i.e.*, volume button, power button, back to the previous page, quit to the main screen).

Concerning the screen orientation, portrait mode allowed right handed and left handed users to use the same interface. It was also good for group playing because targets were moved from the bottom to the upside part of the screen, so users could be positioned in front or by the sides of the devices.

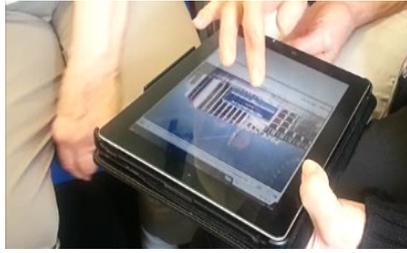


Figure III.4 Picture: users interacting together. One user holds a tablet by the side on portrait mode and another user touches the screen with a middle finger

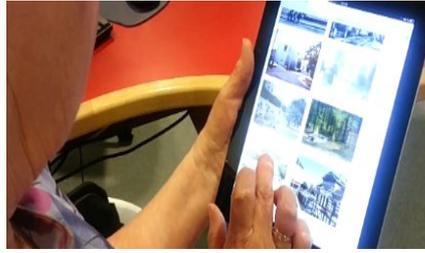


Figure III.5 Picture: one user holds a tablet by the side, but some devices have power and volume button at this emplacement. The user uses the middle finger to interact



Figure III.6 Picture: one user holds a smartphone on the hand and interacts with the index finger



Figure III.7 Picture: during a collaborative situation, one user shows the screen to the others and uses the small finger to interact. The device is hold by the bottom



Figure III.8 Picture: during an individual interaction, the tablet is placed on a desk and the user places the hands to avoid reflection of the light on the bright screen

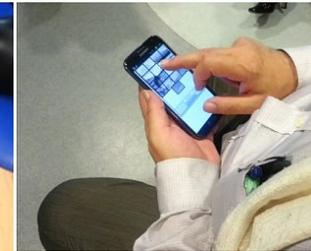


Figure III.9 Picture: one user holds a smartphone with his left hand and his thumb touches the volume button

Sometimes the gesture of the finger or the pen was not registered by the device (long nails, side of the finger, side of the pen). Users felt frustrated and changed the input modality (pen to finger, finger to pen) or the finger (index, middle finger, smaller fingers to smaller pieces). They appreciated the pen because it does not hide the screen as much as the hand.

For interacting with the pen, the pen should be kept upper straight. If the pen is laid down, the touchscreen cannot recognize the gesture, as illustrated in Figure III.10. In Figure III.11, the user uses the finger to interact but still holding the pen. The user is also holding the tablet by the bottom but some devices have power or start buttons at this emplacement.



Figure III.10 Picture: the pen is laid down. The screen does not recognize the interaction

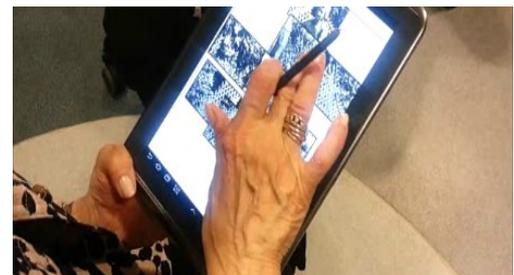


Figure III.11 Picture: the user holds the pen but interacts with her fingers

For the design evaluation, the interactive system is set to be single-touch. We could observe some errors related to this setting. For example, during the interaction with the index finger, one user places the palm of the hand on the tablet, as shown in Figure III.12 and Figure III.13. The puzzle piece that was moving appears on this second touch emplacement, under the user's hand, as shown in Figure III.14.



Figure III.12 Picture: the user touches a puzzle piece with index finger

Figure III.13 Picture: the user drags the piece to its corresponding position

Figure III.14 Picture: the user's hand (palm) touches the bottom of the screen and the pieces appears on this second touch emplacement

Participants strategies for tactile interaction

The different postures employed by the participants show how users adapt their positions according to the situation and to device to accomplish interaction.

Different strategies for interacting have also been observed and analyzed. Some of them are not supported by the system but could be implemented later. They are described on the Table III.5.

Table III.5 Strategies of interaction on touchscreen of older users observed in the present study

Strategies	Supported by the system	Proposals and support
Slipping the finger or the pen from the initial position to the final position: slowly	Yes	-
Slipping the finger or the pen from the initial position to the final position: fast	No, the pieces arrive later	Optimize the performances of the system Puzzle Touch
Small gestures pushing the piece	Yes	Smoothing the gestures Tutorials Online help to new users
Fast gestures, pushing the pieces as they would continue on the same direction	No, pieces stay where the finger released the screen	Similar to a swipe, test the direction and continue the trajectory of the targets

Typology of errors

The group setting during the design evaluation session did not allow the access to the individual performances during the games. However, the empirical observation provided enriching information about the difficulties the participants found when manipulating the touchscreen devices and interacting with the system. Globally, the difficulties the users find during interaction generate errors of interaction, for example: holding the pen laid down prevents the user to execute the gestures of interaction, or pushing the power button causes the interruption of the interaction.

We have summarized the difficulties and common errors we observed and classified them according to their causes. Some are related to the device, the input modalities, the interaction techniques or the user profiles. Table III.6 describes the common errors as well as some proposals to address and prevent these errors.

Table III.6 Common difficulties users find during interaction with touchscreen devices and tactile interaction, common errors that occur and proposals for solution

Typology	Causes and difficulties	Errors	Proposals
Devices	Small buttons are hard to find, to identify and to push, such as power button, volume controls.	Pushing physical buttons, unintentionally or by mistake, can disturb or interrupt the interaction.	Special case to hide physical buttons (<i>i.e.</i> inside a box, with a flap, a slipping panel). Different design of the device displaying explicit buttons.
	Onscreen controls and soft buttons are hard to find and to identify, such as back to home, previous page, and screenshots.	Touching onscreen controls or soft buttons, unintentionally or by mistake, can disturb or interrupt the interaction.	Possibility of disabling onscreen controls and soft buttons. Define a constant location. Better design of the onscreen controls and interaction areas for easier identification.
	Reflection on the screen can disturb the visibility of the display.	Not identifying the interaction zones or selecting an undesired option.	Using a protector film.
	Finger marks on the screen can disturb the visibility of the display.	Not identifying the interaction zones or selecting an undesired option.	Using pen interaction. Provide cleaning tissue.
	Difficult to hold with the hands.	-	Special case to prevent the device of slipping or falling down.
Input modalities	Holding the pen lay down.	Pen based interaction is only detected when the pen is hold straight up.	Pen could allow contact by the sides.
	Small buttons on the pen are difficult to identify.	Pushing the pen buttons, unintentionally or by mistake, interfere on the interaction.	Pen could have explicit buttons. Possibility of disabling pen buttons.

Interactive system	Detect and prioritize only one touch on the screen.	Puzzle pieces appear on the second touch position (i.e., Figure III.14)	Enable multi-touch interaction. Delimitate interaction zones.
Users' profiles	Difficulties to keep arms, wrist and hands floating during interaction.	Secondary touches because the users place the palm of the hand or other fingers on the screen to control the movements.	Prefer pen interaction. Provide support: the system could identify unintentional touches.
	Hands or fingers hiding a part of the screen.	Interacting with fingers sometimes disturb the visibility of the display.	Prefer pen interaction. Adapting target sizes and positions.
	Unregistered touches (low capacitance, dry skin, fingers side or nails).	-	Pen interaction would be more convenient.

III.4.3. Discussion

The aim of this study was to verify the design of Puzzle Touch as an interactive system to be used during experimental studies of tactile interaction of older adults. We were interested in observing the acceptance of the design evaluation activity for older adults, analyzing the interaction with the system and observing how older users execute drag-and-drop interaction, try different input modalities and manipulate touchscreen devices. The tactile puzzle games were installed in seven different mobile devices, with different screen sizes (from small smartphones to large tablets) and allowing interaction with pen and fingers.

The design evaluation took place as an exploratory study, during a social activity in a familiar place. We were able to create a favorable context for learning and sharing about technologies. During the debriefing, older adults demonstrated their interest in learning more about the touchscreen and the mobile technologies and novice users appreciate the tactile puzzle games to learn and accomplish tactile interaction.

The application of the existing accessibility guidelines has been demonstrated to be effective. The interactive system, conceived as a web application, was successfully installed in different mobile devices, running different operating systems. It allowed users to interact with different screen sizes and use different input modalities. Drag-and-drop interaction has shown to be an effective interaction technique for moving the puzzle pieces even in small screen sizes.

Concerning the graphical interface and the targets design for the interactive system, the images we selected were helpful to arouse the participants' interest to the activity. The size of the targets and the interaction technique were appropriate for older

users, they were able to understand and execute the interaction. The smallest targets were smaller than 16 mm width on a 3.5 inches screen smartphone but no users found they were not too small to be moved. The colors and details of the images helped the users to solve the puzzle games even with small targets.

The results obtained present the postures of the participants for manipulating the devices and the executing the gestures of interaction as well as the strategies they employed for accomplishing the task. Additionally, results of the empirical observation provide an exhaustive report of problems and difficulties the users found during interaction. The difficulties were related to the devices, the input modalities, the settings of the interactive system or even the users' skills. In most of the times, the difficulties generated errors of interaction, such as unintentional activation of onscreen controls interrupting the interaction (Harada et al., 2013; Kobayashi et al., 2011).

Our results present a detailed report and classification of the common errors according to their causes. This classification allows us to define the parameters of the interactive system that should be modified in order to improve its usability for older adults. The next section describes how this adaptation will be applied to a new version of Puzzle Touch, followed by a conclusion of the analysis of the design evaluation.

III.5. *Application of results and new design*

In view of the analysis presented in the previous section, the settings of the interactive system Puzzle Touch have been modified to redress some of the usability problems identified during the exploratory study we described. The single-touch version of the interactive system makes it difficult to detect and prioritize more than one simultaneous touch on the screen. This setting generate errors of interaction: the puzzle pieces the users are moving appear on the second touch position, disturbing the execution of the gesture of interaction. Our proposal to solve this problem is to enable multi-touch interaction and delimitate interaction zones.

By consequence, the interactive system has been optimized to detect simultaneous points of contact on touchscreen. This version of the system allows multi-touch interaction, *i.e.* two or more pieces can be moved by the user at the same time. The consequence of the activation of the multi-touch is the possibility of delimitating the interaction zones in order to try to identify unintentional touches on the screen. For the tactile puzzle games, the interaction zones are the puzzle pieces. When the user selects a puzzle piece by touching this graphical element with a finger or a pen, the puzzle piece

will follow the touch coordinates as long as there is a contact of the user finger or pen with the screen. Touching outside or around the puzzle pieces (e.g., blank areas of the game zone, the grid of targets, pieces already placed) does not trigger any action.

After the modification of this setting, the interaction areas of the game play are independent: as the puzzle pieces are dragged, touching the empty zones around targets do not interfere on the current position of other pieces. By doing so, we prevent errors related to secondary touches, *i.e.*, when the user places the palm of the hand or another finger over the screen inadvertently, for resting or for better controlling the movements of the fingers; it does not interfere on the movement of the puzzle pieces. Besides, this adaptation does not affect the appearance of the games for the users, as exemplified in Figure III.15 and Figure III.16.

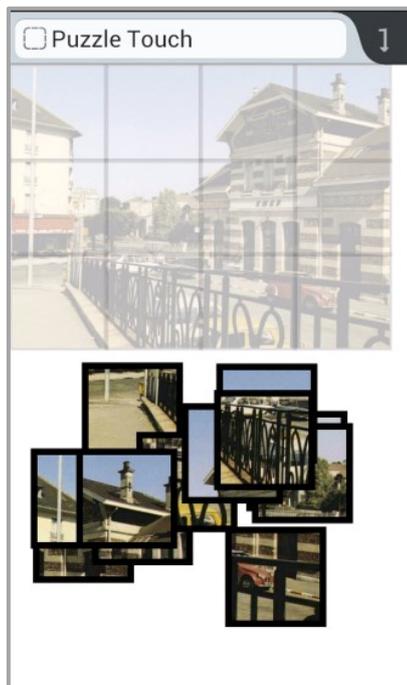


Figure III.15 Screenshot of an initial state of a puzzle game of the system Puzzle Touch after the modification of the parameters: multi-touch interaction and prioritization of interaction zones (puzzle pieces)

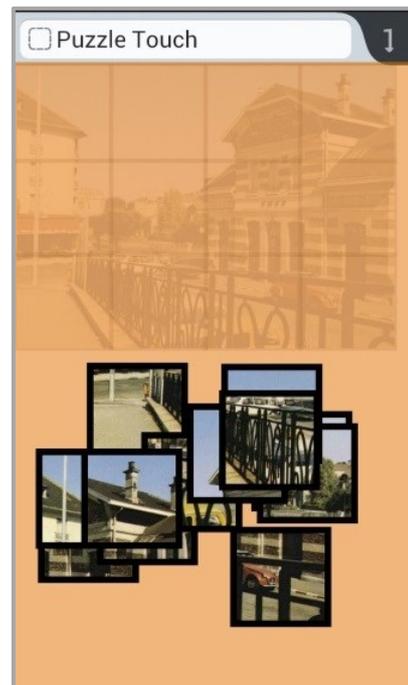


Figure III.16 Screenshot of an initial state of a puzzle game of the system Puzzle Touch highlighting the filtered zones (orange colored), where accidental touches does not interfere on the users' interaction

III.6. Conclusion

In this chapter we described the design of the interactive system Puzzle Touch. According to our analysis of factors influencing the acceptance of interactive technologies by older adults, presented in Chapter II (II.1, p. 34), we considered factors related to the users' context (*e.g.* social interaction) and subjective evaluation (*e.g.* enjoyment) to design an interactive system that could facilitate the participation of older adults. Then, following an iterative design method, we specified the context, the users' requirements and produced the first version of the interactive system. Finally, we conducted an exploratory study to verify the possibility of using this system during the experimental protocols to evaluate tactile interaction of older adults.

The main contribution of this chapter is our analysis of the process of design of tactile interactive system destined to older adults, addressing our Research Question 2 (How to design tactile interactive systems to older adults?).

Our choices for the design and the evaluation method were helpful to introduce the tactile interaction and touchscreen device to older adults, especially to the novice ones. Taking into account elements from the users' context, creating a social activity and supporting the participants during their first experiences with the interactive system created a positive attitude of the participants towards the system and the devices. This kind of activity is well suited to this group of users and should be adopted for recruitment meetings. Concerning their subjective evaluation, playing a game has been well perceived by the participants. They expressed less anxiety and they did not hesitate to interact or make mistakes, creating a more natural environment for the study. Tactile puzzle games can be used for assessing touch information and allow the evaluation of tactile interaction of older adults. This confirms the usefulness of Puzzle Touch for our experimental protocols. Moreover, in order to favor the discovery and use of technologies among elderly populations, we recommend this approach for design evaluation sessions, usability studies and first experiences with mobile devices, when it is possible.

The empirical observation resulted on the identification of usability problems that older users faced during interaction with tactile interactive systems and the manipulation of touchscreen devices, such as unintentional activation of onscreen controls and difficulties for executing the gestures of interaction. Indeed, most of difficulties participants found during interaction generated errors, which are frustrating for the users, who need to develop strategies for recovering or ask for support. The identification of the causes of difficulties and errors and this analysis contributes to complete our answer to

our Research Question 1 (What are the factors preventing older adults to use mobile technologies?). This demonstrated that errors occurred during tactile interaction prevent older adults to use mobile technologies.

The main interest in the typology of errors was to define errors related to the interactive system. These errors were addressed through the adaptation of the parameters of the interactive system. The interaction zones have been delimited and this adaptation prevent errors related to unintentional touches on the screen.

Concerning the errors related to the devices or input modalities, it is necessary to evaluate tactile interaction of older adults in different situations of use of touchscreen. Moreover, it is important to take into account the diversity of user profiles. The experimental protocol implemented in Chapter IV (p. 121) evaluates tactile interaction of older adults in order to better understand the factors influencing performances during drag-and-drop interaction. We also evaluate how the delimitation of interaction zones is effective for preventing errors related to unintentional touches on the screen.

The present chapter described the first cycle of an iterative design method for Puzzle Touch. In a future work, Puzzle Touch could become a serious game for helping older users to learn tactile interaction. More than entertainment and pastime applications, there are games being designed with therapeutic and informational endings (Gamberini et al., 2009; Ordonez et al., 2011). For example, serious games destined to older users aim to stimulate cognitive skills (Vasconcelos et al., 2012), promote exercising (Leinonen et al., 2012) or help to learn interaction (Abrahão et al., 2013). The future versions of Puzzle Touch should dynamically modify the settings of the system (*e.g.*, accuracy constraints, number and size of targets) in order to adapt the challenge of the game to the progress of the user. Perspectives for continue the design of Puzzle Touch are presented in the Attachment (p. 285).

Chapitre 4 : L'étude de l'interaction drag-and-drop sur écran tactile pour les personnes âgées

Résumé

L'objectif de ce chapitre est d'identifier les facteurs qui influencent l'utilisabilité de l'interaction tactile par les personnes âgées. Un protocole expérimental a été mis en œuvre pour évaluer les effets de taille d'écran, de modalité d'interaction et des profils utilisateur sur le temps et les taux d'erreurs de l'interaction drag-and-drop pendant la réalisation de puzzles tactiles avec le système « Puzzle Touch ».

Nous souhaitons également évaluer l'adéquation du drag-and-drop aux habiletés motrices des personnes âgées. Pour la vérification de la précision du geste d'interaction, le système « Puzzle Touch » a été modifié afin de présenter des jeux avec deux niveaux de contraintes pour le positionnement des cibles : un niveau plus difficile, demandant beaucoup de précision (95%) et un plus facile, ajustant les pièces automatiquement au-delà d'un seuil de 80% de recouvrement de la cible. Les jeux ont été paramétrés pour afficher douze pièces carrées.

24 sujets âgés (65-86 ans) ont participé à cette étude. Des vérifications avant l'expérience ont permis de déterminer les profils des participants, incluant un test pour la vue et des questionnaires sur leur expérience préalable avec des technologies interactives (ordinateurs et écrans tactiles). Les coordonnées des touches sur les écrans tactiles ont été enregistrées par le système interactif, y compris les touches en dehors des zones d'interaction, et une grille d'observation a été remplie par l'expérimentateur durant l'expérience. Comme mesures d'utilisabilité, nous avons calculé le temps de mouvement par cible et le nombre d'erreurs de précision. Nous comptabilisons une erreur lorsqu'une pièce est déposée en recouvrant au moins 50 % de la bonne cible sans atteindre un recouvrement de 80 % (versus 95%) selon le niveau de précision demandé.

Globalement les sujets ont fait moins d'erreurs durant l'interaction avec le stylet, spécialement sur le smartphone (Motti et al., 2014b) mais nous avons observé une grande variabilité de temps de mouvement et du nombre d'erreurs entre les sujets.

La diminution de la contrainte de précision requise pour positionner les cibles a permis d'augmenter l'utilisabilité de l'interaction sur les différentes situations de l'étude (smartphone et tablette, doigt et stylet). Le temps de mouvement a été réduit de 3 +/-1.9 secondes par cible à 2 +/-1.2 secondes par cible et le nombre d'erreurs de

positionnement a été divisé par cinq. Cette adaptation a aussi permis de diminuer la variabilité des performances entre les sujets.

Afin d'expliquer cette variabilité, une analyse sur les effets d'âge a été conduite. La variabilité des deux mesures (temps et erreurs) augmente avec l'âge. L'analyse des médianes nous fait remarquer que parmi le groupe de participants âgés de 80 ans ou plus certains ont accompli des temps de mouvement plus courts et fait moins d'erreurs que les participants âgés entre 75 et 79 ans. Pour expliquer ce résultat, nous avons vérifié les effets de l'expérience préalable des participants avec des technologies interactive. En effet, les sujets qui utilisent un ordinateur ont réalisé des temps de mouvement plus courts et ont fait deux fois moins d'erreurs que les autres sujets.

Concernant l'expérience préalable avec écrans tactiles, les personnes expérimentées ont réalisé des temps plus courts mais il n'y a pas de différence significative pour le nombre d'erreurs avec les personnes novices. Cela démontre que le drag-and-drop tactile est facile à apprendre pour les utilisateurs novices (Motti et al., 2015a).

Par rapport aux jeux de niveaux plus difficile, la réduction de la contrainte de précision pour le positionnement des cibles a supprimé la différence significative du nombre d'erreurs entre les sujets ayant ou pas un usage fréquent de l'ordinateur. Nous affirmons donc que la réduction de la contrainte de précision a amélioré l'accessibilité pour les utilisateurs ayant moins d'expérience avec les technologies, en particulier avec des ordinateurs (Motti et al., 2015b).

Nous avons vérifié l'incidence de la délimitation des zones d'interaction (pièces du puzzle) et constaté que l'interaction avec le doigt a engendré douze fois plus de touches en dehors des zones d'interaction que l'interaction avec le stylet (ex. touches accidentelles).

L'étude décrite dans ce chapitre démontre l'appropriation du drag-and-drop tactile pour les personnes âgées en diverses situations d'usage (tablette et smartphone, doigt et stylet). Cette technique est facile à apprendre pour les personnes n'ayant pas d'expérience avec les technologies interactives et doit être envisagée sur d'autres applications. De plus, l'adaptation des niveaux de contrainte pour le positionnement des cibles permet d'améliorer l'utilisabilité et l'accessibilité de l'interaction.

IV. Study of the drag-and-drop interaction on touchscreen for older adults

In the previous chapter, we designed Puzzle Touch, a tactile interactive system for assessing touch information during tactile interaction of older adults. Following an iterative design method, we considered the characteristics of this population in order to facilitate their participation during the experiments (our recommendations are described in Chapter II, Table II.2, p. 47). Older participants were able to accomplish drag-and-drop interaction with different screen sizes and input modalities and they appreciated the activity. After the design evaluation, the settings have been modified to improve the usability of the system, delimitating the interaction zones in order to prevent errors of interaction. By consequence, the Puzzle Touch system will be used to include older participants on our next experiment.

Drag-and-drop interaction has been recommended to older adults because previous studies demonstrated that it can improve the accuracy of the gestures (Mertens and Jochems, 2010; Wacharamanotham, 2011), interaction performances improve rapidly (Kobayashi et al., 2011; Mertens and Jochems, 2010) and older adults prefer this interaction technique to tap (Kobayashi et al., 2011), that requires higher manual dexterity.

The aim of the present chapter is to evaluate the appropriateness of drag-and-drop interaction on touchscreen for older adults. As touchscreen devices are available with different screen sizes and used with different input modalities, we need to evaluate interaction on smartphone and tablet with pen and fingers. The accessibility of tactile interaction means to take into account the situations of use of mobile devices as well as characteristics of users with different profiles and needs. So we are also interested in evaluating effects of aging and previous experience with interactive technologies on the users' performances.

In this chapter, we will address our Research Question 3: Which aspects of use of touchscreen can affect usability and accessibility of tactile interaction for older users?

In order to evaluate the accuracy of the gestures of drag-and-drop interaction, the settings of the interactive system Puzzle Touch have been modified to require two different levels of constraint for positioning the targets. Additionally, we demonstrate how the delimitation of interaction zones implemented after the design evaluation

(Chapter III, III.5, p. 112) help to prevent errors related to unintentional touches on the screen.

IV.1. *Experimental design and methods*

In this section we present our main hypothesis and the experiment designed to their verification: the settings of the interactive system, the experimental task, the touchscreen, the procedures, the measures we defined for the evaluation and the analysis of the collected data.

IV.1.1. *Hypotheses*

Four main hypotheses have been formulated for this study.

Hypothesis 1: The responsive layout of the system Puzzle Touch adapts the sizes of the targets to the size of the screen. Bigger sizes of the targets have been recommended to older adults because it facilitates target acquisition during tap tasks with pen (Hourcade and Berkel, 2006) and finger interaction (Hwangbo et al., 2013; Jin et al., 2007). We hypothesize that interaction on smartphone is error prone and takes longer times because the smaller size of the targets that requires more accurate interaction.

Hypothesis 2: Reducing the number of errors and avoiding supplementary manipulation is a main requirement for usability of interaction. For this reason, lowering the constraints of accuracy for positioning the targets reduces time of movement and number of errors, facilitating drag-and-drop.

Hypothesis 3: Because of the aging effects on sensorial and cognitive skills (Caprani et al., 2012) it is expected that times of movement and error rates increase with the age. The oldest subjects take longer times or make more errors.

During finger interaction, the hand is partially hiding the screen, while pen interaction allows a better visibility of the targets' positions. So our fourth hypothesis concerns the number of unintentional touches during the interaction.

Hypothesis 4: Pen interaction reduces the number of unintentional touches.

IV.1.2. *Settings of the interactive system for interaction evaluation*

The game play as described in the design evaluation is maintained (III.3). The game is over when all the puzzle pieces are correctly placed.

The games were generated with 12 squared puzzle pieces and the target sizes were adapted according to the size of the screen. Table IV.1 describes the size of the targets on smartphone and on tablet and the settings of the interactive system.

Table IV.1 Settings of the interactive system

Parameter	Characteristics of the devices and development choices
Targets sizes and number	12 medium targets: <ul style="list-style-type: none"> • 19x19mm on the smartphone (85 pixels width) • 35x35mm (195 pixels width) on the tablet
Constraints of accuracy	Two levels: 80 % at the lower level and 95% at the higher level
Number of pieces that can be dragged simultaneously	One piece or more. This game is set to be multi-touch.

For the following experiment, devices will be blocked on portrait orientation. The image is presented as a watermark on the background for the grid to reduce the cognitive workload for the task, so participants can be focused on the accuracy of their gestures. The grid of targets is displayed on the top of the screen and consisted of three lines and four columns; each emplacement corresponds to one of the twelve puzzle pieces randomly placed on the bottom of the screen.

In order to evaluate the effects of drag-and-drop on the accuracy of the gestures, two levels of constraints for positioning the targets have been set for the game: high and low accuracy. The higher constraint of accuracy requires dropped pieces to be covering at least 95% of their corresponding target. If this condition is met, the piece is magnetized to fits it's exact position and cannot be removed. The covering threshold for the lower constraint is set to 80%.

Figure IV.1 shows a screenshot of an instance of the game. Figure IV.2 illustrates a puzzle piece that does not match the covering threshold required for a high accuracy level; it should be moved again until the accuracy requirement is match. Figure IV.3 illustrates a puzzle piece correctly placed. When the piece is correctly placed, its position is automatically adjusted, there is a visual feedback (the piece “flashes”) and the piece remains fixed.



Figure IV.1 A screenshot of the system Puzzle Touch



Figure IV.2 Example of positioning: the piece is covering less than 95% of its emplacement and should be correctly positioned



Figure IV.3 Example of positioning:) the piece is covering at least 95% of its emplacement and the positioning is validated

Following the procedures of the design evaluation, we selected images of different views of the city subjects live in to arouse their interest and create social interaction. Therefore eight images were selected generating one puzzle game for each condition (Appendix VII.4.1, p. 237). Informal tests during the demonstration meetings allowed the verification of the readability of the images and the playability of the games on high and low constraints of accuracy.

IV.1.3. *Task*

The main task is dragging the puzzle pieces, randomly displayed below the grid, to their corresponding emplacement on the grid (targets). Once the user touches a puzzle piece with pen or finger, the piece follows the movement as long as there is a contact with the screen (drag). When the user releases the screen, the piece stops (drop).

IV.1.4. *Touchscreen devices and input modalities*

The devices have been chosen for this study: a smartphone (Galaxy Note II, screen 5.5 inches WXGA 1280x720 Super AMOLED) and a tablet (Galaxy Note 10.1,

screen 10.1 inches WXGA 1280x800 LCD). Both devices allow interaction with pen and fingers. The pen is 115 mm long and 6 mm of diameter.

IV.1.5. *Procedures*

For the recruitment of subjects, the Puzzle Touch system and the goals of this study were presented on associations regrouping senior citizens and public libraries where older adults were used to frequent or take computer lessons at Toulouse, France. Being aged of 65 years old or more was the only criteria of inclusion.

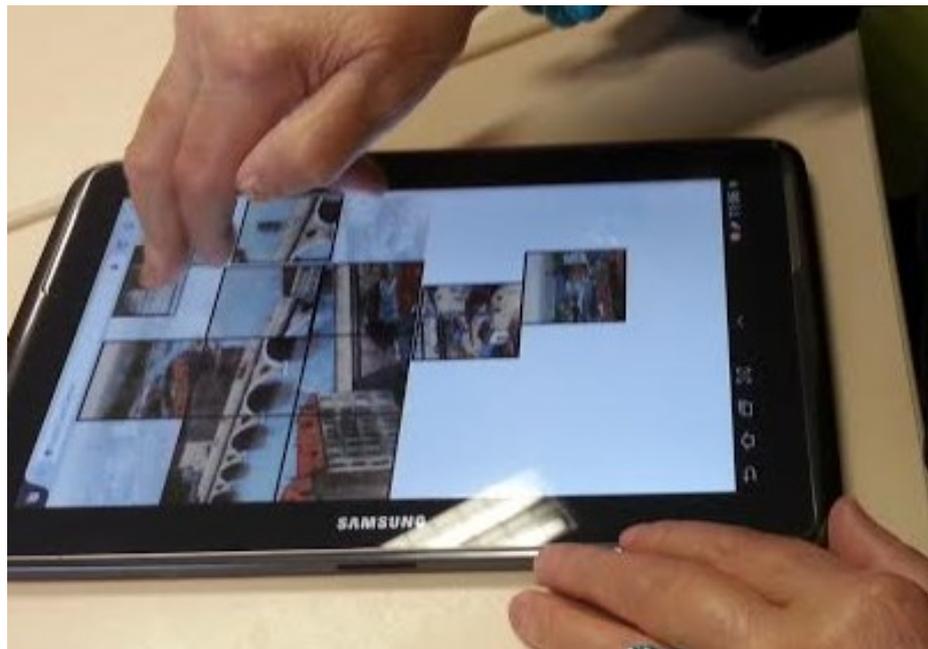


Figure IV.4 Picture: older adult playing a tactile puzzle on a tablet during a recruitment meeting

After a demonstration meeting, volunteers had an appointment for an individual session.

The individual sections took place in a quiet place (separated room or library) with artificial light at the evening. It lasts about 30 minutes. Participants signed a written consent form. Subjects were seated and the devices were horizontally placed on a table, but not fixed. The experiment schedule followed was:

- 1) Every subject passed a learning phase (at least 4 practice games with both devices and interaction techniques at the lower accuracy level).
 - a. Any touch outside the game play zone has not been blocked (buttons, menus and tactile shortcuts). During the learning phase, the experimenter advised the participants about the physical buttons and the interactive zones of the touchscreen.
- 2) Then subjects passed a pre-experiment verification in order to provide information about their skills and experiences. They were informed that the

goal of this experiment is to evaluate the interaction technique and the interactive system, not their abilities. Data collected by the pre-experiment test and questionnaires will be used to better understand the variability of performances between subjects.

- a. We started by eyesight tests of vision from near. Three applications for eyesight tests, presented in Appendix VII.3.1 (p. 231), were installed and displayed on the smartphone. They were chosen to measure color perception, central vision acuity and contrast sensitivity.
 - b. Due to time constraints and privacy, they were not questioned about their cognitive capabilities and there were no other measures through testing. However, subjects were questioned about any motor control problem, injury or difficulty of accuracy that could affect hands, fingers, arms or upper-limb movements. Then they were questioned about educational levels, practice of puzzle games or electronic games and previous experience with technologies: how often they use computers, cell phones, tablets and smartphones, and if they have any of these devices. This questionnaire is filled up by the experimenter (Appendix VII.2.2, p. 228).
- 3) During the experiment, each subject executed eight tactile puzzle games.
- a. Subjects were told to play the games with accuracy.
 - b. They played four games on each device (smartphone and tablet): with two input modalities (pen and finger) and two accuracy levels (80% and 95%). On each device, they executed first the games the easier level, then the games requiring higher accuracy. The order of the devices and input modalities has been counter-balanced.
 - c. Every touch inside the game zone has been registered by the interactive system (coordinates, targets and timestamp). A detailed description of the procedures for registering touch information is presented in the technical documentation (Attachment, p. 285).
 - d. While subjects executed the tasks, the experimenter filled an observation grid (Appendix VII.2.1, p. 227), taking notes about user's postures, movements of hands and fingers, main difficulties and comments. This data will be used for better understand the variability between subjects and their postures. At the end of the experiment, subjects were questioned about appreciation, preferences and difficulties (Appendix VII.2.3, p. 230).

IV.1.6. *Measures*

IV.1.6.1 *Independent variables*

The independent variables treated on the present study are: constraints of accuracy (high and low), screen sizes (smartphone and tablet) and input modalities (pen and finger).

Additionally, we are interested in investigating the effects of some characteristics of the subjects' profile: age and experience of using technologies, particularly computers and touchscreen.

IV.1.6.2 *Dependent variables*

For the present study we have defined three dependent variables as evaluation criteria: time and errors. Additionally, the system registered the number and the coordinates of unintentional touches. How these variables have been calculated is described below.

Time: mean time of movement per target

The instruction for the task was to execute the games with accuracy. For this reason, on the present study, we evaluate time of movement. Total time of movement refers to the time subject spent moving the puzzle pieces. Contrarily to the time of completion, it does not include reflection time or reaction time because we considered that they are related to the puzzle solving activity. Time of movement takes into account all the sub-movements users may execute for positioning the targets. The mean time of movement per target is the ratio between the total time of movement of a game and the number of targets.

Errors: mean number of errors of per target

An error of accuracy occurs when a puzzle piece is released in its right emplacement, covering at least 50% of the target, but it does not match the 95% accuracy requirement set for the game. We fixed this 50% threshold because it indicates the user was able to find and reach the correct target. The number of errors of accuracy measures the number of supplementary moves for positioning a target accurately. As long as the accuracy requirements are not met, the subject needs to move the piece again.

We considered that pieces dropped outside the grid of targets or on wrong targets could be a part of the strategy for the games. By consequence, we defined errors of accuracy as the only evaluation criterion for error rates.

The ratio between the total number of errors of accuracy of a game and the number of targets has been calculated.

Unintentional touches: mean number of touches outside the interaction zone per target

The Puzzle Touch system has been set to prioritize the interaction zones, i.e., the puzzle pieces. This adaptation, based on our analysis of the results of the design evaluation (III.5), doesn't affect the layout of the game but is supposed to prevent errors related to unintentional touches. The touches around the puzzle pieces but inside the game zone do not trigger any interaction. However, on encumbered layouts or other applications (e.g. soft keyboards, menus), unintentional touches on "blank" zones or onscreen controls, such as icons, can trigger events and generate errors of interaction.

The coordinates of the touches outside the puzzle pieces have been registered. The ratio between the total number of unintentional touches during a game and the number of targets has been calculated.

IV.1.7. Data analysis

Data is not normally distributed according to the results of Shapiro Wilk test (for all subjects, time: $W= 0.88$, $p\text{-value}= 2.59e-11$; errors: $W= 0.79$, $p\text{-value}= 2.202e-15$, unintentional touches: $W= 0.58$, $p\text{-value} < 2.2e-16$).

Consequently, the analysis of significant effects was made with statistical test for non-parametric data. Wilcoxon signed rank test has been used to look for significant effects of the constraints of accuracy, screen sizes and input modalities. Kruskal-Wallis test has been used for verifying age effects (four age-ranges). Mann-Whitney U test has been used to look for significant effects of participants' profile (use of computers, use of touchscreen). A Bonferroni correction has been applied for the post-hoc analysis of subsets of data, setting the p-value to 0.025.

Data distribution curve for time and errors is skewed left. For this reason we detailed the median values to indicate tendencies and one inter-quartile value to indicate deviations.

IV.2. Results

In this section, we describe the profiles of the participants, the effects of the different situations of the study, the effects of the different users' profiles, the effects of the settings of the interactive system (constraints of accuracy) and the analysis of the unintentional touches detected during interaction.

IV.2.1. *Participants*

24 older adults (range 65-86, mean 74.25, SD= 5.70) participated in the experiment. They were 16 women and 8 men.

Results from the eyesight tests and data assessed through the initial questionnaire were used to characterize the subjects' profiles and they are detailed on Table IV.2.

Five participants were not able to correctly describe all the images presented on the screen during the eyesight tests, but they were able to complete the tactile puzzle games during the learning phase and the experiment, so their participation has been retained. They have been identified on the table as subjects with insufficient eyesight correction (IC). All the other subjects had sufficient eyesight correction (SC).

The following characteristics are based on their answers to the initial questionnaire.

Concerning their educational level, 13 subjects did primary school; the other 11 completed higher education.

We asked if they have any difficulties for moving the hands or fingers or any injury or illness that could affect manual dexterity. 15 subjects did not report any dexterity problems. 9 subjects reported some dexterity difficulties because of common motor control decline related to the normal aging such as arthrosis (3 subjects), ancient injuries affecting fingers or hands movement (3 subjects) or sensibility (1 subject), light tremor (2 subjects). Even if this group of subjects reported dexterity problems, they were able to complete the tactile puzzle games during the learning phase and the experiment.

Subjects were also questioned about their experience of using technologies.

Concerning the use of computers, 16 reported having a computer and using it regularly (almost every day) and 8 reported not having a computer and rarely using one

Concerning their previous experience of using touchscreen, 8 subjects reported having a touchscreen device (smartphone or tablet) and using it regularly (almost every day). The other 16 reported no possession of touchscreen devices and no previous experience of using interactive technologies.

Table IV.2 Subject's profiles

Users	Age	Gender	Education	Sight*	Dexterity (self-reported)	Use of computer**	Use of touchscreen**
P1	65	Male	Higher	SC	Normal	5	5
P2	65	Female	Primary	SC	Normal	5	1
P3	66	Female	Higher	SC	Normal	5	1
P4	68	Male	Higher	SC	Normal	5	1
P5	69	Female	Higher	SC	Normal	1	1
P6	70	Male	Primary	IC	Difficulties (tremor)	1	1
P7	70	Female	Higher	SC	Difficulties (moving the finger)	5	1
P8	71	Male	Primary	SC	Normal	1	1
P9	72	Female	Higher	SC	Difficulties (sensibility)	5	1
P10	73	Female	Primary	SC	Difficulties (arthrosis)	1	1
P11	73	Female	Primary	SC	Difficulties (moving the finger)	2	5
P12	74	Female	Higher	SC	Difficulties (arthrosis)	4	1
P13	74	Female	Higher	SC	Difficulties (arthrosis)	5	1
P14	74	Female	Higher	SC	Difficulties (arthrosis)	4	4
P15	74	Male	Primary	SC	Normal	5	2
P16	77	Male	Primary	SC	Normal	5	5
P17	77	Female	Primary	IC	Normal	1	1
P18	78	Male	Higher	IC	Normal	5	5
P19	80	Female	Primary	SC	Normal	5	5
P20	80	Female	Primary	SC	Normal	1	1
P21	82	Female	Primary	SC	Difficulties (moving the hands)	3	1
P22	82	Male	Higher	SC	Normal	5	1
P23	82	Female	Primary	IC	Difficulties (tremor)	1	1
P24	86	Female	Primary	IC	Normal	5	5

*Based on the results of the eyesight verification: SC) Sufficient correction, IC) Insufficient correction.

**Frequency of use: 1) I never use it, 2) I have already used or I rarely use it, 3) I use it at least once a month, 4) At least once a week, 5) Every day or almost every day

From the notes taken in the observation grid, we are able to report main considerations about their postures for accomplishing tactile interaction.

All the subjects used the right hand to interact. Index and major were the common used fingers for finger interaction. Thumb, index and major were the three fingers used to hold the pen during pen interaction. No subject tried multi-touch interaction; they moved one piece at a time.

According to their answers to the final questions, we report their preferences and comments about the interaction.

Concerning their preferences, 9 participants said they prefer finger interaction and 8 participants say they prefer pen interaction. The other 7 participants said they do not have any preference. 14 participants prefer playing the puzzle games with the tablet rather than the smartphone and 1 participant prefers the smartphone. 9 participants do not have a favorite screen size.

21 participants appreciated playing puzzle games at the touchscreen devices and they would like to continue the activity. The other 3 participants wouldn't have searched for this kind activity on touchscreen devices by themselves.

IV.2.2. *Effects of screen sizes and input modalities*

For evaluating the effects of the screen sizes and input modalities on interaction performances of older adults, we consider games on high and low accuracy requirements together in order to improve the representation of the variety of situations of interaction on touchscreen.

IV.2.2.1 *Screen sizes*

Globally, subjects took longer times on tablet than on smartphone, even if they made more errors on smartphone. Mean time of movement per target was 2.6 +/-1.5 seconds on tablet and 2.4 +/-1.5 seconds on smartphone. The number of errors per target during interaction on smartphone was 0.6 +/-1.6 and on tablet 0.4 +/-0.7.

Effect of screen sizes are statistically significant on time ($Z= -3.87$, $V= 1270$, $p\text{-value}= 0.0001$) and on errors ($Z= 1.68$, $V= 2788$, $p\text{-value}= 0.0013$).

IV.2.2.2 *Input modalities*

Mean time of movement per target during finger and pen interaction was about the same even if subjects made more errors during finger interaction than during pen interaction. Time for finger interaction was 2.5 +/-1.6 seconds per target and for pen 2.4 +/-1.4 seconds per target. The number of errors per target during finger interaction was 0.6 +/-1.3 and 0.4 +/-1 during pen interaction.

Input modalities did not have significant effects on time of movement ($Z= 1.96$, $V= 2863$, $p\text{-value}= 0.05$) but effects were significant on number of errors ($Z= 0.64$, $V= 2502.5$, $p\text{-value}= 0.0006$).

IV.2.2.3 Screen size and input modalities

On smartphone, there were more errors during finger interaction (0.6+/-1.4) than during pen interaction (0.5+/-1.5) for a small difference on time of movement (finger: 2.5 +/- 1.5 seconds, pen: 2.3 +/- 1.6 seconds). Effects of input modalities techniques were not significant on time ($Z= 1.29$, $V= 714$, $p\text{-value}= 0.2$) but significant on number of errors ($Z= 0.56$, $V= 642.5$, $p\text{-value}= 0.0061$).

Interacting on tablet, probably due to the bigger size of the screen and targets, canceled or reduced the effects of input modalities on time and on errors. During finger interaction, subjects made 0.6 +/- 0.9 errors and spent 2.6 +/-1.7 seconds per target and during pen interaction they made 0.4 +/-0.7 errors and spent 2.6 +/-1 seconds per target. There is no significant effect of input modalities on time ($Z= 1.54$, $V= 738$, $p\text{-value}= 0.13$) neither on errors ($Z= 0.29$, $V= 616.5$, $p\text{-value}= 0.04$).

Even if there was no significant difference for input modalities during tablet interaction, the number of errors for all subjects on both screen sizes and both accuracy levels showed that pen allowed more accurate interaction. Time of movement was longer during finger interaction on both screen sizes.

Figure IV.5 shows mean time of movement and Figure IV.6 shows mean number of errors per target on smartphone and tablet according to the input modalities. We can observe that there is a bigger variability on error rates on smartphone.

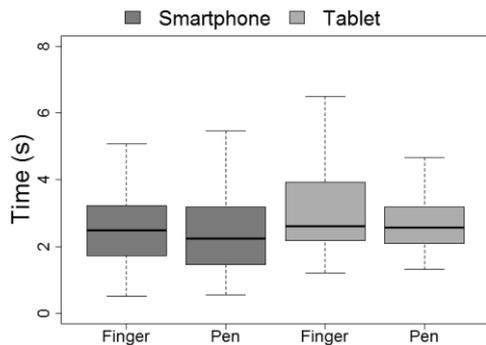


Figure IV.5 Time of movement per target (s) according to the device and input modality for both accuracy requirements.

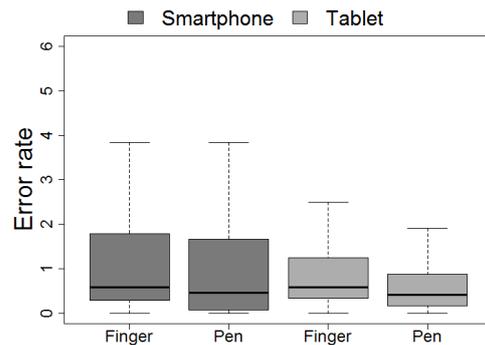


Figure IV.6 Mean number of errors per target according to the device and input modality for both accuracy requirements..

IV.2.3. Effects of lowering the accuracy requirements on interaction

performances

In this section, we are interested in the effects of the different accuracy requirements for positioning the targets.

The mean time of movement for positioning a target for all subjects was reduced from 2.83 +/-1.9 seconds per target during the high accuracy level games to 2.08 +/-1.2 seconds per target during the low accuracy level.

Concerning the mean number of errors per target, subjects made on average 5 supplementary gestures to adjust pieces accurately on high accuracy levels. The number of errors decreased from 1.33+/-1.83 during high accuracy levels to 0.25 +/-0.33 during low accuracy level.

Statistically, the effects of the constraints of accuracy required for positioning the targets were significant on time ($Z= -7.78$, $V= 199$, $p\text{-value}= 7.36e-15$) and on the number of errors ($Z= -8.34$, $V= 45.5$, $p\text{-value} < 2.2e-16$).

However, there is a big variability of interaction performances between subjects. In order to try to understand this variability, we investigate the differences between the situations of the task.

Lowering the constraint of accuracy reduced time and number of errors with both input modalities, on both screen sizes. Table IV.3 shows mean time of movement per target and mean number of errors per target on both accuracy requirements on smartphone and tablet, during pen and finger interaction. The difference is significant between the eight situations of the experiment on time (chi-squared= 128.37, $DF= 23$, $p\text{-value} < 2.2e-16$) and on number of errors (chi-squared= 102.36, $DF= 23$, $p\text{-value}=5.49e-12$).

Table IV.3 Time and errors on both accuracy requirements for the different situations (medians and inter - quartiles)

Constraints of accuracy	Device	Input modality	Time (s)	Errors
High accuracy	Smartphone	Finger	2.95 +/-1.61	1.79 +/-2.40
		Pen	2.78 +/-2.08	1.67 +/-1.67
	Tablet	Finger	3.57 +/-2.10	0.88 +/-1.33
		Pen	2.59 +/-1.09	0.79 +/-1.04
Low accuracy	Smartphone	Finger	2.08 +/-2.08	0.29 +/-0.42
		Pen	1.55 +/-0.83	0.08 +/-0.19
	Tablet	Finger	2.39 +/-1.21	0.33 +/-0.46
		Pen	2.53 +/-1.24	0.25 +/-0.33

Figure IV.7 shows the differences in mean time of movement per target and Figure IV.8 shows the differences in for mean number of errors per target for each association of device and input modality.

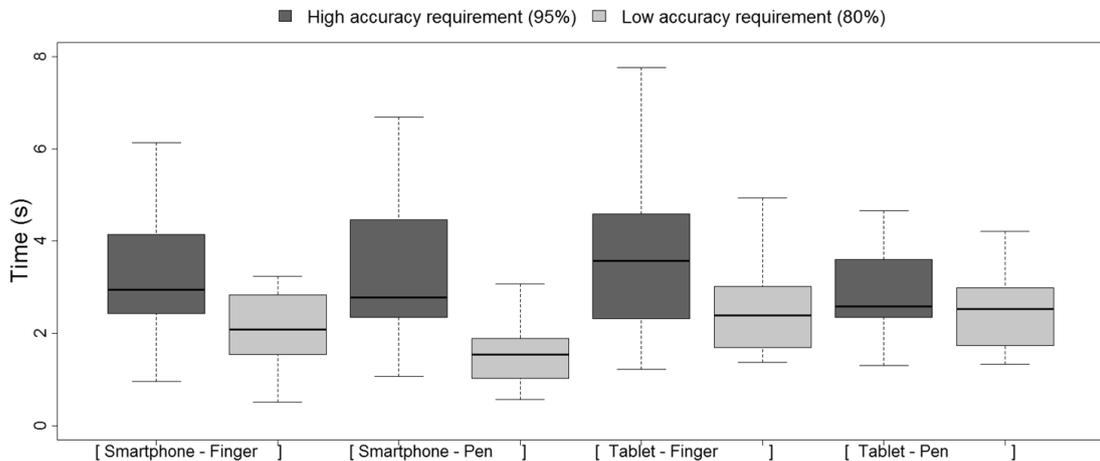


Figure IV.7 Time of movement per target (in seconds) according to the device, input modality and constraint of accuracy. Lower constraint of accuracy reduces time of movement during finger and pen interaction on smartphone and tablet.

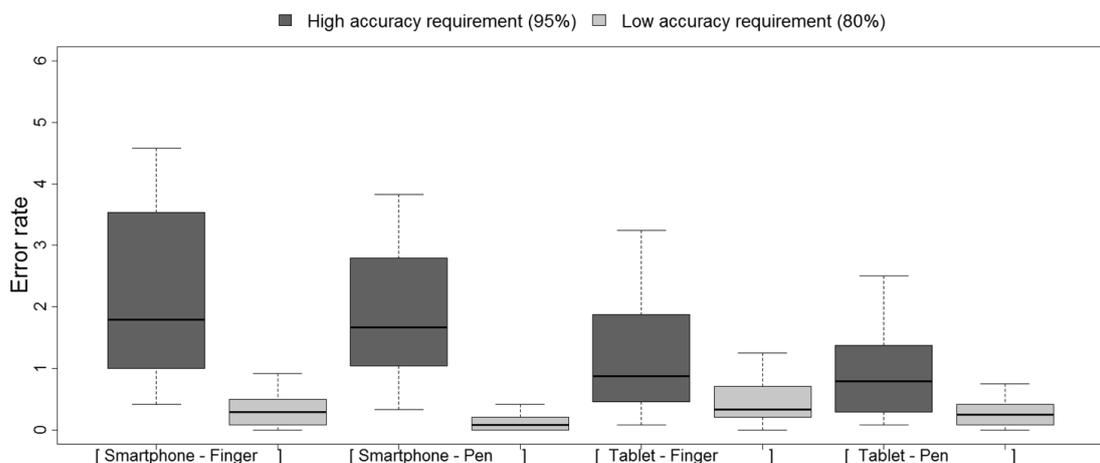


Figure IV.8 Mean number of errors per target according to the device, input modality and constraint of accuracy. Lower constraint of accuracy reduces number of errors during finger and pen interaction on smartphone and tablet.

There is a great variability of interaction performances between subjects during all situations of the study, especially for the levels requiring higher constraints of accuracy. This result shows that the lower constraints of accuracy improve accessibility on smartphone and tablet, for pen and fingers interaction. Next, in order to try to understand the variability between subjects, the effects of aging have been investigated.

IV.2.4. *Effects of aging*

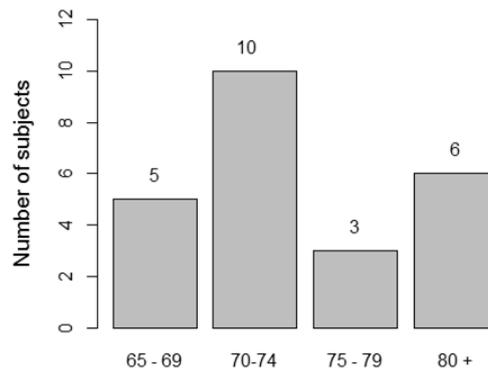


Figure IV.9 Number of subjects according to their age range

To evaluate the effects of aging, subjects have been divided into four age-groups: 65 to 69 years old (5 subjects), 70 to 74 years old (10 subjects), 75 to 79 years old (3 subjects), 80 or older (6 subjects). Figure IV.9 shows the number of subjects on each age-group.

The values of mean time of movement per target for each group are: 2.37 +/-0.8 seconds for subjects aged 65 to 69, 2.37 +/-1.2 seconds for subjects aged 70 to 74, 3.55 +/-1.6 seconds for subjects aged 75 to 79 and 3.04 +/-2.6 seconds for subjects aged 80 or older. We could say that time of movement is related to the age because older adults spent longer times and the variability also increases with the age, but surprisingly the median time of movement for the oldest group (80 years old or older) is inferior to the group of subjects aged 75 to 79. For the two accuracy levels required for the games together, there is a significant effect of age on time (chi-squared= 19.66, DF= 3, p-value= 0.0002). Figure IV.10 shows mean time of movement per target for each age-group.

Concerning the number of errors per target, values by age range are as follows: 0.29 +/-0.5 for subjects aged 65 to 69, 0.5 +/-1.13 for subjects aged 70 to 74, 0.83 +/-1.16 for subjects aged 75 to 79 and 0.63 +/-1.65 seconds for subjects aged 80 or older. The variability and the number of errors increases with the age but subjects aged 80 years old or older made fewer errors of accuracy than subjects aged 75 to 79. Effects of aging were also significant on number of errors (chi-squared= 15.84, DF= 3, p-value= 0.001) considering the two levels of accuracy together. Figure IV.11 shows mean number of errors per target for each age-group.

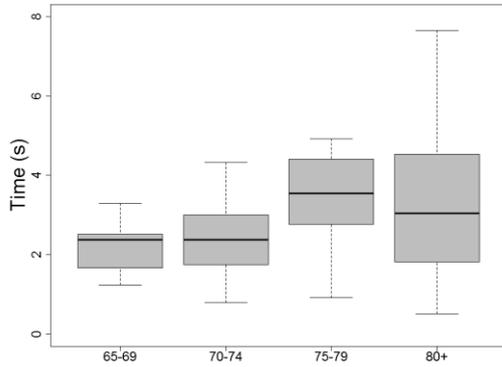


Figure IV.10 Time of movement per target (in seconds) according to the age-groups. Variability increases with age..

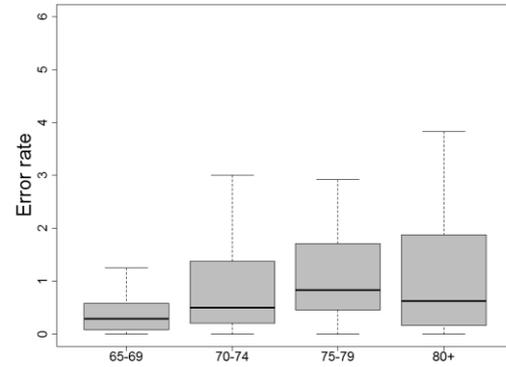


Figure IV.11 Mean number of errors per target according to the age-groups.

As discussed in the state-of-the-art (Chapter II, II.1.1, p. 37), previous experience of using interactive technologies can have an effect on interaction performances. In order to better understand the variability between subjects of all age groups and the better performances of the oldest users, we searched for effects of their previous experience with computers and touchscreen.

IV.2.5. *Effects of experience of using interactive technologies*

IV.2.5.1 *Experience of using touchscreen*

Subjects with previous experience using touchscreen spent 2.26 +/-1.4 seconds per target and the novices spent 2.58 +/-1.6 seconds. Despite the similar values, previous experience of using touchscreen had significant effects on time ($Z= 10.52$, $W= 5205.5$, $p\text{-value}= 0.002$).

The difference was not significantly different on number of errors ($Z= 7.60$, $W= 4406.5$, $p\text{-value}= 0.39$). This may indicate that the experience of using touchscreen helps users to interact faster. However, novice users are able to execute drag-and-drop interaction to accomplish the tactile puzzle games as accurately as experienced users.

Figure IV.12 and Figure IV.13 show times and error rates, respectively, for novice or experienced users of touchscreen.

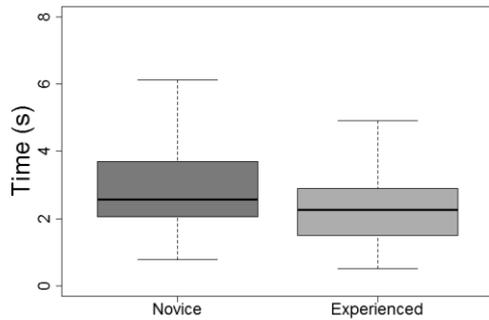


Figure IV.12 Times of movement per target for novice and experienced users

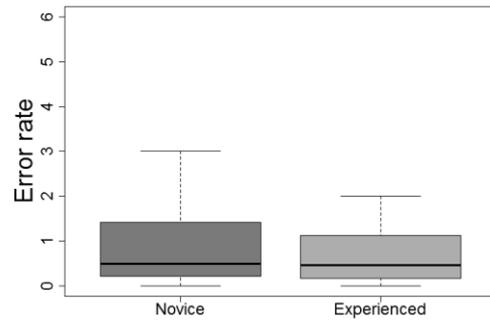


Figure IV.13 Number of errors per target for novice and experienced users

IV.2.5.2 Experience of using computer

Subjects who use computers spent 2.35 +/-1.2 seconds per target and the other subjects spent 3.02 +/-1.9 seconds. Subjects who use computers made about 0.42 +/-0.93 errors per target and subjects who do not use a computer made 0.79 +/-1.54 errors per target. The difference between these groups of subjects has been confirmed as statistically significant on time ($Z= 12.66$, $W= 5792.5$, $p\text{-value}= 2.98e-06$) and errors ($Z= 9.46$, $W= 4915.5$, $p\text{-value}= 0.02$) but the variability in performances remain important for the two groups.

Figure IV.12 and Figure IV.13 show times and error rates, respectively, according to the experience of using computers of the participants.

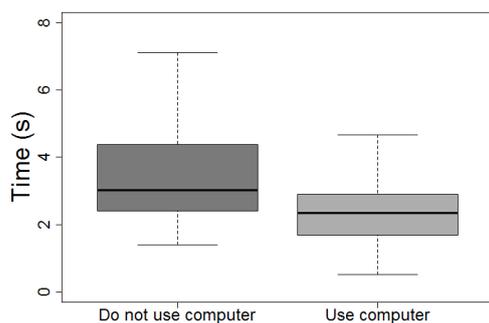


Figure IV.14 Times of movement for subjects with and without experience of using computers

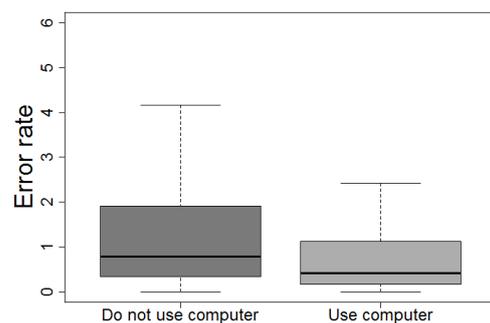


Figure IV.15 Number of errors for subjects with and without experience of using computers

IV.2.6. Effects of the constraints of accuracy for different age groups

The variability between subjects diminishes during the lower accuracy levels. By consequence, the effects of the constraints of accuracy have been investigated for the different subjects' profiles according to their age group.

Table IV.4 details mean time of movement and mean number of errors per target on high and low constraints of accuracy according to the age groups. Concerning the age groups, significant effects were found during high accuracy levels on time (chi-squared= 19.19, DF= 3, p-value= 0.00025) and errors age (chi-squared= 19.33, DF= 3, p-value= 0.0002). Effects of aging are still significant during low accuracy levels on errors (chi-squared= 11.77, DF= 3, p-value= 0.008) but not on time (chi-squared= 7.06, DF= 3, p-value= 0.07).

Table IV.4 Time and errors on high and low accuracy levels according to age groups (medians and inter - quartiles)

Users profile effects	Time on high levels	Time on low levels	Errors on high levels	Errors on low levels
65-69	2.40 +/-0.48*	1.98+/-0.88	0.58+/-0.60*	0.08 +/-0.27*
70-74	2.59 +/-1.12*	1.81+/-1.00	1.33 +/-1.96*	0.25+/-0.29*
75-79	4.42 +/-2.10*	2.99 +/-1/76	1.71 +/-1.48*	0.50 +/-0.46*
80 or older	3.98 +/-2.87*	2.37 +/-1.94	1.88 +/-2.04*	0.17 +/-0.38*

* Significant effects of aging: p-value < 0.025

IV.2.7. Effects of constraint of accuracy for participants with different experience of using interactive technologies

IV.2.7.1 Experience of using touchscreen

Concerning the previous experience with technologies, there was no significant difference between novice and subjects who had experience of using touchscreen on time (Z= 6.90, W= 1261, p-value= 0.07) neither on errors (Z= 5.32, W= 1106.5, p-value= 0.52) during the high accuracy levels. The difference is significant on time on low accuracy levels (Z= 8.11, W= 1379, p-value= 0.0059) but not on number of errors (Z= 5.99, W= 1172.5, p-value= 0.25).

Subjects with experience of using touchscreen took shorter times on both accuracy levels, but they benefited of low accuracy requirements to reduce time of movement more than novice users. Table IV.5 describe mean time of movement and mean number of

errors per target during high and low accuracy levels for the two groups of subjects according to their experience of using touchscreen.

Table IV.5 Time and errors during high and low accuracy levels according to the experience of using touchscreen (medians and inter - quartiles)

Subjects' profile	Time for high levels	Time for low levels	Errors for high levels	Errors for low levels
Use touchscreen	2.63 +/-1.37	1.68 +/-1.11*	1.13 +/-1.33	0.17 +/-0.27
Do not use touchscreen	3.01 +/-2.18	2.36 +/-1.35*	1.33 +/-1.94	0.29 +/-0.42

* Significant differences of experience of using touchscreen: p-value < 0.025

IV.2.7.2 *Experience of using computer*

There were significant effects of use of computers on time ($Z= 9.17$, $W= 1482$, p-value= 0.00038) and on errors ($Z= 8.30$, $W= 1397.5$, p-value= 0.004) for the high accuracy levels. During the low accuracy levels there is still a significant effect of use of computer on time ($Z= 9.12$, $W= 1477$, p-value= 0.00044). However, no significant difference was found on errors ($Z= 5.96$, $W= 1168.5$, p-value= 0.26). Table IV.6 describe mean time of movement and mean number of errors per target during high and low accuracy levels for the two groups of subjects according to their experience of using computers.

Even if subjects using computers made fewer errors than subjects without experience of using computers, lowering the constraints of accuracy reduced the effects of experience with technologies on accuracy of drag-and-drop interaction.

Table IV.6 Time and errors during high and low accuracy levels according to the subjects' profiles: use of computer (medians and inter - quartiles)

Subjects' profile	Time for high levels	Time for low levels	Errors for high levels	Errors for low levels
Use computer	2.59 +/-1.37*	1.76 +/-0.10*	1.04 +/-1.44*	0.17 +/-0.33
Do not use computer	3.88 +/-3.54*	2.78 +/-1.50*	1.92 +/-2.33*	0.33 +/-0.44

* Significant differences of experience of using computer: p-value < 0.025

IV.2.8. *Unintentional touches*

In this section, we evaluate the number and the coordinates of the touches outside the interaction zones (*i.e.* puzzle pieces). These touches do not interfere on the

displacement of the puzzle pieces. These unintentional touches have been more frequent during finger interaction, as described on Table IV.7. The effects of the situations of the study on the number of unintentional touches is statistically significant (chi-squared= 50.19, DF= 23, p-value= 0.00087).

Table IV.7 Number of unintentional touches per target for pen and finger interaction on smartphone and tablet (medians and inter - quartiles)

Device	Input modality	Number of unintentional touches (per target)
Smartphone	Finger	0.71 +/-1.56
	Pen	0.00 +/-0.21
Tablet	Finger	0.67 +/-0.69
	Pen	0.08 +/-0.10

There is no significant difference between the screen sizes ($Z = -3.39$, $V = 1401$, $p\text{-value} = 0.90$) but the difference between the two input modalities has been statistically confirmed ($Z = 5.12$, $V = 3728.5$, $p\text{-value} = 1.24e-15$).

In order to analyze the positions of these unintentional touches, the coordinates of the touches for all subjects on low and high constraints of accuracy have been represented on density plots. Figure IV.16 and Figure IV.17 represent the density of areas of unintentional touches on smartphone during finger and pen interaction, respectively. We can observe that unintentional touches are more frequent on the bottom part of the screen, where the puzzle pieces should be acquired to be positioned on the grid.

Figure IV.18 and Figure IV.19 represent the density of areas of unintentional touches on tablet during finger and pen interaction, respectively. There is a bigger concentration of unintentional touches the bottom-right part of the screen, probably because subjects were right handed and could have accidentally touched the screen while moving the puzzle pieces.

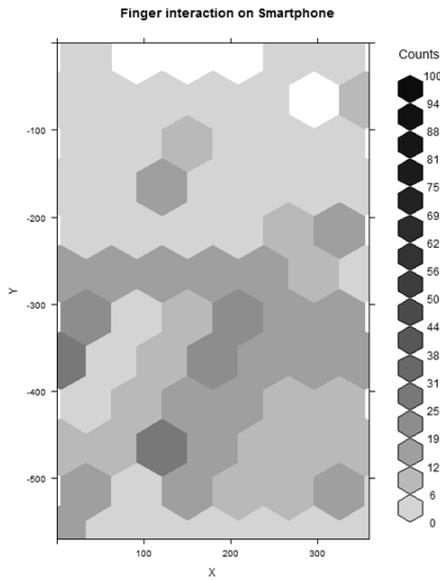


Figure IV.16 Representation of areas of bigger density of unintentional touches during finger interaction on smartphone

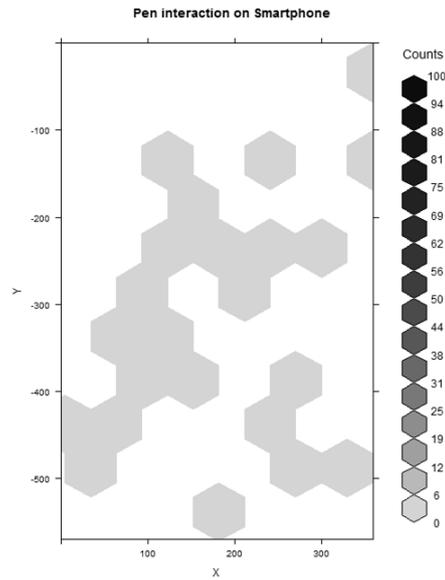


Figure IV.17 Representation of areas of bigger density of unintentional touches during pen interaction on smartphone

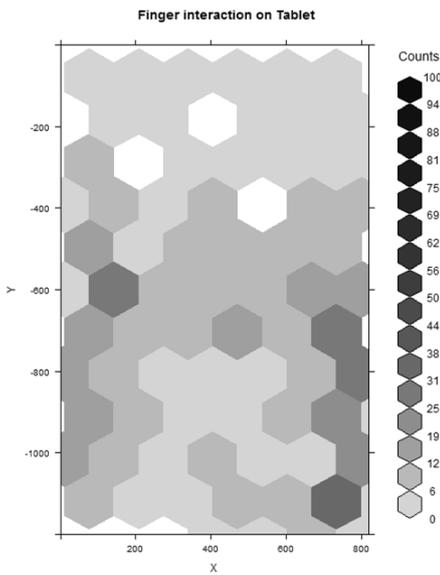


Figure IV.18 Representation of areas of bigger density of unintentional touches during finger interaction on tablet

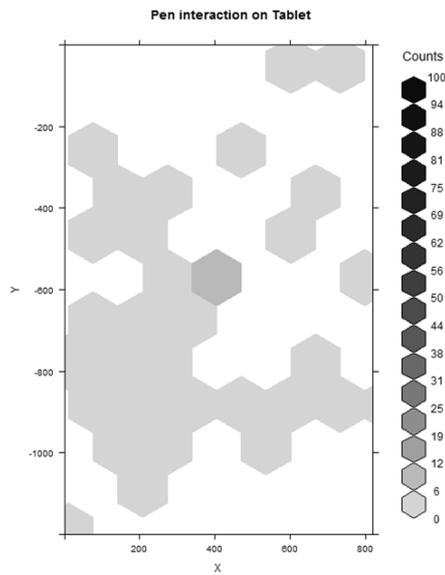


Figure IV.19 Representation of areas of bigger density of unintentional touches during pen interaction on smartphone

IV.3. Discussion

The aim of the present study is to evaluate the appropriateness of drag-and-drop interaction on touchscreen for older adults, on different screen sizes, during pen and finger interaction. Additionally, we verified the effects of two levels of constraints for positioning the targets and the effects of different users' profiles (age-range, experience of

using computer and touchscreen) on interaction performances (time and error rates). The results of our experiment are discussed in this section.

IV.3.1. *Drag-and-drop interaction and tactile puzzle games for older adults*

During the recruitment meetings, Puzzle Touch system allowed novices and experienced older users to learn and accomplish tactile interaction during the execution of puzzle games on touchscreen devices. Drag-and-drop interaction and tactile puzzle games allowed the participation of older adults with different profiles on the experiment described in this chapter. This result confirms our observations described on Chapter III (III.4.3, p. 111).

It is important to highlight that most of the participants of this study were interested in information and communication technologies, 16 of them using a computer very often and 8 having previous experience with touchscreens. This shows that there is still some reluctance of older populations on adopting and using technologies as well as getting involved on activities concerning design and evaluation of technologies. Social interaction and serious games can arouse older adults' interest and help them to discover touchscreen devices.

The participants have different user' profiles and it has been reflected on the variability of interaction performances observed on the results. However, the population of this study can be considered representative of the heterogeneity of older users. Improving the accessibility of tactile interaction means to take into account the different situations of use but also the variability of characteristics and special needs of older adults.

IV.3.2. *Bigger screen sizes and pen interaction allow more accurate interaction*

For accomplishing the task, participants spent longer times of movement on tablet than on smartphone, even if they made more errors on smartphone. **Hypothesis 1 is not confirmed.** Interaction on smartphone is error prone but travelling distances are shorter which implies reduced time of movement during interaction on the small screen sizes.

However, the shorter times of movement for positioning the targets on smartphone can be considered to confirm the appropriateness of drag-and-drop interaction

for small screen sizes where the small targets requires fine dexterity for the movements of interaction.

Times of movement were longer on tablet but there are fewer errors of interaction on this device, where the size of the targets is bigger (Motti et al., 2014b). This result is in line with Stöbel *et al.* (2010), who affirm that older adults prefer to take longer times but execute successful interaction (Stöbel et al., 2010).

Moreover, our results confirm previous studies showing the advantages of larger screen sizes on accuracy of interaction (Kobayashi et al., 2011). Increasing the size of the targets has been recommended for older adults executing tapping for pointing tasks (Hwangbo et al., 2013; Jin et al., 2007). The variability of time and errors is also reduced during interaction on tablet, which suggests an improvement of usability and accessibility on bigger screen sizes.

Concerning the input modalities, the accuracy of the gesture is improved during pen interaction for older adults, contrary to the results of a previous study comparing pen and finger interaction. Hourcade and Berkel (2006) evaluated target selection tasks with tapping gestures on a small screen device (about 3.5) and demonstrated that finger interaction were more accurate than pen interaction on time and accuracy for older adults (Hourcade and Berkel, 2006). However, older subjects were able to perform 87.6% of accuracy during pen interaction and small targets (16 mm). For novice users, holding a pen may seem more natural than touching the screen directly with the fingers. Besides, pen interaction reduces the occlusion of the screen by the hand during interaction. Even if pen interaction seems natural and accurate, a pen is not always available for the user and some users may prefer interact with the fingers. For this reason, we argue that the usability of finger interaction should be further evaluated and improved for older adults.

The effects of the screen sizes and input modalities on interaction performances are certainly related to the movements of the users and the strategies they adopt to accomplish interaction. For this reason, the users' postures and movements should be investigated from an ergonomic point of view (Chapter V, p. 155).

IV.3.3. *Lowering constraints of accuracy for improving accessibility*

Lowering the constraints of accuracy from 95% to 80% resulted on shorter times of movement and fewer errors of accuracy on both screen sizes, for the two input modalities. Time of movements has been reduced from 3 +/-1.9 seconds per target on high accuracy levels to 2 +/-1.2 seconds per target on low accuracy levels. Moreover, the

number of errors has been divided by five. This effect was found for all subjects and also for the different groups according to the users' profiles. **Hypothesis 2 is confirmed.** Lowering the constraint of accuracy facilitates drag-and-drop, reducing the time and number of supplementary gestures for accomplishing interaction (Motti et al., 2015b).

Besides, this adaptation of the constraint for the positioning of targets facilitate interaction on smartphone and tablet, during finger and pen interaction, reducing the variability of interaction performances between subjects on time of movement and number of errors. It means that lowering the constraint of accuracy can improve the accessibility of drag-and-drop interaction in different situations of use of touchscreen. Therefore, we propose this adaptation technique for supporting tactile interaction for older adults.

IV.3.4. *Age as a predictor of performances*

Due to the aging effects on cognitive, motor and sensorial systems, we would expect that interaction performances would be related to age (Caprani et al., 2012). Studies that compared different age groups (adults and older adults) demonstrated that older adults take longer times and made more errors than younger (Findlater et al., 2013; Hourcade and Berkel, 2006).

Analyzing games of high and low constraints of accuracy together, the variability on time and error rates between participants is significant and increased for the older age-ranges. The analysis of the median values shows that some participants in the group of the oldest subjects, aged 80 or older, made shorter times and fewer errors than subjects aged 75 to 79 (Motti et al., 2014b). **Hypothesis 3 is not confirmed.**

This effect is outlined during games set for requiring high accuracy. In these situations of the study, the number of errors could be considered to be affected by aging because the oldest group took more time and made more errors. However, for the games requiring lower constraints of accuracy, median values of performances show that adults aged 80 years old or older made shorter times than adults aged 75 to 79. Moreover, the oldest group made fewer errors than the group of subjects aged 75 to 79 and those aged 70 to 74. This result demonstrates how this adaptation technique has improved the accessibility of the interaction for the oldest subjects.

The state-of-the-art on studies about tactile interaction of older adults, described in Chapter II (II.3.1.5, p. 64), discussed about the different time criteria that have been used to evaluate users' performances, such as the time to accomplish a task (time of

completion), the time to start a gesture for reaching a target (reaction time) or the effective time for executing a gesture of interaction (time of movement). However, aging affects working memory, what could influence reaction time or reflection time (Caprani et al., 2012). To overcome this fact, isolating the time of movement has been used to evaluate the accuracy of interaction of older adults (Leonard et al., 2005; Lopicard and Vigouroux, 2012). For this reason, in the present study, only the time of movement has been used to evaluate the gesture of interaction. As drag-and-drop demands continuous contact with touchscreen, this gesture of interaction can improve the accuracy for older users with low dexterity (Mertens and Jochems, 2010; Wacharamanotham, 2011). Our results confirm that drag-and-drop interaction can facilitates interaction for the oldest groups of users.

The variability of performances also increases with the age. So we verified the effects of previous experience with technologies. Indeed, this result could be explained by the fact that 67% of the subjects among the oldest group use a computer. Among subjects aged 70 to 79 years old, on the other hand, only 46% use a computer.

IV.3.5. Previous experience with technologies as predictor of performances

According to the information assessed through the initial questionnaires, we identified subjects who use computers and subjects who had experience of using touchscreen.

Some subjects who use computers spent shorter times of movement and made twice fewer errors than users who do not use computers. This effect could be expected, because previous experience with technologies can help users to learn and understand interaction as indicated on the literature (Caprani et al., 2012).

Concerning the previous experience with touchscreen, some experienced users spent shorter times but there is no significant difference for the number of errors between these two groups of users. This means that novice older adults were able to execute drag-and-drop interaction as accurately as experienced users.

Even if previous experience with technologies has a considerable effect on acceptance and adoption of technologies, as discussed in Chapter II (II.1.1, p. 37), among the studies we reviewed about tactile interaction for older adults, only a few have included older adults with previous experience with touchscreen (II.3.1.1, p. 48). Our

study demonstrates how experience of using computers and touchscreen helps older adults to outperform novice users.

Additionally, touchscreen technologies are widely employed nowadays and smartphones and tablets have become mainstream technologies. The next generation of older users will have more experience with touchscreen. It is important to take into account this factor as a predictor of acceptance of technologies as well as the effects of the previous experiences on interaction performances for usability testing and design evaluation. On the other hand, it is also important to support interaction for novice users in order to prevent digital exclusion.

IV.3.6. Accessibility of drag-and-drop interaction for older users without experience with technologies

The experience of using computers showed significant effects reducing error rates for all the situations of games and for higher accuracy levels. But there is no significant difference on error rates between subjects who use and who do not use computers for the interaction with games requiring lower accuracy levels. This result demonstrates that lowering the constraint of accuracy improves the accessibility of drag-and-drop interaction especially for subjects without experience of using computers (Motti et al., 2015b).

Another interesting result is the effect of lower accuracy requirements on the variability of performances between subjects. Apparently, lowering the accuracy constraints reduced the variability of error rates between subjects on global results as well as between subjects with different user' profiles.

IV.3.7. Ease of use of tactile interaction

The direct interaction on the display screen has been recommended for older adults because it reduces the cognitive workload (Caprani et al., 2012), provides better performances when compared to other input devices (N. Schneider et al., 2008) and reduces the gap of performances between younger and older groups (Findlater et al., 2013).

Our results demonstrate that some novice users were able to accomplish drag-and-drop interaction as accurately as experienced users. Experienced users spent shorter times but the reduced number of iterations of our study do not allow us to evaluate learning effects (subjects played only eight games, one on each different situation of interaction).

Mertens *et al.* (2010) evaluated text-entry tasks with gestures requiring continuous contact with the screen (*i.e.* “trabing”) and they demonstrated that novice older users were able to execute better performances and stabilization after twenty trials (Mertens and Jochems, 2010).

According to our analysis, the absence of significant effects of experience use of touchscreen on error rates confirms the ease of use of tactile interaction for novice users.

IV.3.8. *Delimitating interaction zones for preventing errors related to unintentional touches on the screen*

The number of touches outside the interaction zones was reduced during pen interaction. **Hypothesis 4 is confirmed.** Concerning the relationship between the unintentional touches and the screen sizes, their number increases with the bigger traveling distances required during interaction on tablet.

Unintentional touches on the screen can cause substitution errors (*e.g.* when the user touches other keys during typing tasks) (Nicolau and Jorge, 2012; Wright *et al.*, 2000) or unintentional activation of onscreen controls (Bradley *et al.*, 2011; Mallenius *et al.*, 2007).

For the present study, the supplementary gestures for correcting the positioning of the targets have been used as an evaluation criterion for accuracy. Errors of accuracy, for example, concern insertion errors (*e.g.* when the user touches neighboring keys during typing tasks) (Nicolau and Jorge, 2012) or slipping errors (*e.g.* when the finger or pen slips and selects the adjacent targets) (Moffatt and McGrenere, 2007). According to our analysis, errors of accuracy occur when users have understood the interaction, found the right target but then made an error related to the execution of the gesture of interaction.

The difficulties older users find during interaction has reported different kinds of errors, such as missing targets, unperceived feedback and misunderstanding labels (Harada *et al.*, 2013; Moffatt and McGrenere, 2007; Nicolau and Jorge, 2012). Errors can be really disturbing for older adults because it demands supplementary manipulation for recovering, correct, undo or restart an action (Bradley *et al.*, 2011). Globally, errors indicate the non-adaptation of the graphical user interfaces or interaction techniques to the user’s motor skills. Distinguishing the different types of errors and understanding their causes is important to propose adequate solutions (Fisk *et al.*, 2009).

The analysis of the number and the positions of the unintentional touches shows how the prioritization of interaction zones has been a considerable help to prevent errors and support user's during tactile interaction. Concerning drag-and-drop interaction, the continuous contact with the screen improves the accuracy of the gesture by helping to prevent slipping errors.

IV.3.9. *Limitations*

One limitation of this study is the number of subjects. Further investigation need to be done to evaluate the effects of the different user's profiles with a bigger number of participants.

The number of games played by each participant had the advantage of proposing a rapid experiment protocol. However, the evaluation of the effects of different accuracy requirements has been done in only one cycle of iterations.

Another limitation of this study is the size of the targets. The interactive system was set to display twelve targets and the size of the targets was adapted according to the size of the screen. Previous studies evaluating the effects of the sizes of the targets on interaction performances have demonstrated that bigger targets facilitate interaction for older adults during tapping tasks with pen (Hourcade and Berkel, 2006) and finger interaction (Hwangbo et al., 2013; Jin et al., 2007). Future work should evaluate the effects of different sizes of targets for drag-and-drop interaction.

IV.3.10. *Perspectives*

The present study demonstrated the appropriateness of drag-and-drop interaction for older adults interacting with pen and finger on smartphone and tablet. Drag-and-drop interaction should be adapted, proposed and evaluated to other applications, such as text entry tasks, web browsing, phone functions, etc.

Reducing the constraint for positioning the targets by lowering the accuracy requirements of the games facilitate drag-and-drop interaction. This adaptation corresponds to virtually expanding the size of the targets without modifying the graphical layout. As perspectives, this adaptation should be evaluated to be applied to others interactive systems. Low constraint of accuracy should be helpful for graphical user interfaces with encumbered layouts, small screen sizes or even when finger interaction is detected. On these situations, the number and the positions of targets do not always allow

the application of other support techniques such as expanding the targets size or the area of the cursor.

The delimitation of interaction zones for preventing unintentional touches can have a helpful impact on tactile interaction by preventing errors. This parameter should be further evaluated and also applied to other interactive systems.

After the design and evaluation of the system Puzzle Touch, we are now interested in adaptations on the design of Puzzle Touch that could improve usability and accessibility of drag-and-drop interaction for older users. Moreover, concerning the Puzzle Touch system, the parameters of the game should be dynamically adapted to the users' needs and progress in order to encourage interaction while keeping the challenge of the games for improving user-experience in a long term use.

IV.4. *Conclusion and future work*

The results described in this chapter demonstrate the appropriateness of drag-and-drop interaction for older adults with different user' profiles (age, experience of using computers, experience of using touchscreen) interacting with pen and finger on smartphone and tablet.

We demonstrate that screen sizes and input modalities can affect interaction performances. Older adults take longer times during interaction on tablet, where the travelling distances for drag-and-drop interaction are bigger, even if they made more errors on smartphone. Subjects also made more errors during finger interaction, but there is no significant difference between pen and fingers on time of movement.

We also demonstrate the effects of the users' profiles, particularly age and experience with technologies on interaction performances. Results show that some of the oldest subjects sometimes perform better than subjects from other age groups, probably because their previous experience of experience of using computers or touchscreen can reduce the effects of aging that could limit their skills for learning interaction, solving puzzle games or reduce the accuracy needed for executing the gestures of interaction. Novice adults were as accurate as experienced users, showing that tactile interaction is easy to learn.

Lowering the constraint of accuracy for positioning targets on touchscreen reduces the variability between the different performances, improving accessibility on different situations of use and for users with different profiles, especially users who do not use a computer. We have discussed the adaptation of the constraints for positioning

the targets as a support technique to reduce time and error rates. Lowering the accuracy requirements corresponds to virtually expanding the size of the targets, facilitating drag-and-drop interaction.

Moreover, we have demonstrated that delimitating the interaction zones was an effective solution to prevent errors related to unintentional touches.

In order to facilitate the use of tactile interactive systems, some elements of the layout of graphical interfaces have been evaluated to older adults. Bigger targets sizes have been demonstrated to reduce time of interaction and number of errors for this group of users during tapping tasks and this adaptation have been recommended for tactile interactive systems destined to older users (Hwangbo et al., 2013; Jin et al., 2007; Loureiro and Rodrigues, 2014). In our future work, the effects of the size of the targets on drag-and-drop interaction performances should be studied.

In the presented study, we only included older participants. Studies about tactile interaction of older adults have demonstrated that older users make more errors and take longer times for executing gestures of interaction than younger users (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006). The effects of aging on psychomotor and physiological systems imply a decreased accuracy of the gestures, which could explain the difficulties older users find for accomplishing tactile interaction (Caprani et al., 2012). It is though necessary to understand the reasons of the decrease of interaction performances with aging through the analysis of their movements during interaction with touchscreen device. The experiment described in Chapter V evaluates the effects of aging on interaction performances, including a deeper analysis on the causes of the gap of performances between adults and older adults on time and error rates.

Chapitre 5 : Différences de postures et mouvements du poignet entre personnes âgées et adultes et leurs conséquences sur les performances d'interaction

Résumé

L'objectif de ce chapitre est de démontrer l'apport de l'analyse du mouvement lié à l'exécution du geste d'interaction pour comprendre la relation possible entre les caractéristiques du mouvement et les performances d'interaction. Le poignet est particulièrement sollicité lors de l'exécution de gestes d'interaction sur écran tactile (Jacquier-Bret et al., 2014a; Werth and Babski-Reeves, 2014; Young et al., 2013). Cependant, les contraintes sensorimotrices liées aux effets de l'âge sur les systèmes psychomoteur et physiologiques ont des conséquences sur les postures et mouvements de cette articulation (Laursen et al., 2001; Wright et al., 2011). L'analyse des postures et mouvements du poignet durant une tâche d'interaction tactile permet de comprendre la différence de performance d'interaction entre les personnes âgées et les adultes.

Dans ce chapitre, nous décrivons la mise en œuvre d'un protocole expérimental pour enregistrer les mouvements des utilisateurs durant l'interaction avec des écrans tactiles et les mettre en relation avec les coordonnées des touches enregistrées par le système interactif « Puzzle Touch ». 15 sujets âgés (65 – 84 ans) et 15 sujets adultes (18-45 ans) ont été recrutés pour réaliser des gestes d'interaction drag-and-drop sur smartphone et tablette, avec doigt et stylet. Le système a été configuré pour générer deux tailles de cible en chaque dispositif (neuf larges ou seize petites). De plus, afin d'évaluer des gestes pour des tâches demandant plus de précision, la contrainte de positionnement des cibles a été définie à 95%. Pour l'analyse du mouvement, les sujets étaient équipés avec des marqueurs anatomiques sur la tête, tronc, bras et main. Le plan de rotation du poignet a été estimé pour permettre l'évaluation des angles et amplitudes angulaires de la déviation radial-ulnaire (RU), flexion-extension (F/E) et pronation-supination (P/S).

Globalement, la posture des sujets âgés et adultes est caractérisée par une déviation radiale, extension et pronation du poignet durant l'exécution du geste drag-and-drop sur des écrans tactiles horizontalement fixés sur la table. Ce résultat complète la littérature car des études sur la saisie de texte ont démontré une déviation ulnaire, flexion et pronation du poignet (Werth and Babski-Reeves, 2014) ou encore une extension extrême du poignet durant l'interaction avec des écrans tactiles inclinés (Young et al., 2013).

L'analyse des performances d'interaction permet d'établir que le drag-and-drop peut réduire mais ne pas supprimer les effets de l'âge. Les sujets âgés ont mis deux fois plus de temps et ont fait également deux fois plus d'erreurs que les sujets adultes. Concernant les postures du poignet, les angles moyens de déviation radiale et extension des sujets âgés sont plus fermés que ceux des adultes, mais les angles moyens de pronation étaient plus ouverts. De plus, chez les sujets âgés nous avons constaté une augmentation des amplitudes de mouvement. Les caractéristiques des mouvements des personnes âgées indiquent une atteinte de déviations angulaires contraignantes du poignet (Qin et al., 2013), ce qui aurait un impact sur leurs performances d'interaction (temps et nombre d'erreurs).

Concernant les différentes situations d'utilisation des écrans tactiles, l'interaction avec la tablette est caractérisée par une réduction des angles articulaires en comparaison aux mouvements plus restrictifs sur le smartphone. Les distances parcourues pour positionner les cibles sur la tablette impliquent de plus grandes amplitudes de mouvement. L'interaction avec le doigt réduit les angles d'extension du poignet mais augmente la déviation radiale, les angles moyens pronation et les amplitudes de mouvement. D'un point de vue ergonomique, les utilisateurs doivent préconiser la tablette ou le stylet afin de diminuer les risques de problèmes musculo-squelettiques pour des utilisations prolongées des écrans tactiles. De plus, la tablette et le stylet ont eu un impact positif sur les performances, améliorant l'utilisabilité de l'interaction surtout pour les personnes âgées.

Enfin, en ce qui concerne les touches accidentelles, nous avons démontré une corrélation entre leur nombre et les angles d'extension et pronation du poignet. En effet, cela est conforme à la littérature car une moindre extension de cette articulation réduit la distance entre les doigts et l'écran (Young et al., 2013). L'interaction avec le stylet, caractérisée par une moindre pronation du poignet et moindre amplitude de mouvements, permet d'éloigner les doigts de l'écran et réduire le nombre de touches accidentelles.

La différence des mouvements du poignet entre les sujets âgés et adultes renforce l'importance de l'inclusion des personnes âgées lors des étapes de conception et évaluation des systèmes interactifs et techniques d'interaction. L'originalité de ce protocole a été de mettre en relation les mouvements de l'utilisateur et les performances d'interaction. Des analyses complémentaires pourraient évaluer les postures des et les mouvements des membres supérieurs afin de fournir des recommandations pour des interactions plus ergonomiques.

V. *Differences in postures and movements of the wrist between older adults and adults and their consequences on interaction performances*

As discussed in the state-of-the-art presented in Chapter II (II.4.2, p. 74), the studies we reviewed about the movements of the users showed an increased mobilization of wrists during interaction with touchscreen compared to traditional input devices (such as mouse and physical keyboards) (Kim et al., 2014; Shin and Zhu, 2011; Werth and Babski-Reeves, 2014). Typing on touchscreen devices resulted on increased wrist extension compared to laptop computers (Werth and Babski-Reeves, 2014). Moreover, according to the position of touchscreen device (*e.g.* case holding a tablet tilted or vertical), the users' wrist can assume extreme extension angles (*i.e.* greater than 27°) in order to keep the movements of the fingers, avoid the occlusion of the screen, prevent unintentional touches and activation of onscreen controls (Young et al., 2013).

Tactile interaction has been recommended for older adults (Caprani et al., 2012; Findlater et al., 2013) but when comparing this group to younger users, older adults usually make more errors and take longer times to execute the gestures of interaction (M. K. Chung et al., 2010; Findlater et al., 2013; Hourcade and Berkel, 2006). In fact, human aging is related to changes in perceptual, psychomotor, cognitive and physical systems and these changes could hinder the movements of interaction. The effects of aging on physiological and psychomotor systems imply a decrease on the accuracy of the gestures, which could explain the difficulties older users find for accomplishing tactile interaction. Moreover, recent touchscreen technologies are high sensitive and executing the gestures of interaction requires fine dexterity and motor skills of the users (Jin et al., 2007; Wacharamanotham, 2011).

For this reason, studying the movements of older users during interaction with touchscreen is necessary to try to elucidate the decrease of interaction performances commonly reported for this group of users. In the present chapter, we address our Research Question 4: What are the differences in movements of interaction between older-aged adults and younger adults that are related to their performances?

Previous studies on the movements of the arms of older adults have demonstrated the effects of lower muscle strength and decline in sensorimotor systems related to the aging on the movements of the arms (Cooke et al., 1989; Darling et al., 1989). Roy *et al.* (1996) discussed the effects of aging on the trajectories of movements of arms of older

adults, resulting on lower speeds and increased spatial variability among individuals (Roy et al., 1996). Wright *et al.* (2011) showed how the age-related changes in proprioceptive acuity of the upper-limbs resulted on impaired detection of wrists' joint motions for older adults, negatively affecting goal-oriented arm movements (Wright et al., 2011). Indeed, the results of the study of Varadhan *et al.* (2012) show that older adults make slower movements and employ cautious motor strategies, which are strongly dependent on the particular features of the task they are executing, in order to compensate decline in sensorimotor and physiological system (Varadhan et al., 2012). These lower movements, taking longer movement times, increased deceleration phases and more sub-corrective movements have been demonstrated to be reflected on the movements of interaction of older adults, including mouse tasks (Laursen et al., 2001; Walker et al., 1997) and tactile interaction (Lepicard and Vigouroux, 2012).

The analysis of the movements of the users during the execution of the gestures of interaction is necessary to try to elucidate the differences of performances of tactile interaction between older adults and adults. The experimental protocol described in this chapter was implemented to analyze the postures and movements of the wrist of in order to understand their consequences on time and error rates. The wrist is high solicited during interaction with touchscreen (Shin and Zhu, 2011; Werth and Babski-Reeves, 2014; Young et al., 2013) but postures and movements of this articulation are affected by aging (Wright et al., 2011). By consequence, the present study focuses on the postures and movements of the wrist.

In order to help older users to overcome the decrease of accuracy related to the aging, drag-and-drop interaction has been proposed to older adults because sliding the finger on the screen can improve the accuracy of the gestures (Mertens and Jochems, 2010; Wacharamanotham, 2011). However, following the results discussed in Chapter IV (p. 121), the effects of different size of targets should be evaluated. Bigger sizes of targets have been demonstrated to reduce time of movement and number of errors for older users executing tapping tasks (Hwangbo et al., 2013; Jin et al., 2007). For this reason, in the present study, subjects execute drag-and-drop interaction for positioning targets with two sizes of targets on each touchscreen device.

This chapter describes the analysis of the performances (time and error rates) and postures and movements of the wrist (angular deviations and ranges of motion) of two groups of subjects: older adults (aged 65 to 84) and adults (aged 18 to 45) executing drag-and-drop interaction for positioning targets with the system Puzzle Touch (presented in Chapter III, p. 93).

V.1. *Experimental design and methods*

In this section we present our main hypothesis and the experiment designed to their verification: the settings of the interactive system, the experimental task, the touchscreen devices and equipment for assessing the subjects' movements and postures, the procedures, the measures we defined for the evaluation and the analysis of the collected data.

V.1.1. *Hypotheses*

Four main hypotheses for this experimental study have been formulated. First, two hypotheses concern the differences in performances and postures of the wrist between the two groups of subjects.

Hypothesis 1: The continuous contact with the screen for positioning the targets with drag-and-drop interaction can improve the accuracy of the gesture and facilitate the interaction for older adults. There are no differences in performances (time and error rates) between older adults and adults.

Hypothesis 2: In order to compensate the age-related changes in sensorimotor systems, the postures of the wrist of older adults assume increased articular deviations during tactile interaction.

Then, the other two hypotheses concern the effects of the different situations of the study on the users' performances and postures of the wrist. In our previous study, described in Chapter IV (p. 121), results demonstrated that older adults' performances are increased on tablet and during pen interaction.

Hypothesis 3: Confirming our previous results, bigger screen sizes and pen reduces the differences in performances between older adults. We expect to find the same results for adults. However, the improvement on performances is compensated by increased angular deviations and range of movements of the wrist.

Hypothesis 4: Tapping on small sizes of targets has been considered difficult for older adults, increasing the number of errors (Hourcade and Berkel, 2006; Hwangbo et al., 2013; Jin et al., 2007). For drag-and-drop interaction, the size of the targets does not affect interaction performances.

V.1.2. *Settings of the interactive system Puzzle Touch*

The Puzzle Touch system has been set to display puzzle games with two sizes of targets, corresponding to nine large or sixteen small puzzle pieces, adapted to the screen sizes as described in Table V.1. The same image, presenting an urban architectural monument from a colored and high contrasted postcard has been used for all the situations, as illustrated on Figure V.1 and Figure V.2.

Table V.1. Target sizes according to the screen sizes (tablet and smartphone)

Number of targets	Target sizes on smartphone	Target sizes on tablet
9 large targets	25x16 mm	46x35 mm
16 small targets	19x16 mm	35x27 mm

The results of the experimental study presented in Chapter IV (IV.2.3, p. 132) showed that low constraints of accuracy reduce the variability between subjects with different profiles. To stand out the effects of the age between the two groups of subjects and requires a higher accuracy for the execution of the movements, the setting of the constraint of accuracy have been defined to 95%. The game play as described in the design evaluation is maintained (Chapter III, III.3.1, p. 101). Table V.2 summarizes the settings of the Puzzle Touch system for the present study. The other parameters have been set by default.

Table V.2 Settings of the interactive system

Parameter	Characteristics of the devices and development choices
Targets sizes and number	Nine large and sixteen small targets
Constraint of accuracy	95 %
Number of pieces that can be dragged simultaneously	Numerous pieces. The games are multi-touch.



Figure V.1 Screenshot of an instance of the game set for nine puzzle pieces on smartphone

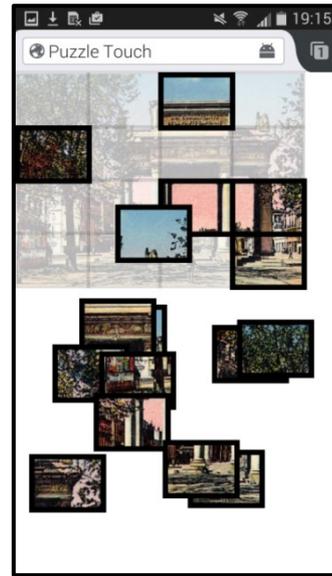


Figure V.2 Screenshot of an instance of the game set for sixteen puzzle pieces on smartphone

V.1.3. *Task*

Drag-and-drop interaction is the gesture of interaction required for positioning the targets. The task is the same as described in Chapter IV (IV.1.3, p. 124).

V.1.4. *Apparatus and equipment*

The equipment consists of a motion tracking system registering user's movements while the touch information was registered by the interactive system Puzzle Touch installed in the touchscreen devices. Figure V.3 shows an overview of the laboratory and the motion capture equipment.

A preliminary study, described in the Appendix VII.5.1 (p. 240), allowed the identification of motion strategies of adults during interaction with touchscreen and established the parameters of the experimental study.

V.1.4.1 *Touchscreen devices and input modalities*

The same devices and input modalities described in the experiment presented in Chapter IV (IV.1.4, p. 124) are used in the present study: a smartphone and a tablet, allowing pen and finger interaction. The pen measures 115 mm long and 6 mm diameter.

V.1.4.2 *Motion capture*

An optoelectronic motion capture system was used to track body's movements. Six *Oqus 400* cameras (Qualisys AB, Gothenburg, Sweden) were placed around the subject and recorded the positions and trajectories of the reflective markers.

A calibration is done by a pre-defined measurement procedure using a wand and a frame. The frame is an L shaped structure used as a reference for obtaining the desired coordinate system. The wand should be moved inside the measurement volume in all three directions (about 60 seconds). The software used for registering data from cameras includes a 3D view window for monitoring.

Markers are placed on the subject's head, trunk, upper limb and hands following the International Society of Biomechanics (ISB) recommendations (Wu et al., 2005). Details and anatomical positions are presented on



Figure V.3 Picture: equipment for motion capture, pan from the subject's position

Table V.3 and illustrated on Figure V.4.

Technical markers were added on arms so the positions of anatomical markers could be estimated in case of hidden by the users' movements. Technical markers were also placed on the devices, as described in Table V.4.

Tactile interaction also requires high dexterity of the movements of the fingers. Subjects were also equipped with a data glove and a magnetic sensor for tracking hands orientation and fingers angles. Subjects were also equipped with a data glove *CyberGlove* (Virtual Technology, Palo Alto, CA USA) and the orientation of the hand was register with a magnetic sensor *Flock of Birds* - FOB (Ascension Technology Inc., Burlington, Vermont, USA). The data collected through the *FOB* and the *CyberGlove* will be used for further evaluation.

Table V.3 Anatomical positions for reflective markers during motion capture

Body's segment	Markers identification and position
Head	HG, HR: Temple (right and left) HF: Forehead HC: Chin
Trunk	C7: <i>Spinal process</i> of the 7 th cervical vertebra T8: <i>Spinal process</i> of the 8 th thoracic vertebra JUG: <i>Incisura jugularis</i> (suprasternal notch) Ster: <i>Procesus xiphoideus</i> (most caudal point on the sternum)
Upper-limb	AcroG, AcroD: <i>Acromion</i> (right and left) UMD, UMG: <i>Humerus medial epicondyle</i> (most caudal point, right and left) ULD, ULG: <i>Humerus lateral epicondyle</i> (most caudal point, right and left) RSPD, RSPG: <i>Radial styloid process</i> (most caudal point, right and left) USPD, USPG: <i>Ulnar styloid process</i> (most caudal point, right and left)
Hands	MCPD2, MCPG2: 2 nd <i>Metacarpophalangeal</i> (right and left) MCPD5, MCPG5: 5 th <i>Metacarpophalangeal</i> (right and left)

Table V.4 Emplacement of technical reflective markers during motion capture

Technical markers	Markers identification and position
Body	BD1, BD2, BD3, BG1, BG2, BG3: arms (right and left) ABD1, ABD2, ABD3, ABG1, ABG2, ABG3: forearms (right and left)
Devices	T1, T2, T3: bottom left corner, up left and right corners of the tablet (respectively) S1, S2, S3: bottom left corner, up left and right corners of the smartphone (respectively)

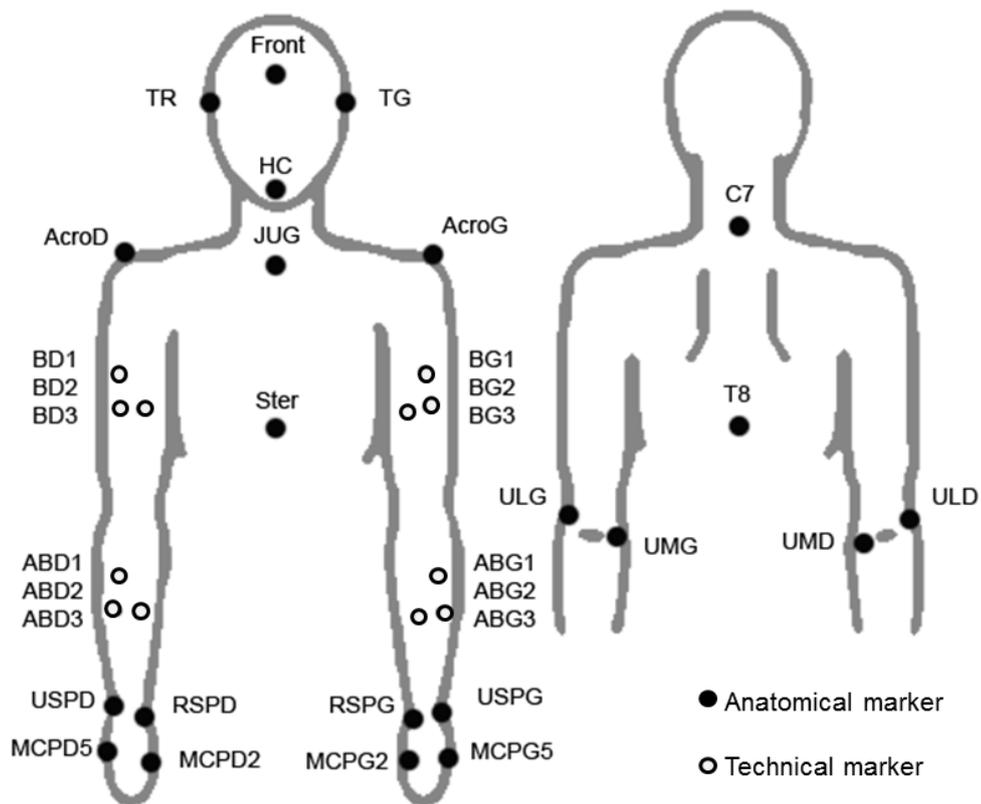


Figure V.4 Illustration of the reflective markers positions

Figure V.5 represents the subject equipped for the experiment, with the hands resting on the desk. This is the subjects' initial and final position for the experiment. If the situation of the study requires pen interaction, the subjects holds the pen before the task starts. Figure V.6 represents the subject during interaction. Figure V.7 shows the reconstitution of the body of the subject on wireframe and Figure V.8 shows a detail of the markers employed to define the movements and postures of the wrist.

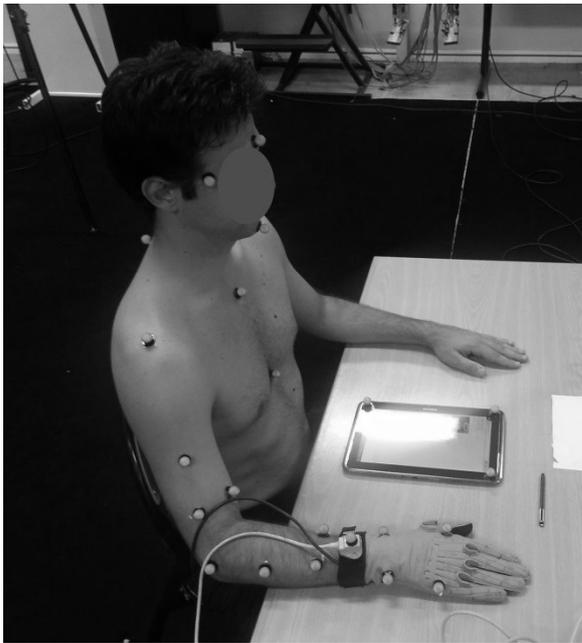


Figure V.5 Picture: initial and final position of the subject for the experiment, with the arms resting on the desk

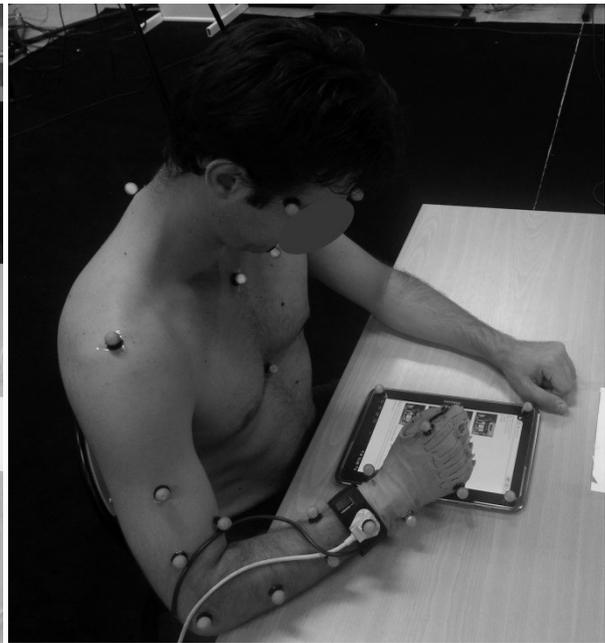


Figure V.6 Picture: position of the subject during pen interaction with a tablet, horizontally fixed on the desk

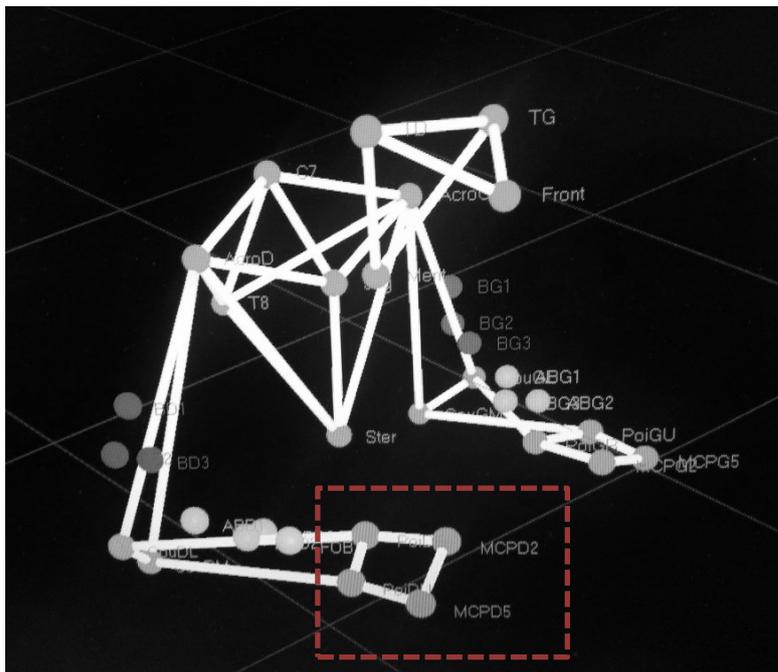


Figure V.7 Illustration of reconstruction of body segments according to the emplacement of the markers on the subjects' body

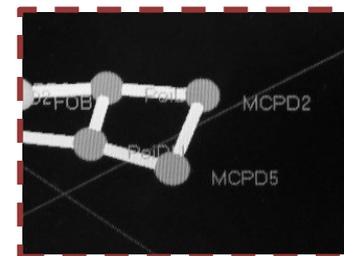


Figure V.8 Detail (zoom) on the markers placed on subjects' wrist and hand (right side)

Assessment of postures and movements of the wrist

In the present study, we focus on the analysis of the postures and movements of the wrist.

Concerning the movement, the mean wrist elevation during the task should provide relevant information to the comprehension of the number of unintentional touches observed during the task. The trajectories of the wrist have been defined according to the coordinates of the central point of this articulation, estimated in the middle of the two anatomical markers placed on the distal part of the forearm of the dominant hand (RSPD and USPD).

Concerning the postures, we evaluated mean angles and ranges of motion of wrist on three axes: Ulnar or Radial deviation (RU); Flexion or Extension (FE); Pronation or Supination (PS) during the task. For estimating the postures of the wrist, the plan of the rotation of the hand has been defined based on the coordinates of four anatomical: the two placed on the distal part of the forearm (RSPD and USPD) and the two placed on distal extremities of metacarpi 2nd and 5th (MCPD2 and MCPD5). The movements of the wrist are evaluated by the range of motions on RU, FE and PS of this articulation.

Wrist elevation (Z axis)

The mean elevation of the wrist (perpendicular to the devices placed horizontally on the desk) has been calculated through the central point between the two anatomical markers placed on the distal part of the forearm (*radial styloid process* - RSPD and *ulnar styloid process* - USPD).

Wrist radial or ulnar deviation (RU)

The radio-ulnar deviation of the wrist is represented by the angle between the hand and the touchscreen on the plan (0, X, Y), i.e., the plan of the desk. The rotation is around the vertical axis, perpendicular to the desk plane. The angle is 0° when the anteroposterior axis of the hand is aligned with the anteroposterior axis of the device. When the hand pivots on the side of the radius, it is a radial deviation and the angle is positive. When the hand pivots the side of the ulna, it is an ulnar deviation and the angle is negative.



Figure V.9 Illustration: radial deviation (adapted from ISO 9241-400:2007)

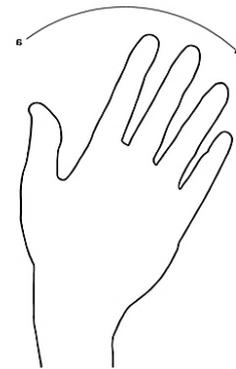


Figure V.10 Illustration: ulnar deviation (adapted from ISO 9241-400:2007)

Figure V.11 illustrates the orientation of the wrist for radial and ulnar deviation according to the position of the vertical axis, represented on the device.

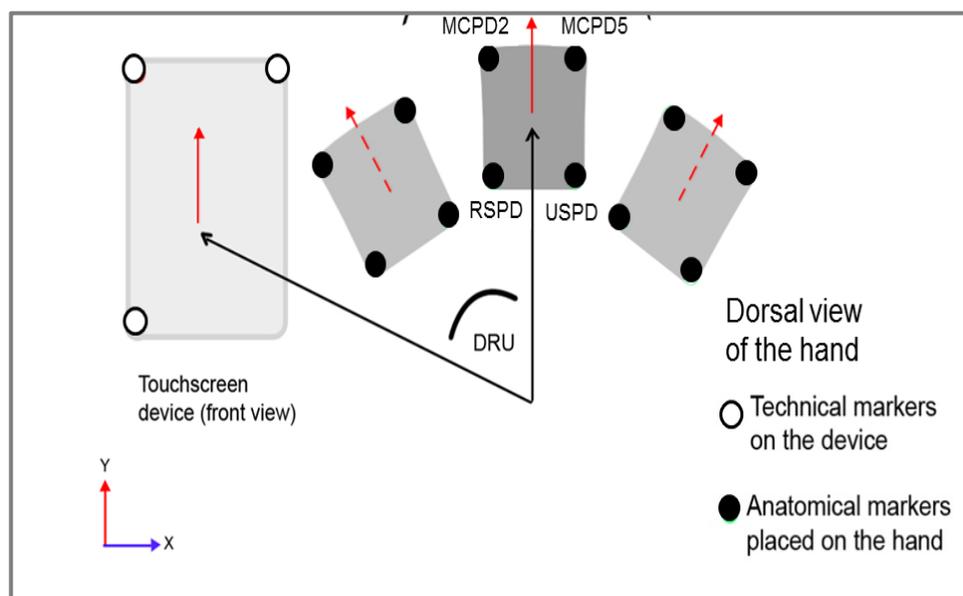


Figure V.11 Representation of the orientation of the hand and device for the estimative of radial-ulnar angular deviation of the wrist

Wrist flexion or extension (FE)

The flexion or extension of the wrist is represented by the angle formed by the hand and the device in the plane (0, Y, Z). The rotation is around the medio-lateral axis. The angle is 0° when the vertical axis of the hand is aligned with the vertical axis of the device. When the hand moves towards the device, it is a flexion and the angle is negative. When the hand moves away from the device, it is an extension and angle is positive.

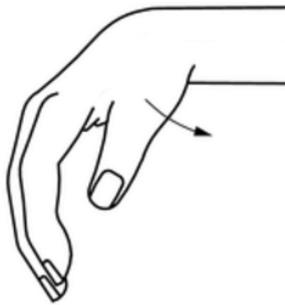


Figure V.12 Illustration: flexion (adapted from ISO 9241-400:2007)

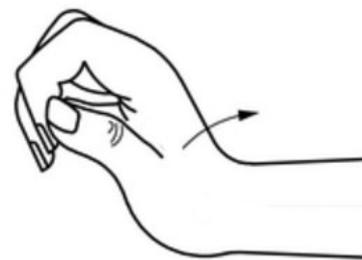


Figure V.13 Illustration: extension (adapted from ISO 9241-400:2007)

Figure V.14 illustrates the orientation of the wrist during flexion or extension according to the position of the mediolateral axis, vertical to the device.

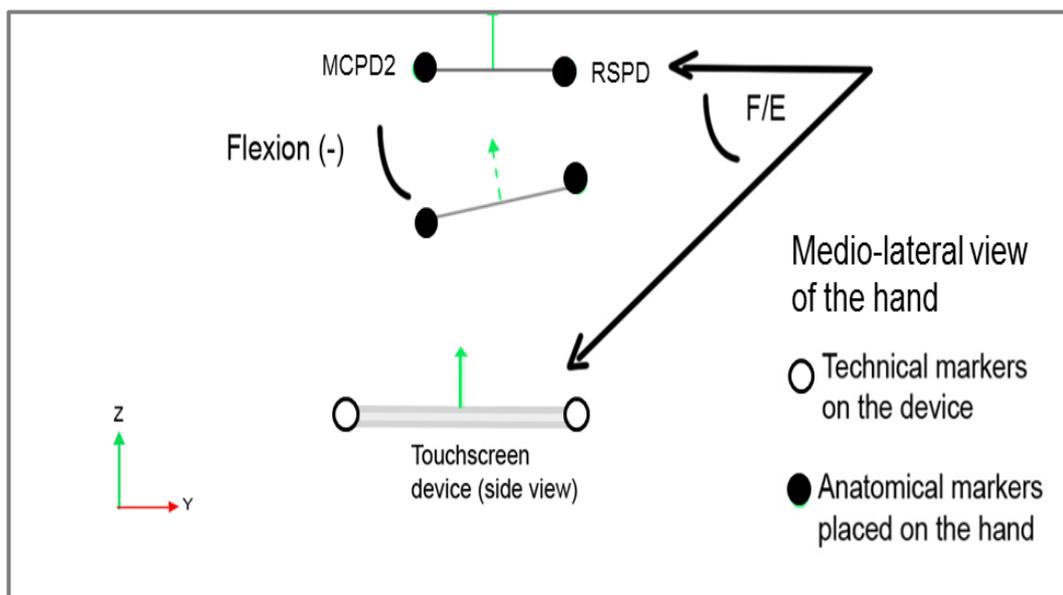


Figure V.14 Representation of the orientation of the hand and the device for the estimative of the flexion-extension angular deviation of the wrist

Wrist pronation or supination (PS)

The pronation or supination of the wrist is represented by the angle formed by the hand and the device in the plane (0, X, Z). The rotation is around the anteroposterior axis. The angle is 0° when the mediolateral hand axis is aligned with mediolateral the device. The rotation of the thumb away from the device, it is a supination and the angle is positive. When rotation brings the thumb closer to the device, it is a pronation and the angle is negative.

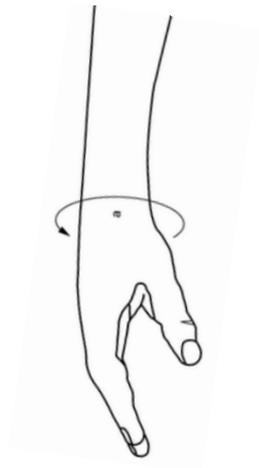


Figure V.15 Illustration: supination (adapted from ISO 9241-400:2007)

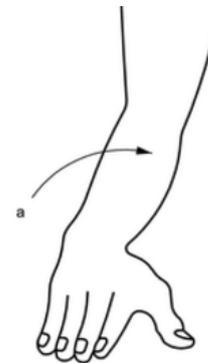


Figure V.16 Illustration: pronation (adapted from ISO 9241-400:2007)

Figure V.17 illustrates the orientation of the wrist during pronation or supination according to the position of the anteroposterior axis, represented on the device.

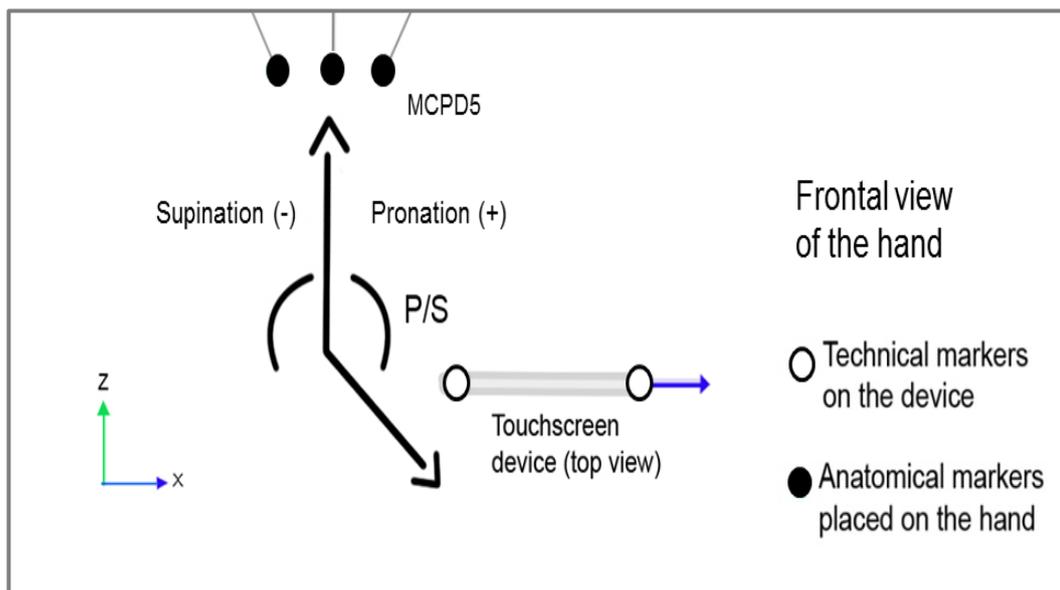


Figure V.17 Representation of the orientation of the hand and the device for the estimative of the pronation-supination angular deviation of the wrist

V.1.5. Procedures

30 able-bodied subjects have been recruited for the experiment, 15 adults and 15 older adults. The recruitment phase included demonstration meetings on seniors clubs, public libraries, workshops for learning computers and associations for game players in Toulon, France. The inclusion criteria were to be aged between 18 and 45 years old or being 65 years old or older.

Individual sessions of the experiment took place at the HandiBio research team's laboratory in the University of Toulon. The experiment schedule was the following: familiarization and consent, assessment of users' profiles, subjects' instrumentation and then the experimental tasks.

- 1) Familiarization phase: Before the experiment, subjects executed some practice trials with both screen sizes and both input modalities. For the demonstrations and the practice trials, images presenting monuments of the city subjects live in have been used to generate the puzzle games, helping to arouse interest in the activity. The procedures of the experiment were described to the subjects and they signed a formal consent.
- 2) For assessing the users' profiles, we verified eyesight, cognition, dexterity and experience of using interactive technologies. The following tests have been chosen because they are non-invasive and the questionnaires would not prolong the duration of the experiment. Subjects were informed that the purpose of these questionnaires was to verify the homogeneity of the users' profiles of the subjects in order to better understand eventual variabilities among their strategies of interaction.
 - a. First, they passed an eyesight control (color, central vision and contrast perception by *healthcare4mobile*, Appendix VII.3.1, p. 231).
 - b. A second questionnaire for motor control assessment (*Abilhand Rasch* analysis for rheumatoid and arthritis patients, Appendix VII.3.2, p.233)
 - c. Then they answered to a questionnaire for cognitive assessment (Montréal Cognitive Assessment - *MoCA*, Appendix VII.3.3, p. 234)
 - d. We collected subjects' weight and height, dominant hand size (drawn on a paper sheet) and they were questioned about previous injuries or motor difficulties on dominant hands, arms or upper limbs. They were also questioned about previous experience and use and frequency of use of computers and touchscreen, puzzle games, video and electronic games and level of education.
- 3) To assess Biomechanics and kinematics of body's movements, subjects have been equipped with reflective markers on head, trunk and upper limb so their positions can be registered by the motion capture system. Adults wore a data glove assessing the movements of palm and fingers for further analysis.

Figure V.18 illustrates the position of the four anatomical markers that define postures and movements of the wrist in the present study (RSPD, USPD, MCPD2, MCPD5).

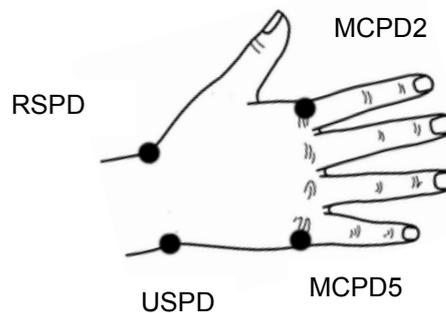


Figure V.18 Illustration: dorsal view of the right hand and emplacement of reflective markers used for estimating elevation and articular angles of the wrist (adapted from ISO 9241-400:2007)

- 4) During the experiment, subjects executed repeated series of tactile puzzle games.
 - a. To better understand the adaptation of the body's movements around the devices, the touchscreen devices on portrait mode were horizontally fixed on the desk in front of them; the top of the devices was placed at 30 cm from the border of the desk. The same desk and chair were used for all subjects.
 - b. There are eight different conditions of the game for the experiment (two screen sizes, two interaction techniques and two number and size of targets). The eight conditions of the game have been randomly permuted for each iteration series
 - c. Measures must be repeated so we can calculate the average position for each subject. To avoid fatigue for older participants, they executed three iterations series. Adults executed five iterations series. A ten minute pause was respected between each series of iteration.
 - d. Two experimenters were presented on the room. One launches the capture through the software and verifies the recording of the movements. When the subject ends a game and get back to the initial position, the experimenter stops the capture. The second experimenter prepares the devices and verifies the recording of the touch information by the interactive system. The second experimenter also filled an observation grid (attachment VII.2) while subjects executed the tasks, taking notes about user's postures, movements of hands and fingers, main difficulties and comments.
 - e. After each iteration series and at the end of the experiment, subjects were asked to evaluate their motor and visual fatigue. At the end, they were questioned about preferences for input technique, screen size and their comments or difficulties for interacting.

Figure V.19 represents the experimental setup for the analysis of the movements of the wrist during interaction with touchscreen devices. Tablet (dashed line) or smartphone (dotted line) were horizontally placed on the desk with three reflective markers (white circles) placed on top right, top left and bottom left corners. Four markers placed on the subjects hand (dark circles) were used to estimate wrists postures and movements (RSPD, USPD, MCPD2, MCPD5).

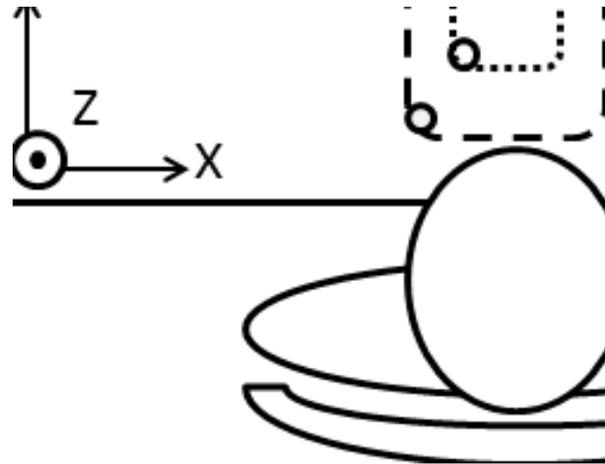


Figure V.19 Representation of the experimental setup for the analysis of the movements of the wrist during interaction with touchscreen devices.

Figure V.20 represents the position and orientation of the device and the hand according to the coordinates of the reflective markers as registered by the motion capture system in three dimensions (X, Y, Z).

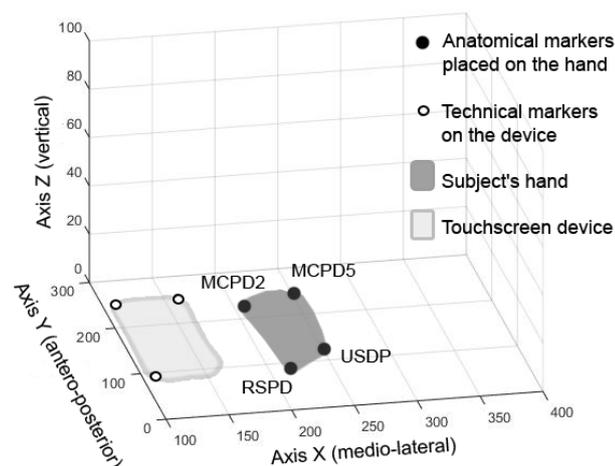


Figure V.20 3D representation of device and hands markers positions and orientation

V.1.6. Measures

Four independent variables were defined in order to verify the hypotheses of this study. The dependent variables concern the interaction performances (three measures) and the postures and movements of the wrist (five measures).

V.1.6.1 Independent variables

The independent variables are those who distinguish the situations of the study and the groups of subjects:

- Two groups of subjects: adults and older adults,
- Screen sizes: smartphone or tablet,
- Input modalities: pen of fingers,
- Number and size of targets: nine large or sixteen small targets.

V.1.6.2 Dependent variables

Interaction performances

Three measures have been defined to evaluate interaction performances in the present study (as described in Chapter IV (IV.1.6.2, p. 127) :

- Time: the mean time of movement per target,
- Errors: the ratio between the total numbers of errors of accuracy of a game and the number of targets,
- Unintentional touches: the ratio between the total numbers of unintentional touches registered during a game and the number of targets.

Movement and posture assessment

Four measures have been defined to evaluate the movements and postures of the wrist:

- Elevation of the wrist: height of the wrist on the axis perpendicular to the devices (Z axis).
- Ulnar or Radial deviation (RU): Angle between the device and hand on the plane X, Y ($Z=0$). When the hand pivots on the side of the radius, it is a radial deviation and the angle is positive. When the hand pivots the side of the ulna, it is an ulnar deviation and the angle is negative.
- Flexion or Extension (FE): Angle between the device and hand on the plane Y, Z, ($X=0$). When the hand moves away from the device, it is an extension and angle is positive. When the hand moves towards the device, it is a flexion and the angle is negative.
- Pronation or Supination (PS): Angle between the device and hand on the plane X, Z, ($Y=0$). When rotation of the wrist brings the thumb closer to the

device, it is a pronation and the angle is positive. When the rotation of the wrist takes the thumb away from the device, it is a supination and the angle is negative.

V.1.7. Data analysis

Data from 960 observations were collected. One observation consists of touch information of completed puzzle games registered by the interactive system Puzzle Touch and data collected by motion tracking system. At the total, 360 observations from older subjects (15 older adults x 8 situations of interaction x 3 iterations) and 600 observations from adult subjects (15 adults x 8 situations of interaction x 5 iterations) have been collected. In this section, we describe data analysis for measures of interaction performances and measures for postures and movements of the wrist and dragging gestures. Complementary information about data distribution can be found in the Appendix VII.5.1 (p. 240).

V.1.7.1 Interaction performances

In order to evaluate the same conditions for adults and older adults, only the first three iterations of adults and older adults are used for HCI evaluation of the effects of the different screen sizes, input techniques, and size of targets and subjects' profiles on time and errors. We run through approximately 9000 gestures of interaction drag-and-drop for positioning targets (720 complete puzzle games), 4500 from older adults and 4500 from adults.

From the touch information registered by the interactive system, we extract data concerning the time of movement, the number of errors and coordinates of touches outside interaction areas (unintentional touches).

Global results of time and errors are not normally distributed according to the results of Shapiro Wilk test, as described in Table V.5. By consequence, we used statistical tests for non-parametric data. Friedman test has been used for evaluating significant differences between the situations of the experiment. Wilcoxon rank sum test with continuity correction has been used to search for significant effects of screen sizes and input techniques. Mann Whitney signed rank test was used to evaluate age-groups (two groups: adults and older adults) and use of touchscreen. Kruskal-Wallis test has been used to search significant differences between the three iteration series and age-groups.

Time and errors distribution curves are skewed left. For this reason, we present median values for tendencies and one inter-quartile for variability.

Table V.5 Summary of dependent variables for performances and data distribution

Evaluation criteria	Distribution
Time	W= 0.8315, p-value < 2.2e-16*
Errors	W= 0.7014, p-value < 2.2e-16*
Unintentional touches	W= 0.236, p-value < 2.2e-16*

* Results from Shapiro Wilk test. Data is not normally distributed: p-values < 0.01

V.1.7.2 Postures and movements of the wrist

First, the raw data registered by the motion tracking system have been exported to be filtered and clipped. We run through approximately 4500 gestures of interaction drag-and-drop for positioning targets (360 complete puzzle games) from older adults and 7500 from adults.

Procedures for exporting measures from raw data

The procedures for filtering, clipping and exporting the parameters for the evaluation of movements are detailed below and illustrated by the examples that succeed.

- **Filtering:** First, data have been filtered to reduce noise inherent to instrumentation without losing much information. A second order Butterworth filter with a low-pass cut-off frequency of 6 Hz has been used to smooth wrist trajectories and the angular deviations.
- **Time clipping:** Then, to isolate the part of the movement concerning our study objet, i.e., the execution of the gestures drag-and-drop for positioning the targets, a time clipping has been applied following the evolution of the wrist elevation (axis Z). At the initial position for starting the task, subjects have their hands resting on the desk beside the devices. The first movement of the wrist is its displacement into the area above the touchscreen and the “tap” into the button start to launch the puzzle games. The beginning of the task has been identified following the first peak and clipped at the first valley of the trajectory representing wrist elevation. The same way, the last movement of the wrist, once the task is accomplished (the last target has been positioned), subjects moved their hand back to the initial position. The end of the task has been identified following the last peak and clipped at the before-last valley (i.e., last valley before the last peak) of the trajectory representing wrist elevation. The start and end times for clipping were extracted and used to clip movement trajectories and articular angles.
- **Extracting spatial-temporal parameters:** Once the task time was isolated for trajectories and articular angles, we evaluate the evolution of articular angles (mean angles, amplitude) and trajectories of the wrist. The mean values and the amplitudes of wrist elevation (Z axis) and the three

motion features (RU, FE, and PS) were calculated and exported to a data table.

Figure V.21 represents the wrist trajectory on Z axis (elevation) for one subject (B5) during finger interaction on smartphone, for a nine pieces puzzle games (larger targets) at the first iteration. After filtering, peaks have been identified as well as start and end positions.

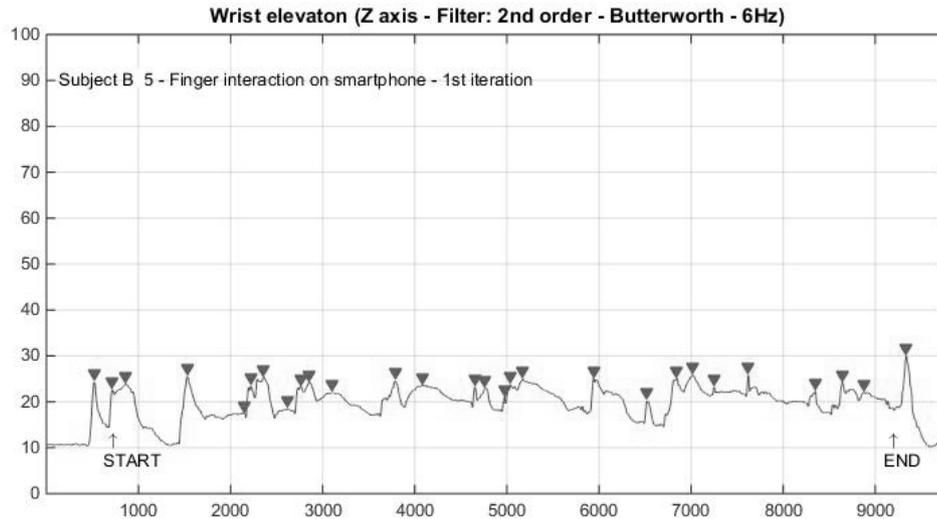


Figure V.21 Representation of wrist trajectory on Z axis (elevation). Peaks have been identified on filtered signal and start and end positions defined after first valley and before last valley, respectively

Figure V.22 represents the trajectory of the rotational center of the wrist of one subject during interaction with touchscreen before filtering and clipping procedures. Figure V.23 represents the trajectory the wrist of one subject during the task, after filtering and clipping procedures.

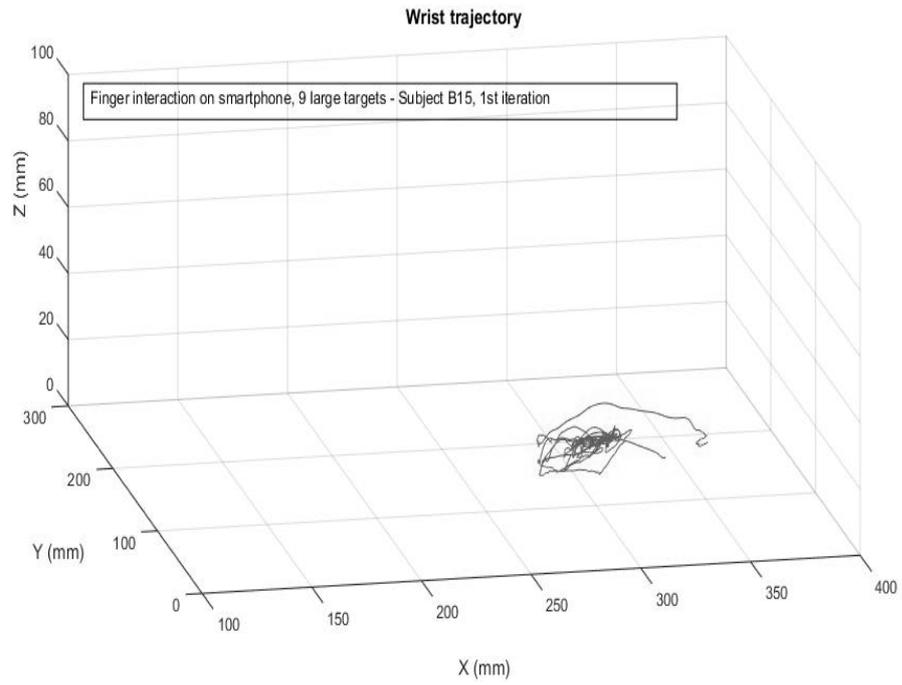


Figure V.22 Representation of the wrist trajectory on 3D (X, Y, Z) for the task before clipping

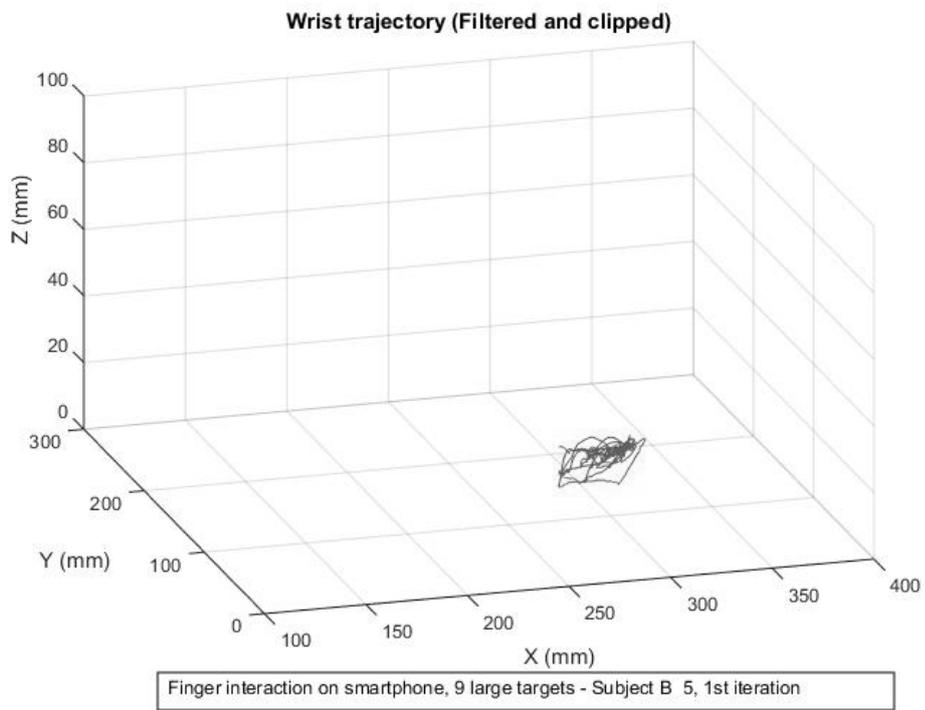


Figure V.23 Representation of the wrist trajectory on 3D (X, Y, Z) for the task (filtered and clipped)

Wrist elevation (Z axis)

The trajectory of the wrist has been calculated and the elevation has been estimated through the distance between the rotational center of the wrist and the devices on the Z axis. Figure V.24 represent the wrist elevation of one subject through time during the task Height zero is the position of the device. The mean elevation has been calculated (thick reference line) and the range of motion have been defined between minimum and maximum values of filtered and clipped data (dashed reference lines).

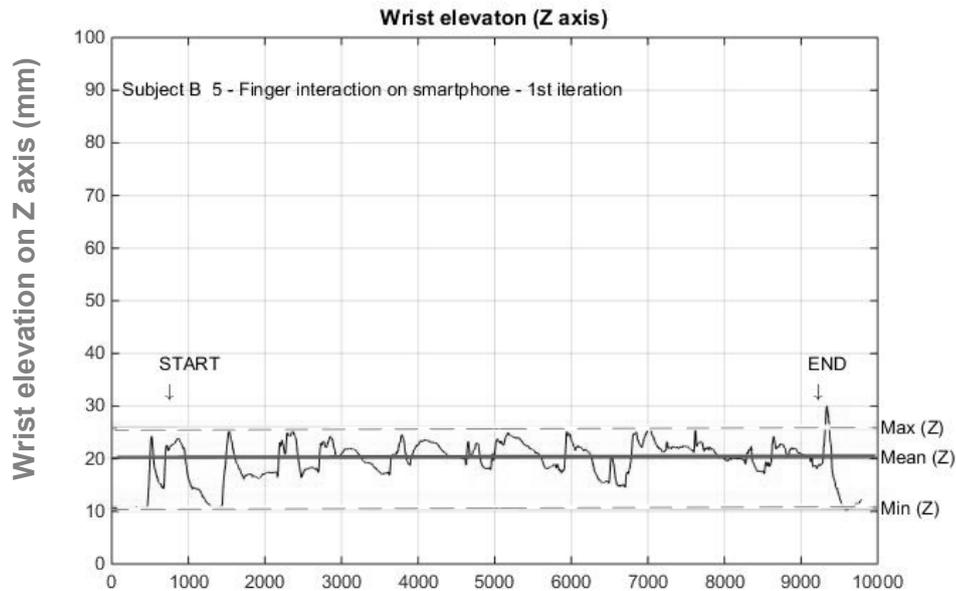


Figure V.24 Representation of wrist trajectory on Z axis (elevation)

Wrist radial or ulnar deviation

The radial or ulnar deviation angles of the wrist have been calculated between the hand position and the tactile devices on the desk plane (0, X, Z). Figure V.25 represents the angular deviations (radial or ulnar) of the wrist of one subject through time during the task. The mean deviation angle has been calculated (thick reference line). The range of motion has been defined between minimum and maximum values of filtered and clipped data (dashed reference lines), as represented on the graph. Negative values correspond to an ulnar deviation and positive values correspond to a radial deviation of the wrist.

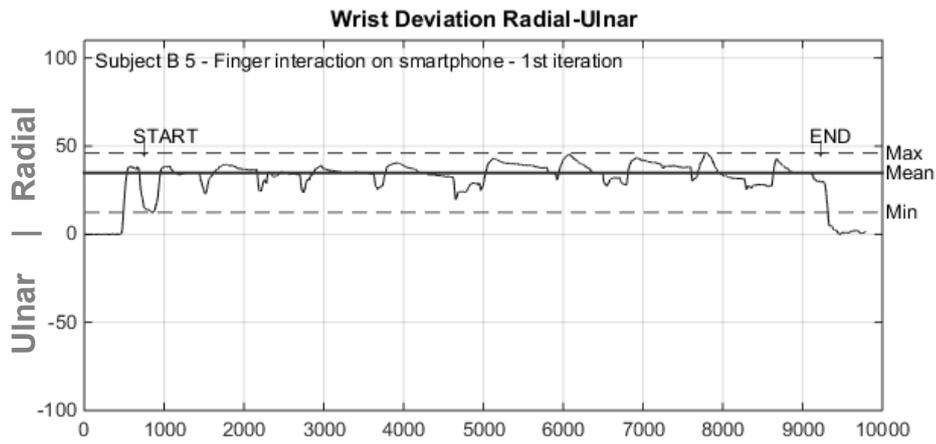


Figure V.25 Representation of wrist radial-ulnar deviation angles through time

Wrist flexion or extension

The flexion or extension angles of the wrist have been calculated on the plane (0, Y, Z). Figure V.26 represents the angular deviations (flexion or extension) of the wrist of one subject through time during the task. The mean deviation angle has been calculated (thick reference line). The range of motion has been defined between minimum and maximum values of filtered and clipped data (dashed reference lines), as represented on the graph. Negative values correspond to flexion and positive values correspond to extension of the wrist.

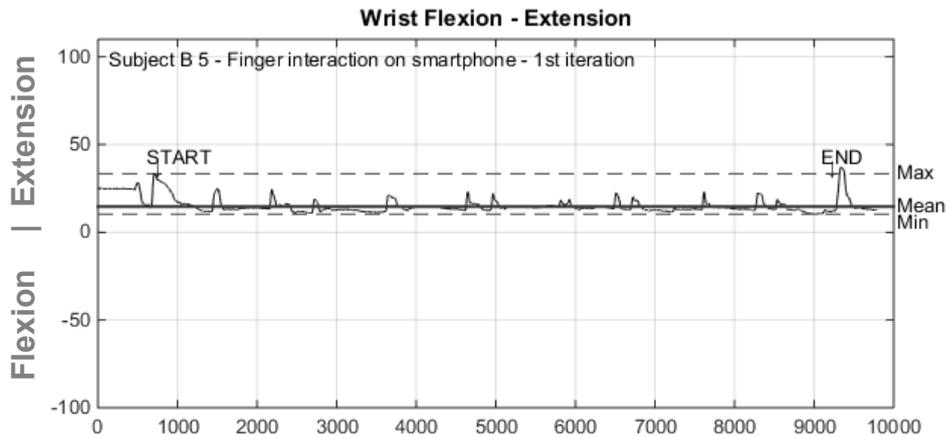


Figure V.26 Representation of the flexion-extension angular variations of the wrist through time

Wrist pronation or supination

The pronation or supination angles of the wrist have been calculated on the plane (0, X, Z). Figure V.27 represents angular deviations (pronation or supination) of the wrist of one subject through time during the task. The mean deviation angle has been calculated (thick reference line). The range of motion has been defined between minimum and maximum values of filtered and clipped data (dashed reference lines), as represented on the graph. Negative values correspond to supination and positive values correspond to pronation of the wrist.

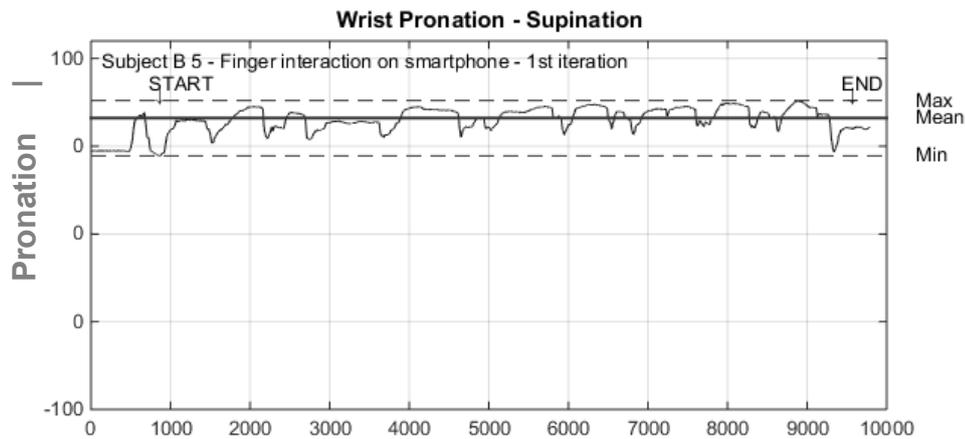


Figure V.27 Representation of the pronation-supination angular variations of the wrist through time

Data is not normally distributed according to Shapiro Wilk test. Table V.6 summarizes the dependent variables and describes the results from Shapiro Wilk test for data distribution.

Table V.6 Summary of dependent variables for analysis of postures of the wrist and data distribution

Evaluation criteria	Distribution
RU	<ul style="list-style-type: none"> • Mean: W= 0.993, p-value= 9.305e-05* • Range: W= 0.911, p-value < 2.2e-16*
FE	<ul style="list-style-type: none"> • Mean: W= 0.9864, p-value= 3.112e-06* • Range: W= 0.8579, p-value < 2.2e-16*
PS	<ul style="list-style-type: none"> • Mean: W= 0.958, p-value= 6.742e-16* • Range: W= 0.844, p-value < 2.2e-16
Mean wrist elevation	<ul style="list-style-type: none"> • Mean: W= 0.9658, p-value= 6.431e-12* • Range: W= 0.7859, p-value < 2.2e-16*

* Results from Shapiro Wilk test. Data is not normally distributed: p-values < 0.01

Consequently, we verified the difference between the two groups of subjects (age effects) with Mann Whitney U test. We searched for effects of screen sizes (tablet or smartphone), targets sizes (large or small on each device) and input modalities (pen or finger) with Wilcoxon signed rank test. Friedman test was used to analyze the variances between the eight different situations of the study.

Data distribution curves are skewed left. For these reason, the descriptive statistics for the results indicate median values for tendencies and one inter-quartile for variability.

V.1.7.3 *Relationship between variables*

The relationships between interaction performances and postures and movements of the wrist have been verified with Spearman correlation method. For the analysis of the relationship between variables, we describe the Spearman coefficient of correlation (weak: 0.3; moderate: 0.5; strong: 0.7).

V.2. Results

In this section, we describe the profiles of the participants, the effects of aging on interaction performances and postures of the wrist. Then we search for the effects of the different situations of the study: screen sizes, targets sizes, input modalities.

V.2.1. *Participants*

30 volunteers participated of this study: 15 adults and 15 older adults.

Table V.8 summarizes the characteristics of the participants, detailed in Table V.7.

Table V.7 Summary of participants' characteristics (means and standard deviations)

	Age	Weight (kg)	Height (cm)	Hands' length (cm)	Major fingers' length (cm)	Score for dexterity text	Score for cognitive test
Older adults	73 +/-5.2	67.8 +/-10.5	166.8 +/-10.5	18.1 +/-1.3	8.2 +/-0.6	25.3 +/-1.9	28.1 +/-2.6
Adults	30.3 +/-7.4	74.7 +/-10.7	179.3 +/-8.2	19.7 +/-1	9.1 +/-0.5	26.7 +/-0.6	30 +/- 1.2

Table V.8 Subjects' profiles (A= Adults, B= Older adults)

	Id	Age	Gender	Weight (kg)	Height (cm)	Hands' length (cm)	Major fingers' length (cm)	Use of touchscreen*
Adults	A1	18	M	73	188	21.5	9.7	5
	A2	20	M	68	185	20	9.2	5
	A3	23	M	74	191	21.5	10	5
	A4	26	M	96	191	20.4	9.5	5
	A5	27	F	55	173	18	8.5	5
	A6	28	F	71	174	19	9	5
	A7	29	M	75	176	18.6	8.2	5
	A8	30	M	71	175	20	9	5
	A9	31	M	72	183	19.5	9	5
	A10	32	F	68	170	19	8.5	5
	A11	33	M	84	175	19.8	9	5
	A12	33	F	80	175	20	9	5
	A13	37	M	65	170	19	9	2
	A14	43	M	73	171	18.5	9	5
	A15	44	M	95	192	20.5	9.5	5
Older adults	B1	65	F	64	155	17	7.5	1
	B2	66	M	83	185	20	9	1
	B3	68	M	83	187	20	9	1
	B4	68	F	57	160	18	8.5	3
	B5	70	M	68	178	18	8	1
	B6	72	F	75	160	17	8	1
	B7	73	F	50	155	16	8	2
	B8	73	F	61.5	170	19	8	5
	B9	74	F	69	162	17	8	5
	B10	74	M	72	168	19	9	1
	B11	74	F	58	163	18	7.5	2
	B12	77	M	69	171	19	8	5
	B13	78	F	66	164	18	8	1
	B14	79	F	57	155	16	7	1
	B15	84	M	85	169	19	9	1

Subject's profiles are sorted by age. * Frequency of use: 1) I never use it, 2) I have already used or I rarely use it, 3) I use it at least once a month, 4) At least once a week, 5) Every day or almost every day

V.2.1.1 *Older adults*

15 older subjects, aged 65 to 84 years old (mean age 73 +/-5.17, 9 female, 6 male) participated of the experience. Their measurements are described in Table V.7.

Older participants did not present any disability preventing them to execute the gestures of interaction.

Eight older subjects have higher education, six completed high school and one has primary education.

Concerning the experience of using interactive technologies, all the older adults use a computer regularly. Six older adults had previous experience and regular use of touchscreen devices. The others nine had never used touchscreen devices before.

All subjects were right-handed. They used the index finger during finger interaction. Four subjects also used major finger during interaction, one subject alternated between major and ring finger and one subject also touched the screen with the left index. The pen was hold between index, major and thumb.

Concerning their preferences, after the experiment one older subject reported preferring finger interaction and six preferred pen. Six subjects did not have any preference for the input modality. Concerning the sizes of the screens, ten subjects preferred interaction on tablet and two do not have any preference for devices. Two subjects reported they prefer pen for small targets on smartphone and finger for bigger targets or tablet interaction.

V.2.1.2 Adults

15 adults, aged 18 to 44 years old (mean age 30.26 +/-7.36, 4 female, 11 male) participated of the experiment. Their measurements are described in Table V.7.

Adults did not present any disability preventing them to execute the gestures of interaction. All subjects have completed high school and most of them are graduated. Concerning the experience of using interactive technologies, all adults use a computer every day or almost every day and all of them had previous experience with touchscreen devices.

All subjects were right-handed. All of them used the index finger during finger interaction and the pen was hold between index, major and thumb.

Five subjects prefer finger interaction, five prefer pen. Two do not have any preference for input modalities. Six subjects prefer tablet, five subjects prefer smartphone and four do not have any preference for the screen size. Three subjects reported they prefer pen for small targets on smartphone and finger for bigger targets or tablet interaction.

V.2.2. Effects of morphologies

Because of the differences in morphologies between groups, we verified significant differences and effects of morphologies. According to the results of Shapiro Wilk's test, data for age is not normally distributed (p-value= 0.0007). However, data for weight (p-value= 0.5348), height (p-value= 0.2137) and hand's length (p-value= 0.1131) are normally distributed. We found significant differences between groups for age (Mann-Whitney Test, $Z = -9.37$, $W = 225$, p-value= $3.33e-06$), height (Welch T-test, $t = -3.70$, $DF = 26.7$, p-value= 0.0009) and hand's length (Welch T-test, $t = -4.03$, $DF = 26$, p-value= 0.0004). There is no significant difference for weight (Welch T-test, $t = -1.77$, $DF = 27.9$, p-value= 0.0875).

By consequence, we searched for any relationship between subjects' height and hand's length and postures of the wrist or performances during interaction with touchscreen. For the two groups of subjects, higher height is related to bigger hand's length (0.9)

Among older subjects, no relationship was found between hand's length and mean deviation angles of the wrist (FE: -0.1; RU: 0; PS: -0.1). No relationship was found neither between hand's length and performances (time: 0; error rates: -0.1; U.T: -0.1). There is no relationship between hand's length and ranges of motion on FE (-0.2) and RU (-0.1). However, there is a weak relationship between hand's length and ranges of motion on PS (-0.3).

For the other group of subjects, there is no relationship neither between hand's length and mean deviation angles of the wrist (FE: -0.2; RU: -0.2; PS: -0.1). There is no relationship between hand's length and performances (time: -0.2; error rates: -0.1; U.T: -0.2). However, contrary to the group of older adults, there is a weak relationship between hand's length and ranges of motion on FE (-0.3) and RU (-0.3) and no relationship between hand's length and ranges of motion on PS (0).

This analysis demonstrates that subject's different morphologies did not affect mean angular deviations of the wrist during interaction, neither their performances. The users' hand's length can, on the other hand, affect the ranges of motion of the wrist. However, the effects are different for the two groups of subjects. Older adults with small hand's length execute increased ranges of motion on PS while adults with small hand's length execute increased ranges of motion on FE and RU.

V.2.3. Effects of aging

In the present study, we evaluate the differences in interaction performances and postures of the wrist between the two groups of subjects, older adults and adults.

V.2.3.1 Interaction performances

Older adults spent longer times of movement (Figure V.28) and made more errors than adults (Figure V.29). Table V.9 summarizes interaction performances for the two groups of subjects. Concerning the unintentional touches, some touches outside interaction zones have been detected during the interaction of older adults, approximately six unintentional touches per game. For the other group, there was practically no unintentional touches registered during interaction (Figure V.30).

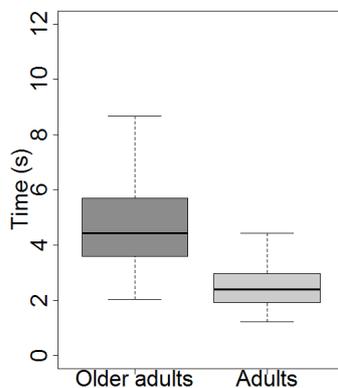


Figure V.28 Time of movement per target (s) for the two groups. Older adults spent longer times than adults.

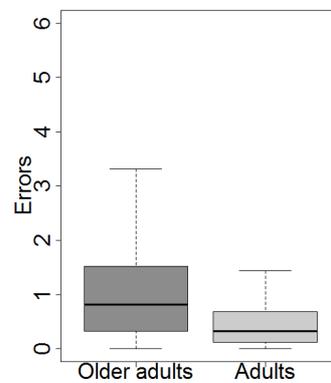


Figure V.29 Number of errors per target. Older adults made more errors than adults.

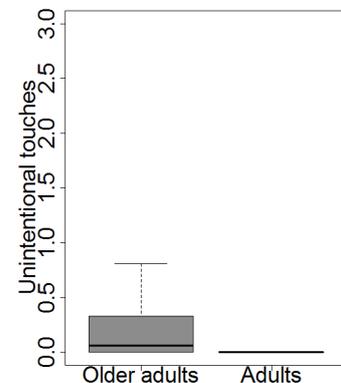


Figure V.30 Number of unintentional touches per target. Adults practically did not touch outside interaction zones.

Table V.9 Interaction performances for older adults and adults (medians and inter-quartiles)

Group	Time (s)	Errors	Unintentional touches
Older adults	4.42 +/-2.10	0.81 +/-1.18	0.06 +/- 0.33
Adults	2.39 +/-1.03	0.33 +/-0.56	0.00 +/- 0.00

The differences in interaction performances between the two groups were statistically significant, as described in Table V.10.

Table V.10. Results of Mann-Whitney test for significant differences in performances between the two groups

Dependent variables	Z	W	P-values
Time	43.13	117721	< 2.2e-16*
Errors	28.11	88037	< 2.2e-16*
Unintentional touches	34.03	161182	< 2.2e-16*

* Significant differences between the two age groups: p-values < 0.05

V.2.3.2 Postures and movements of the wrist

During tactile interaction, older adults and adults assumed a radial deviated, extended and pronated posture of the wrist.

Concerning the differences in postures and movements of the wrist between the two groups, the postures of the wrist of older adults are characterized by an increased radial deviation (Figure V.31), extension (Figure V.32) and smaller pronation angles (Figure V.33). The ranges of motion of older adults are also increased compared to adults on radial-ulnar deviation (Figure V.34), flexion-extension (Figure V.35) and particularly on pronation-supination angles (Figure V.36).

Table V.11 summarizes mean values for angular deviations and ranges of motions for the wrist during interaction with touchscreen. There is a big variability for all subjects and median values for mean angles are close. However, the differences in angular deviations and ranges of motions between these two age groups are statistically significant for the articular angles as described in Table V.13.

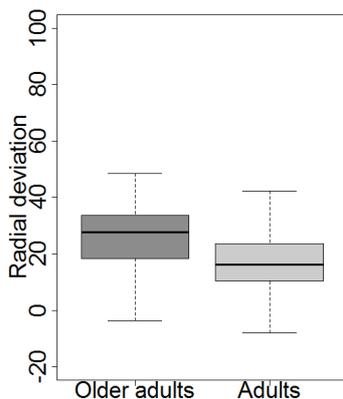


Figure V.31 Mean radial deviation for the two groups.

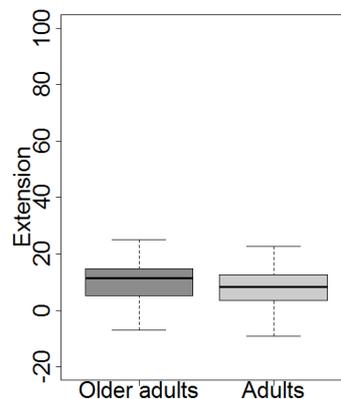


Figure V.32 Mean extension angles for the two groups.

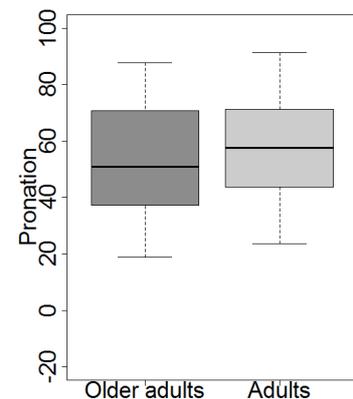


Figure V.33 Mean pronation angles for the two groups.

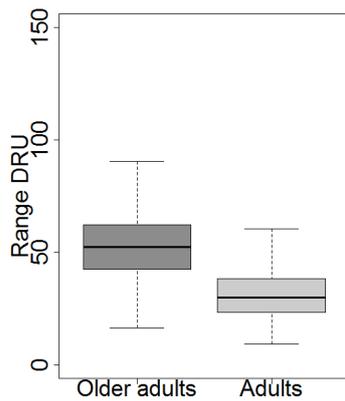


Figure V.34 Ranges of motion on radial-ulnar deviation for the two groups. Older adults executed greater ranges of motion on RU.

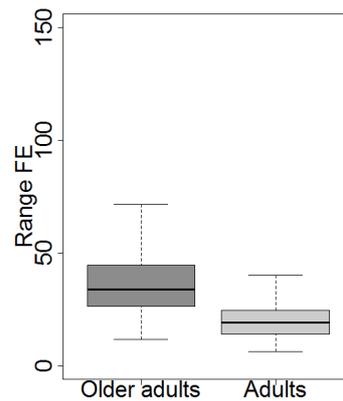


Figure V.35 Ranges of motion on flexion-extension angles for the two groups. Older adults executed greater ranges of motion on FE.

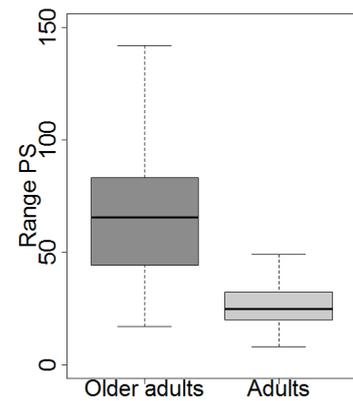


Figure V.36 Ranges of motion on pronation-supination angles for the two groups. Older adults executed greater ranges of motion on PS.

Table V.11 Angular deviations and ranges of motions of the wrist for older adults and adults (medians and inter-quartiles)

Posture	Group	Minimum	Mean angle	Maximum	Range
Radial-ulnar	Older adults	-7 +/-16	28 +/-15	47 +/-15	52 +/-20
	Adults	0 +/-16	16 +/-13	31 +/-16	30 +/-15
Flexion-extension	Older adults	-2 +/-12	11 +/-10	32 +/-16	34 +/-18
	Adults	0 +/-9	8 +/-9	20 +/-10	19 +/-10
Pronation-supination	Older adults	7 +/-37	51 +/-33	79 +/-27	66 +/-39
	Adults	38 +/-27	57 +/-28	70 +/-26	25 +/-12

Concerning the wrist elevation, the mean wrist elevation of older adults during the task is lower than adults (Figure V.37). However, the range of motion on the axis perpendicular to the devices is increased to older adults: their movements are characterized by lower minimum heights, higher maximum heights (Figure V.38).

Table V.12 describes mean wrist elevation and ranges of motion for the two groups.

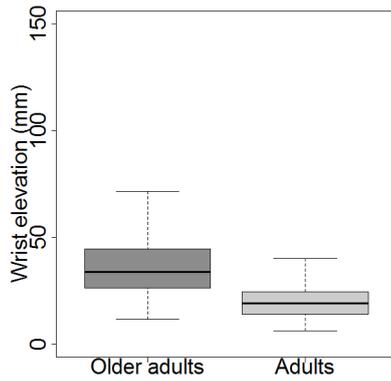


Figure V.37 Mean wrist elevation (mm) for the two groups of subjects.

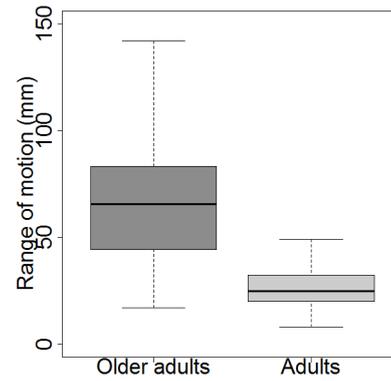


Figure V.38 Range of motion of wrist elevation (mm) for the two groups of subjects.

Table V.12 Mean elevation of the wrist and range of motion for older adults and adults (cm) (medians and inter-quartiles)

Group	Minimun	Mean wrist elevation	Maximun	Range
Older adults	1.1 +/- 0.9	2.9 +/-1.12	9.4 +/- 5.7	8.3 +/-5.9
Adults	2.2 +/- 1.1	3.7 +/-1.7	6.5 +/- 2.9	4.3 +/-2.6

The differences in postures and movements of the wrist between the wrist elevation measurements of the two groups are significant and results of significance tests are described in Table V.13.

Table V.13. Results of Mann-Whitney test for significant differences in postures and movements of the wrist between the two groups

Dependent variables	Z	W	P-values
RU	34.03	161182	< 2.2e-16*
Range of motion RU	42.26	186209	< 2.2e-16*
FE	24.16	131172	2.53e-08*
Range of motion FE	41.52	183971	< 2.2e-16*
PS	11.67	93217	0.00038*
Range of motion PS	45.70	196675	< 2.2e-16*
Mean wrist elevation	7.91	81779	2.893e-10
Range of motion on wrist elevation	35.33	165154	< 2.2e-16*

* Significant differences between the two age groups: p-values < 0.05

V.2.3.3 Relationship between postures and movements of the wrist and interaction performances

For older adults, there is a negative weak correlation between extension angles of the wrist and the number of unintentional touches. The number of unintentional touches is also negatively correlated to the pronation angles of the wrist. This characteristic should be further investigated through the analysis of the effects of the input modalities on the postures of the wrist.

Mean wrist elevation is correlated to the time of movement. Concerning the relationship between postures of the wrist, there is a positive correlation between extension and pronation angles. Concerning the relationship between variables of performances, there is a positive correlation between time and errors as well as between the number of unintentional touches, time and errors. Table V.14 describes the relationship between variables for older adults.

Table V.14 Spearman's coefficient of correlation between interaction performances and postures and movements of interaction for older adults

	Performances			Position and postures		
	Time	Errors	Unintentional touches	Radial deviation	Extension	Supination
Errors	0,62***					
Unintentional touches	0,48**	0,46**				
Radial deviation	-0,10	0,06	-0,01			
Extension	0,04	0,11	-0,25*	0,08		
Pronation	-0,13	0,07	-0,50**	-0,14	0,34*	
Wrist elevation	0,16*	-0,02	0,18	-0,11	-0,18	-0,17

* Weak correlation; ** Weak to moderate correlation; *** Moderate to strong correlation

For adults, there is a negative correlation between time and supination angles and a positive correlation between time and mean wrist elevation. There is a negative correlation between pronation angles and number of unintentional touches. Concerning the relationship between postures of the wrist, there is a negative correlation between radial deviation and pronation angles. There is also a negative correlation between mean wrist elevation and extension angles as well as for pronation angles. Table V.15 describes the relationship between variables for adults.

Table V.15 Spearman's coefficient of correlation between interaction performances and postures and movements of interaction for adults

	Performances			Position and postures		
	Time	Errors	Unintentional touches	Radial deviation	Extension	Supination
Errors	-0,14					
Unintentional touches	0,26	0,11				
Radial deviation	0,10	-0,05	0,05			
Extension	-0,12	-0,05	-0,16	0,16		
Pronation	-0,30*	0,08	-0,31*	-0,38**	0,19	
Wrist elevation	0,31*	-0,27*	0,03	0,08	-0,27*	-0,31*

* Weak correlation; ** Weak to moderate correlation

V.2.4. Effects of screen sizes, targets sizes and input modalities

In this section we search for the differences in performances and movements of the wrist related to the screen sizes, input modalities and targets sizes. The eight situations of the study have significant effects on interaction performances and postures and movements of the wrist for the two groups of subjects. Details about the differences in performances and movements between the eight situations of the study are described in the Appendix VII.5 (p. 240).

V.2.4.1 Screen sizes

The effects of the screen sizes were verified on interaction performances and postures of the wrist for the two groups of subjects.

Interaction performances

There is a bigger variability in time and errors during interaction on smartphone than on tablet for older adults (Figure V.39). Despite the variability, results show that some older adults also made fewer errors on tablet (Figure V.40). The description of interaction performances on smartphone and tablet for the two groups of subjects is presented on Table V.16. For older adults, the differences in time or unintentional touches between the devices are not significant. The verification of significant effects is presented in Table V.17.

Adults, on the other hand, made longer times on tablet than on smartphone even if they made more errors on the smaller screen size than on tablet. The effects of the screen

sizes are statistically significant for time and errors for adults despite the variability of performances observed for this group (Table V.17).

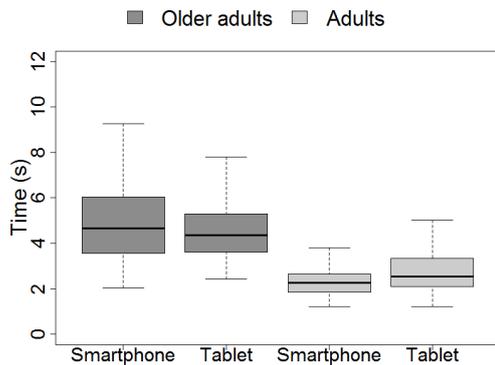


Figure V.39 Time of movement per target (s) for the two groups of subjects on smartphone and on tablet. Adults spent longer times for positioning the targets on tablet.

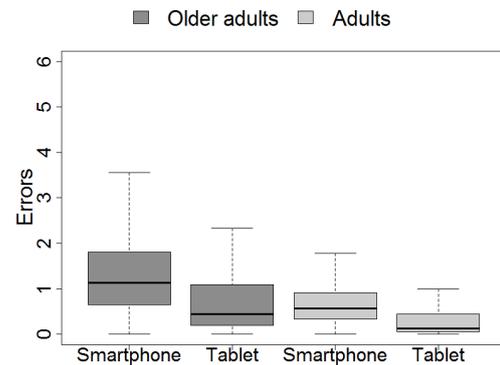


Figure V.40 Number of errors per target for the two groups of subjects on smartphone and on tablet. Both groups made more errors on smartphone, where targets are smaller than those on tablet.

Table V.16 Interaction performances on smartphone and tablet for groups of subjects (medians and inter-quartiles)

	Group	Time (s)	Errors	Unintentional touches
Smartphone	Older adults	4.67 +/-2.46	1.13 +/-1.16	0 +/-0.33
	Adults	2.28 +/-0.79	0.56 +/-0.57	0 +/-0
Tablet	Older adults	4.36 +/-1.68	0.44 +/-0.89	0,06 +/-0.33
	Adults	2.54 +/-1.23	0.13 +/-0.38	0 +/-0

Table V.17. Results of Wilcoxon test for significant differences of screen sizes in interaction performances

	Older adults			Adults		
	Z	V	P-values	Z	V	P-values
Time	2.181	9672	0.029*	-6.721	3440	1.813e-11*
Errors	7.259	13226.5	4.629e-15*	6.623	12781.5	2.2e-16*
Unintentional touches	-5.940	3986.5	0.045	-10.080	1088.5	0.037

* Significant differences of screen sizes: p-values < 0.025

Postures of the wrist

The big variabilities in performances were also observed in the movements of the wrist. Despite the closer median angles, globally, the motion of the wrist of both groups is

characterized by reduced radial deviation (Figure V.41), reduced extension (Figure V.42) and reduced supination angles (Figure V.43) during interaction on tablet when compared to interaction on smartphone. Motion characteristics are presented on

Table V.18.

The ranges of motion on both devices are increased for older adults, who also executed bigger variabilities compared to adults. The median values are similar between devices, but increased on radial-ulnar deviation (Figure V.44) for older adults and adults and the ranges of motion on flexion-extension (Figure V.45) and pronation-supination are increased on tablet for adults (Figure V.46).

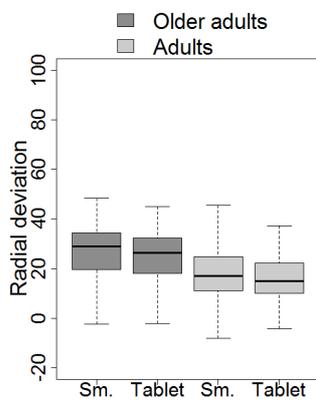


Figure V.41 Mean radial deviation of the wrist of older adults and adults for interaction on smartphone and tablet

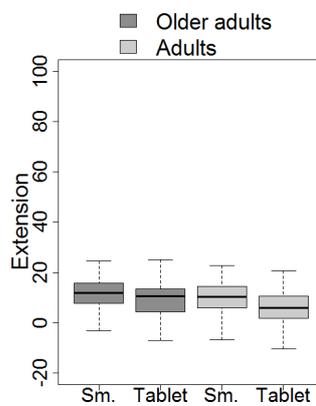


Figure V.42 Mean extension angle of the wrist of older adults and adults for interaction on smartphone and tablet

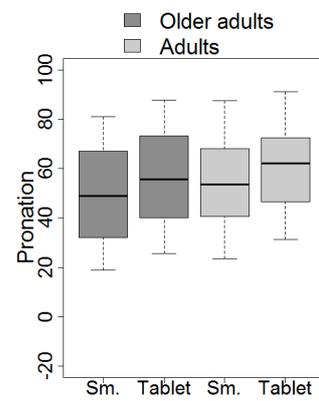


Figure V.43 Mean pronation angles of the wrist of older adults and adults for interaction on smartphone and tablet

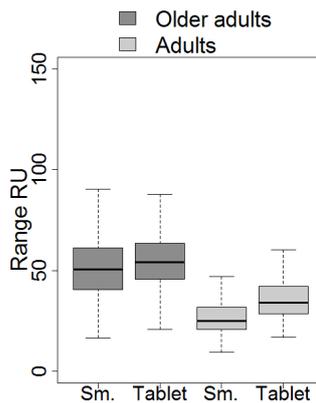


Figure V.44 Range of motion on RU deviation of the wrist of older adults and adults for interaction on smartphone and tablet

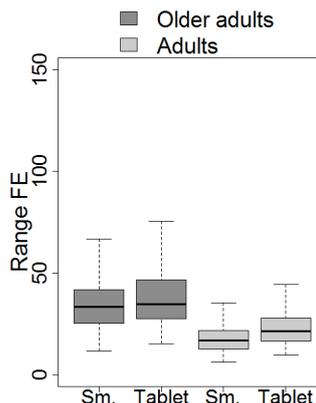


Figure V.45 Range of motion on FE of the wrist of older adults and adults for interaction on smartphone and tablet

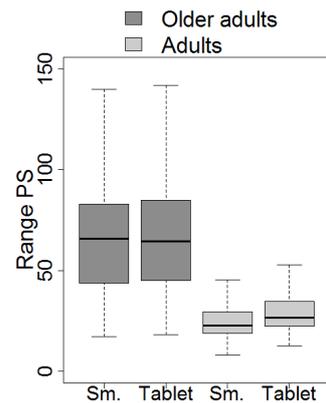


Figure V.46 Range of motion on PS of the wrist of older adults and adults for interaction on smartphone and tablet

Table V.18 Motion features on smartphone and tablet for groups of subjects (medians and inter-quartiles)

	Group	Mean RU	Range RU	Mean FE	Range FE	Mean PS	Range PS
Smartphone	Older adults	27 +/-11	52 +/-19	12 +/-7	36 +/-16	49 +/-35	66 +/-39
	Adults	18 +/-10	28 +/-11	10 +/-6	19 +/-9	54 +/-27	23 +/-11
Tablet	Older adults	25 +/-10	56 +/-20	9 +/-7	40 +/-19	56 +/-33	64 +/-39
	Adults	16 +/-9	35 +/-9	6 +/-6	23 +/-10	62 +/-26	27 +/-12

Mean wrist elevation (Figure V.47) and ranges of motion (Figure V.48) are increased on tablet for older adults and adults, characterized by increased ranges of motion for older adults. Details are described on Table V.19.

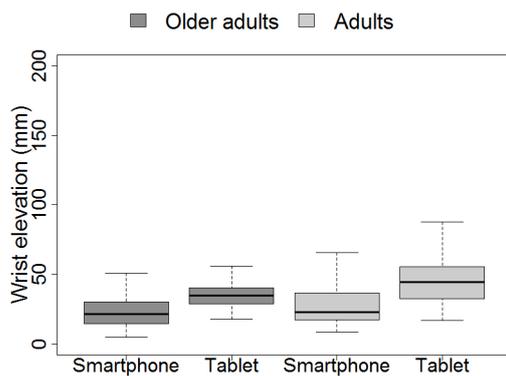


Figure V.47 Mean wrist elevation (mm) for the two groups of subjects on smartphone and tablet.

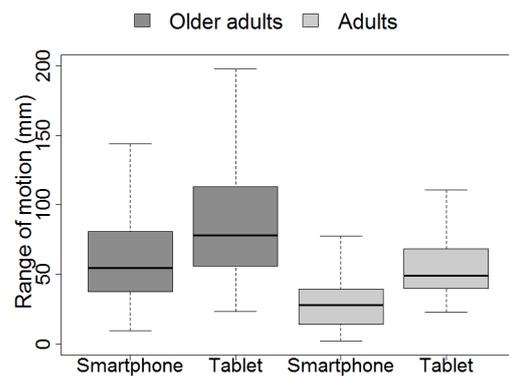


Figure V.48 Range of motion of wrist elevation (mm) for the two groups of subjects on smartphone and tablet.

Table V.19 Mean wrist elevation and range of motions on smartphone and tablet for groups of subjects (medians and inter-quartiles)

	Group	Mean Z (cm)	Range of motion Z (cm)
Smartphone	Older adults	22.94 +/-9.98	73.36 +/-61.39
	Adults	28.22 +/-14.29	30.30 +/-23.07
Tablet	Older adults	35.81 +/-9.75	93.95 +/-55.09
	Adults	45.28 +/-14.71	56.81 +/-22.87

The screen sizes significantly affected mean RU, FE, PF angles and wrist elevation for older adults and adults. The increased range of motion on RU and FE angles and wrist elevation are significant only for older adults. The differences between ranges of motion on smartphone or tablet are significant for RU, FE, PS and wrist elevation for adults. These effects are described in Table V.20.

Table V.20. Results of Wilcoxon test for significant differences of screen sizes in postures and movements of the wrist

	Older adults			Adults		
	Z	V	P-values	Z	V	P-values
RU	3.85	10842	0.0001*	6.58	32472	4.666e-11*
Range of motion RU	-3.01	6039	0.003*	-11.04	5975	<2.2e-16*
FE	7.94	13706	1.972e-15*	10.81	38824	<2.2e-16*
Range of motion FE	-3.36	5796	0.0008*	-10.62	6612	<2.2e-16*
PS	-10.43	844	2.2e-16	-14.02	1497	<2.2e-16*
Range of motion PS	0.27	8333	0.789	-8.45	9868	<2.2e-16*
Mean wrist elevation	-11.21	300	2.2e-16*	-14.90	175	<2.2e-16*
Range of motion on wrist elevation	-6.14	3845	8.16e-10*	-13.82	1787	<2.2e-16*

* Significant differences of screen sizes: p-values < 0.05

V.2.4.2 *Input modalities*

Interaction performances

Concerning interaction performances, the two groups made shorter times of movement during interaction with pen (Figure V.49). Pen interaction did not affect the number of errors for older adults but this number is reduced for adults (Figure V.50). Unintentional touches on the screen were registered during finger interaction for older adults (Figure V.51).

Table V.21 describes performances for both groups with pen and finger.

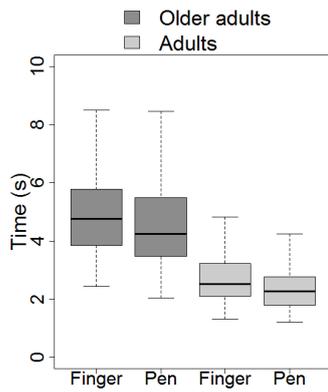


Figure V.49 Time of movement per target (s) for the two groups for finger and pen interaction.

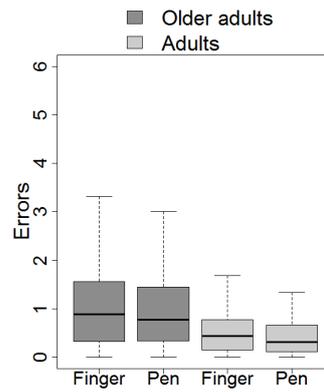


Figure V.50 Number of errors per target for the two groups of subjects for finger and pen interaction.

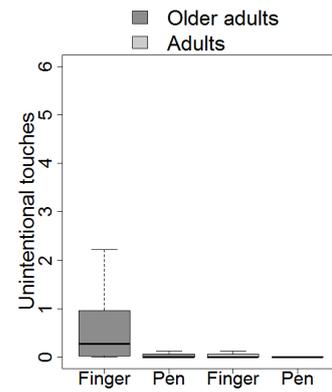


Figure V.51 Number of unintentional touches per target for the two groups of subjects. Older adults made fewer unintentional touches using a pen.

Table V.21 Performances with two input modalities for groups of subjects (medians and inter-quartiles)

Situations	Group	Time	Errors	Unintentional touches
Finger	Older adults	4.76 +/-1.91	0.88 +/-1.23	0.28 +/-0.91
	Adults	2.51 +/-1.10	0.44 +/-0.61	0 +/-0.1
Pen	Older adults	4.24 +/-2.00	0.78 +/-1.11	0 +/-0.06
	Adults	2.28 +/-0.97	0.31 +/-0.56	0 +/-0

Significant effects of input modalities on performances are detailed in Table V.22.

Table V.22. Results of Wilcoxon test for significant differences of input modalities in interaction performances

	Older adults			Adults		
	Z	V	P-values	Z	V	P-values
Time	4.467	11272	7.963e-06*	7.487	13386	7.101e-14*
Errors	- 1.231	7283.5	0.198	-0.510	7788	0.002*
Unintentional touches	1.330	9076	2.2e-16*	-8.619	2111	1.091e-09*

* Significant differences of input modalities: p-values < 0.025

Postures and movements of the wrist

Globally, the posture of the wrist during finger interaction for both groups is characterized by similar but slightly increased median radial deviation angles (Figure V.52) and reduced median extension angles (Figure V.53). Mean pronation angles (Figure

V.54) on the other hand are significantly increased during interaction with finger compared to pen interaction. Table V.23 describes mean deviation angles and range of motion for the two groups of subjects during interaction with pen and finger.

Despite the bigger variability in ranges of motion for older adults, the median values for ranges of motion on radial-ulnar deviation (Figure V.55) and flexion-extension angles (Figure V.56) are increased for this group of subjects during interaction with finger. For adults, input modalities only affected significantly the range of motion on flexion-extension angles. The differences in the range of motion of pronation angles between input modalities are not significant for both groups of subjects (Figure V.57). These effects are described in Table V.25.

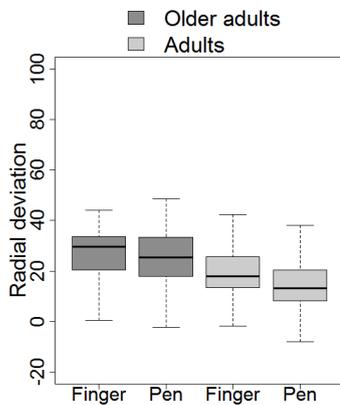


Figure V.52 Mean radial deviation of the wrist of older adults and adults for finger and pen interaction

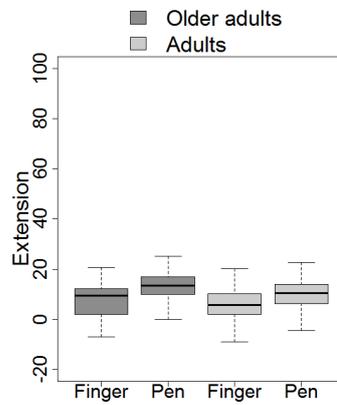


Figure V.53 Mean flexion angle of the wrist of older adults and adults for finger and pen interaction

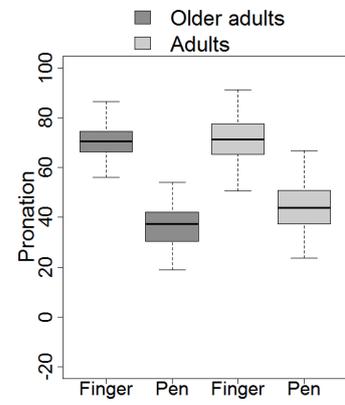


Figure V.54 Mean pronation angles of the wrist of older adults and adults for finger and pen interaction

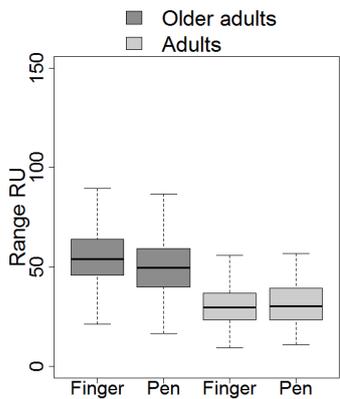


Figure V.55 Range of motion on RU deviation of the wrist of older adults and adults for finger and pen interaction

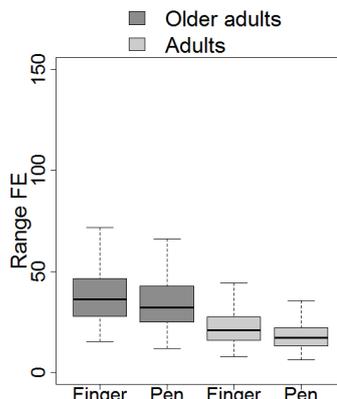


Figure V.56 Range of motion on FE of the wrist of older adults and adults for finger and pen interaction

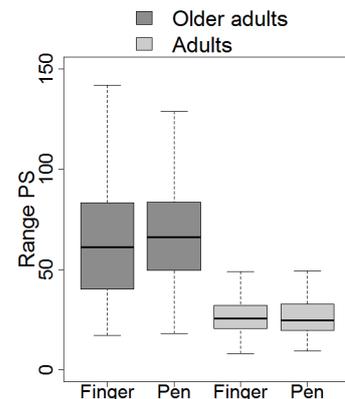


Figure V.57 Range of motion on PS of the wrist of older adults and adults for finger and pen interaction

Table V.23 Motion features with two input modalities for groups of subjects (medians and inter-quartiles)

	Group	Mean RU	Range RU	Mean FE	Range FE	Mean PS	Range PS
Finger	Older adults	30 +/-13	54 +/-18	9 +/-10	36 +/-18	71 +/-8	61 +/-43
	Adults	18 +/-12	30 +/-13	6 +/-8	21 +/-11	71 +/-12	26 +/-11
Pen	Older adults	25 +/-15	50 +/-19	13 +/-7	32 +/-18	37 +/-12	66 +/-34
	Adults	13 +/-12	30 +/-16	11 +/-8	17 +/-9	44 +/-13	25 +/-13

Differences between input modalities are not significant in mean wrist elevation (Figure V.58) neither in ranges of motion for older adults nor adults (Figure V.59). Table V.24 presents wrist elevation and range of motion according to the input modalities for the two groups of subjects. The effects of input modalities on wrist elevation are described in Table V.25.

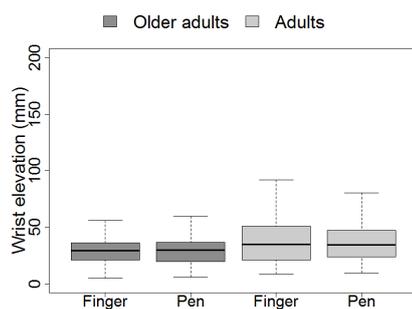


Figure V.58 Mean wrist elevation (mm) for the two groups of subjects during finger and pen interaction.

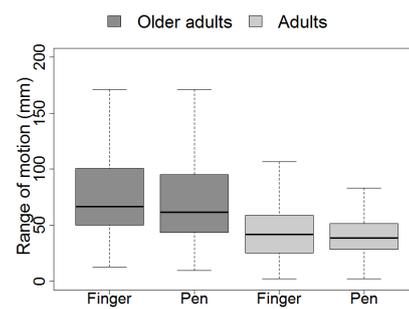


Figure V.59 Range of motion of wrist elevation (mm) for the two groups of subjects during finger and pen interaction.

Table V.24 Wrist elevation and range of motion with two input modalities for groups of subjects (medians and inter-quartiles)

Situations	Group	Mean Z	Range of motion Z
Finger	Older adults	29.51 +/-12.01	88.24 +/-61.42
	Adults	37.35 +/-18.44	45.52 +/-29.53
Pen	Older adults	29.24 +/-11.56	79.08 +/-56.59
	Adults	36.15 +/-15.04	41.59 +/-22.99

Table V.25. Results of Wilcoxon test for significant differences of input modalities in postures and movements of the wrist

	Older adults	Adults

	Z	V	P-values	Z	V	P-values
RU	2.267	9732	0.0234*	11.638	40075	< 2.2e-16*
Range of motion RU	3.560	10637	0.0004*	-0.210	22259	0.834
FE	-9.961	1172	< 2.2e-16*	-9.789	7855	< 2.2e-16*
Range of motion FE	2.931	10197	0.003*	9.388	36692	< 2.2e-16*
PS	11.635	16290	< 2.2e-16*	15.012	45149	< 2.2e-16*
Range of motion PS	-0.899	7516	0.369	1.070	24184	0.285
Mean wrist elevation	-0.220	7991	0.826	-0.922	21189	0.357
Range of motion on wrist elevation	2.320	9769	0.020*	1.531	24877	0.126

* Significant differences of input modalities: p-values < 0.025

V.2.4.3 *Targets sizes*

The effects of the targets sizes during interaction on smartphone and on tablet were verified on interaction performances and postures of the wrist for the two groups of subjects. In this section, we describe main significant effects. The detailed description is presented in Appendix VII.7.1.2 (p. 252).

Interaction performances

Older adults and adults spent longer times for positioning small targets than large targets, on both touchscreen devices. The two groups also made more errors with small targets on smartphone. Older adults only made more errors for positioning small targets than large targets on tablet. Concerning the number of unintentional touches, it also increased during interaction with small targets on tablet and smartphone for older adults. The differences of performances of the two groups between interaction on smartphone and tablet are described in Table V.26.

The effects of the different sizes of targets on smartphone and on tablet were significant for older adults on time, errors and unintentional touches. These effects also produced significant differences in time, errors and unintentional touches for adults. However, during interaction on tablet, the size of the targets only affected the mean time of movement per target for adults. Details are presented in Appendix VII.7.1.2, Table VII.17 (p. 253).

Table V.26 Interaction performances with two sizes of targets for groups of subjects on smartphone (medians and inter-quartiles)

Device	Size of targets	Group	Time	Errors	Unintentional touches
Smartphone	Large targets	Older adults	4.03 +/-1.95	0.89 +/-1.00	0.00 +/-0.19
		Adults	2.01 +/-0.69	0.44 +/-0.56	0.00 +/-0.00
	Small targets	Older adults	5.16 +/-2.64	1.41 +/-1.13	0.13 +/-0.55
		Adults	2.37 +/-0.76	0.66 +/-0.50	0.00 +/-0.06
Tablet	Large targets	Older adults	3.98 +/-1.35	0.33 +/-0.89	0.00 +/-0.33
		Adults	2.50 +/-1.43	0.11 +/-0.22	0.00 +/-0.00
	Small targets	Older adults	4.67 +/-1.72	0.50 +/-0.92	0.09 +/-0.44
		Adults	2.61 +/-1.05	0.19 +/-0.38	0.00 +/-0.00

Postures and movements of the wrist

The size and number of targets did not affect mean angles and ranges of motion of older adults' wrist during interaction on smartphone. During interaction on tablet, the different sizes of targets affected mainly FE and PS angles for the older group of subjects. Globally, sixteen small targets required greater ranges of motion both groups of subjects than nine large targets.

The description of mean angular deviations of the wrist and ranges of motion for older adults and adults, for positioning small and large targets on smartphone and tablet, with finger or pen, and the verification of significant effects on postures of the wrist can be found in Appendix VII.7.1.2 (p. 254).

V.3. Discussion

The present study was conducted to understand the differences in movements between older adults and adults during interaction with touchscreen in order to elucidate the differences in interaction performances between these two groups of subjects. We implemented an experimental protocol to assess the postures and movements of the older adults and adults during the execution of drag-and-drop interaction for positioning targets with the system Puzzle Touch, on smartphone and tablet, during pen and finger interaction.

In this thesis work, we focused on postures and movements of the wrist. We verified differences in interaction performances as well as the angular deviations and ranges of motion of the wrist between two groups of subjects. Then, we analyzed the effects of the different situations of the study, particularly the effects of screen sizes, input

modalities and targets sizes, on performances and movements. In the following subsections, we discuss the results obtained from our experiment.

V.3.1. *Characterization of postures and movements of the wrist during interaction with touchscreen*

Our results demonstrated that older adults and adults assumed a radial deviated, extended and supinated wrist posture during the execution of drag-and-drop interaction on touchscreen devices horizontally fixed on the desk. This result completes the findings of previous studies in the literature about the postures of the wrist during tactile interaction. Young *et al.* (2013) have reported radial deviated and extended postures of the wrist for users executing different tasks with fingers on tablets (Young et al., 2013). Werth and Babski-Reeves (2014) described flexed, pronated and ulnar deviated posture of the wrist during typing tasks on touchscreen (Werth and Babski-Reeves, 2014). These differences on postures of the wrist are certainly related to the devices position, the kind of tasks or the gestures of interaction required for the tasks. Concerning the positions of the devices, tilted positions resulted extension of the wrist for tablets placed on the lap or on the desk tablets (Young et al., 2013). The horizontal positions, on the other hand, resulted on flexion of the wrist for typing tasks (Werth and Babski-Reeves, 2014). In regard of the kind of tasks, typing tasks required ulnar deviations (Werth and Babski-Reeves, 2014) while the execution of other gestures of interaction resulted on radial deviation (Young et al., 2013).

In the study of Young *et al.* (2013), tablets were hold inclined (tilt angles from 15° to 73°) and positioned on subjects' lap or on a desk. Subjects executed web browsing, email and gaming. These tasks require different gestures of interaction, such as tapping for selecting targets, scrolling for reading emails and typing (Young et al., 2013). In our study, the execution of drag-and-drop on touchscreen devices horizontally placed on the desk required a reduced extension of the users' wrist (mean 7°, SD=7) when compared to the extreme postures required for tilted tablets, as presented in the study of Young *et al.* (2013). Drag-and-drop interaction, contrarily to typing tasks, required radial deviation and extension of the wrist, with smaller ranges of motion than the results reported on the study of Werth and Babski-Reeves (2014). In their study, subjects' wrist assumed an ulnar deviated and flexed postures for executing typing tasks on touchscreen devices horizontally placed on the subjects' laps (Werth and Babski-Reeves, 2014).

V.3.2. Variability in performances, postures and movements

Confirming the results presented in Chapter IV (p. 121), there is a big variability in performances between subjects. This variability could be related to the different users' profiles, such as age and experience of use of technologies, as discussed in our precedent analysis, as well as to the different situations of use represented in the study (screen sizes, input modalities). In the present study, we tried to understand the variability of performances through the analysis of the movements of the users.

Indeed, the variability of performances is also reflected in the variability of mean angles and ranges of motion of the wrist we observed in the results we obtained.

For the two groups of subjects, but particularly to the older adults, this variability is indicated values of medians and inter-quartiles intervals that we reported. In fact, as discussed in the literature, the distribution of coordinates of the trajectories of movements and touch positions are Gaussian and distinct for each subject and correspond to each different situation of the study (screen size, input modality) (Bachynskiy et al., 2014; Beringer and Peterson, 1985). First, our analysis of the effects of the different morphologies brings some supplementary information about the variability in postures and movements of the wrist. This analysis demonstrated that subject's different morphologies did not affect mean angular deviations of the wrist during interaction, neither their performances. However, users' hand's length affected the ranges of motion of the wrist.

The differences between the two groups of subjects show that users from different age-groups develop their own strategies to accomplish the gestures of interaction. Indeed, among the participants of the present study, older adults with small hand's length executed increased ranges of motion on pronation-supination while adults with small hand's length executed increased ranges of motion on radial-ulnar deviation and flexion-extension. Future work should evaluate how the users' morphologies and strategies of movements affect upper-limbs postures and movements.

Moreover, the variability on statures between older adults and adults can be considered representative of users of touchscreen devices. Indeed, smaller heights and hands' length are characteristic of older populations compared to younger adults (Annis, 1996).

Additionally, the variability in strategies of movements is reflected on the users' performances. The analysis presented in Chapter IV (p. 121) also presented a big

variability among older subjects, which was interpreted according to their age groups, experience of use of computers as well as use of touchscreen.

V.3.3. Differences in performances between older adults and adults

The results of the analysis of interaction performances showed that the differences in performances of older adults and adults were significant for time and error rates. **Hypothesis 1 is not confirmed.** Even if drag-and-drop interaction helps older adults to accomplish tactile interaction, older adults spent longer times of movement and made more errors than adults. Concerning the number of unintentional touches, there were more touches registered on non-interaction areas during interaction of older adults with touchscreen.

These results are in line with previous studies comparing interaction performances of older adults and adults, reporting longer times and more errors for older subjects executing tapping tasks with pen and finger (Hourcade and Berkel, 2006), digit input (M. K. Chung et al., 2010), typing (Wright et al., 2000) or executing different gestures of interaction on touchscreen (Findlater et al., 2013).

The continuous contact with the screen during drag-and-drop interaction can help older users to overcome the decrease of accuracy related to the aging (Mertens and Jochems, 2010; Wacharamanotham, 2011). However, friction on the screen could be reducing the speed of the gestures and consequently increasing the time of movement. Drag-and-drop interaction may have reduced but it was not enough to cancel the effects of aging on time and number of errors. Findlater *et al.* (2013) have reported longer times for older adults executing drag-and-drop in comparison to other gestures of interaction on touchscreen (Findlater et al., 2013), but the causes of the increased times have not been investigated. Concerning the accuracy of the gesture, the study of Stöbel *et al.* (2010) demonstrated that older subjects were not less accurate than younger for executing gestural patterns on touchscreen, but this group of users also took longer times (Stöbel et al., 2010). Unlike Stöbel *et al.* (2010) (Stöbel et al., 2010), our results showed a significant difference of accuracy between groups of subjects.

As discussed by Young *et al.* (2013), the increased angular deviations of the wrist during interaction with touchscreen are related to the needs of the users to prevent unintentional touches and activation of onscreen controls (Young et al., 2013). Despite of the increased extension of the wrist that characterizes the movements of older adults, several unintentional touches have been registered during interaction for this group of

users. Delimitating the interaction zones was effective for preventing errors that could be related to these unintentional touches on the screen.

V.3.4. Differences in postures and movements of the wrist between older adults and adults

Concerning the differences in postures and movements of the wrist between the two groups of subjects, **hypothesis 2 is confirmed**. The wrist postures of older adults are characterized by increased radial deviation, increased extension and reduced pronation of the wrist. Mainly, the ranges of motion on radial-ulnar deviation, flexion-extension and pronation-supination angles are increased for the older group of users. Minimal and maximal radial deviation, extension and pronation angles are greater for older subjects. Similarly, minimal wrist elevation is lower and maximal wrist elevation was higher for older adults.

From an ergonomic point of view, the increased ranges of motion observed to the older group of subjects indicate an increased deviation from neutral positions of the wrist, reaching angular values that could be close to the limitations of the flexibility of this articulation. For this reason, we can consider that older adults assume more restrictive postures of the wrist compared to the younger group of subjects. Indeed, these characteristics usually imply bigger discomfort for the users and prolonged times of use could improve the risk for musculoskeletal disorders for older adults (Qin et al., 2013).

Drag-and-drop interaction requires continuous contact with the screen for positioning the targets. Typing on touchscreen, on the other hand, requires constant elevation of the hand and floating movements of the fingers. The effects of the different gestures of interaction on mean wrist elevation observed on our study are probably specific to the drag-and-drop interaction.

Additionally, the movements of older adults during interaction are also characterized by a lower wrist elevation. Arms floating during tactile interaction demand muscle strength and motor control. A previous study on the trajectories of the movements of the arms of older adults also showed aging affects reducing the height of the movements of the wrist (Geronimi and Gorce, 2007). Mean lower wrist elevation indicates shorter distances between the hand and the device during drag-and-drop interaction. The increased range of motion on wrist elevation and angular deviations observed for older subjects is probably to compensate the proximity with the device.

We were interested in evaluating mean wrist elevation in order to try to understand the number of unintentional touches during tactile interaction, already described in the result of our previous experiment (Chapter IV, IV.2.8, p. 139). The relevance of this measure is related to the errors of interaction that happen when the user unintendedly touches “blank” zones or other graphical elements (*e.g.* soft buttons, icons), triggering events by error. Harada *et al.* (2013) have reported unintentional touches selecting the wrong targets or launching the scrolling of the screen due to accidental touches with the palms of the hands (Harada *et al.*, 2013). They discuss how unintentional touches hinder interaction for older adults, because users feel they cannot control the events (Harada *et al.*, 2013). For typing tasks, Nicolau and Jorge (2012) discuss that older users unintentionally touched the soft keyboard, resulting on insertions and substitution errors and increasing the cognitive load for the task (Nicolau and Jorge, 2012). Indeed, errors of interaction indicate the non-adaptation of the graphical user interface, interaction technique or features of the touchscreen devices to the users’ abilities and special needs.

As discussed by Young *et al.* (2013), the increased angular deviations of the wrist during interaction with touchscreen are related to the needs of the users to keep the movements of the fingers, avoid the occlusion of the screen and prevent unintentional touches and activation of onscreen controls (Young *et al.*, 2013). For older adults, the increased angular deviations are related not only to the constraints of the direct interaction on touchscreen, but also to the aging effects on the movements of interaction.

V.3.5. Relationship between performances and postures of the wrist

In our study, we searched for the relationship between performances and postures of the wrist for further understand which characteristics of the movements of older adults and adults are related to their different performances. Indeed, the strategies users employed during interaction result on different relationships between performances and postures of the wrist for each group of subjects.

For the older adults, it is interesting to note that the number of unintentional touches is not related to the mean wrist elevation, but to the extension and pronation angles. As discussed by Young *et al.* (2013), postures of the wrist of adults during typing tasks on touchscreen were characterized by extreme extension angles to avoid unintentional activation of onscreen controls (Young *et al.*, 2013). Indeed, increased extension angles result on increased distance between the hand and the screen. Contrarily, the unintentional touches on the screen occur during reduced extension and pronation of the wrist. This effect may indicate that unintentional touches happen not only when the palms of the

hands touches the screen during interaction, but also the because of the other fingers hovering over the screen during drag-and-drop interaction.

Concerning time and error rates, there is a relevant relationship between time and pronation angles, time and wrist elevation and number of errors and wrist elevation for adults. Increased wrist elevation is related to increased time of movement and reduced number of errors for this group of subjects. Moreover, increased pronation angles implied reduced time of movement and reduced number of unintentional touches.

The increased pronation of the wrist reduced the number of unintentional touches for the two groups of subjects and reduced time of movements for adults. This effect has been investigated in relation to the input modalities, because pen interaction resulted on significant decrease of time and errors as well as increase of pronation angles for older adults. Concerning the group of adults, pen interaction resulted on significantly decreased time and increased pronation angles.

V.3.6. Bigger screen sizes and pen interaction for accurate interaction

Older adults made fewer errors during interaction on tablet than on smartphone. Older adults perform better times and made fewer errors during interaction with pen then with their fingers. This result confirms our findings Chapter IV (p. 121), that demonstrated that older adults' performances are increased on tablet and during pen interaction.

Concerning the group of adults, they spent shorter times on smartphone spite of the increased number of errors on this device. This is probably due to the reduced travelling distances related to the smaller size of the screen in comparison to the tablet. Similarly to older adults, they spent shorter times during pen interaction.

Hypothesis 3 is partially confirmed. Bigger screen sizes and pen allowed better performances for older adults and adults. Concerning the movements of the users' wrist, interacting on tablet resulted on increased range of motion on radial-ulnar deviation for older adults and adults. For adults only, tablet interaction required increased range of motion on flexion-extension and pronation-supination angles.

However, in order to execute the gestures of interaction with accuracy on the smartphone, the postures of the wrist assumed increased radial deviation, increased extension and reduced pronation angles when compared to interaction on tablet. In fact, interacting with a small screen size implied reduced ranges of motion and consequently, a more restrictive posture for the wrist.

Concerning the input modalities, pen interaction resulted on reduced radial deviation, increased extension and reduced pronation angles. Pen interaction implied reduced range of motion on flexion-extension for older adults and adults as well as reduced range of motion on radial-ulnar deviation only for older adults.

The differences of postures and movements of the wrist during finger or pen interaction confirm previous results about the effects of input modalities on the indexes of manipulability. Prattichizzo *et al.* (2015) demonstrated that when the users manipulate a pen, the same effort is required to control the motion of the pen tip in all directions, contrarily to the finger, where the effort is dependent of the direction of the movements of the finger tips (Prattichizzo *et al.*, 2015). Besides, during pen interaction, the fingers postures are fixed, holding the pen.

Concerning the effects of the input modalities on interaction performances, the pen would allow a better visibility of the screen because when the pen is touching the screen the wrist assumes a more extended and less pronated posture, keeping the fingers away from the screen even if the input modalities do not affect the wrist elevation.

It is also interesting to note that the analysis of the effects of the screen sizes and input modalities on performances and postures of the wrist demonstrate that the number of unintentional touches on the screen is not affected by the travelling distances on tablet or smartphone. Indeed, the increased number of unintentional touches during finger interaction is related to the reduced extension and increased pronation angles during finger interaction, which keeps the users' fingers touching or hovering over the display. Concerning the ranges of motion, tablets require increased ranges of motion on flexion-extension and pronation-supination angles, also related to the number of unintentional touches on the screen. Besides, the screen sizes affect the mean wrist elevation and the range of motion of the wrist on the axis perpendicular to the table.

From an ergonomic point of view, reduced angular deviations are better suitable for long times of use of touchscreen devices in order to prevent users' discomfort and musculoskeletal disorders. Pen interaction reduced radial deviation and pronation angles of the wrist and the ergonomics of this input modality contributed to improve users' performances. More important than time of movement, avoiding supplementary manipulation (e.g. recovering of errors) is fundamental to facilitate interaction and prevent unnecessary movements. This argument favors pen interaction and bigger screen sizes, not only because they reduce the physical constraints to the movements, but also

because pen and tablet improve the usability of tactile interaction for older and younger users.

V.3.7. Bigger targets facilitates drag-and-drop interaction

Even if drag-and-drop can increase the accuracy of the gestures, allowing older adults to position small targets on small screens such as the one of the smartphone, the two groups of subjects benefited of the size of larger targets on time of movement on smartphone and tablet. **Hypothesis 4 is not confirmed.** Larger targets also reduced the number of errors, with implies a reduced the number of supplementary manipulation for older adults.

Additionally, by reducing the number of supplementary manipulation, large targets facilitate drag-and-drop interaction because it helps to prevent unintentional touches on the screen.

This result complete previous evaluations about the effects of different sizes of targets on tapping, with finger or pen, showing that small targets hinder the interaction performances of older adults (Hourcade and Berkel, 2006; Hwangbo et al., 2013; Jin et al., 2007).

The shortest time was executed during games with large targets and pen interaction, on tablet for older adults and on smartphone for adults. Longest times were executed during games with small targets and finger interaction on smartphone for older adults and on tablet for adults.

The different sizes of targets on smartphone or tablet did not affect the angular deviations of the wrist of older adults neither of adults. There is a significant effect of size of targets on the ranges of motion on radial-ulnar deviation, flexion-extension, pronation-supination as well as wrist elevation only for older adults, on smartphone and tablet. Indeed, the ranges of motion increase for the task with smaller targets, which is probably related to the number of targets. In order to avoid differences related to the number of targets, we calculated the ratio between time and errors during the task and the number of targets. However, further investigation should consider the distinction of the effects of size or number of targets. It is interesting to note that bigger number of targets did not affect the range of motion for the wrist of adults.

V.3.8. Assessing postures and movements of the users during interaction with touchscreen

The experimental protocol implemented for the present study associated HCI and Biomechanics to assess the motion of the wrist during the execution of gestures of interaction on touchscreen. Through the coordinates of the anatomical markers placed on subject's hands and their trajectories registered on a three dimensional space around the devices, we extracted spatiotemporal parameters to calculate mean deviation angles and range of motions on radial-ulnar deviation, flexion-extension and pronation-supination of this articulation. This information was synchronized with the touch coordinates registered by the interactive system installed on two mobile devices, a smartphone and a tablet, during interaction with pen and finger.

In the state-of-the-art presented in Chapter II (II.4.2, p. 74) showed that previous studies collected information on the touchscreen devices to analyze the interaction performances of the participants (Irwin and Sesto, 2012; Kim et al., 2014, 2013; Sesto et al., 2012; Werth and Babski-Reeves, 2014). Their goals were to verify the effects of different motor skills (Irwin and Sesto, 2012; Irwin et al., 2011; Sesto et al., 2012), different parameters of interactive systems (Kim et al., 2013) or different situations of use of touchscreen devices such as screen sizes, input modalities and positions (*e.g.* on a desk, handheld, tilted) (Pereira et al., 2013; Werth and Babski-Reeves, 2014; Young et al., 2013, 2012). The experimental protocol we designed has been effective for assessing the movements of the users and registering touch information. By consequence, we were able to search the relationship between the motion features of the wrist to the interaction performances (time and errors) for accomplishing the interaction task. Moreover, the experiment protocol we implemented provided relevant information for characterizing movements of older adults and adults during interaction on different situations of interaction: with smartphone and tablet, large and small targets, finger and pen interaction.

On HCI studies, motion capture systems have been used to investigate new interaction techniques, such as pointing in large displays (Mayer et al., 2015), interacting with distant screens (Vogel and Balakrishnan, 2005), evaluating the design of input devices (Perelman et al., 2015) or simulating interaction on virtual environments (Appert et al., 2015). The investigation of the ergonomics of interaction has also emerged in HCI in regard of the different situations of use of touchscreen devices, taking advantage of the possibilities of analysis or movements and biomechanical simulations (Bachynskyi et al., 2015, 2014).

V.3.9. *Limitations*

In order to facilitate the inclusion of older adults as participants, older subjects effectuated a reduced number of interactions to reduce fatigue and the duration of the experiment. We assumed that three iteration series of eight conditions of the study could provide sufficient data for the analysis of the movements and performances for this group of users. A further analysis of the learning effects across iterations is described in the Appendix VII.4 (p. 237).

The variability of performances and postures demonstrated in our analysis reflect the heterogeneity of the characteristics of the participants. They are representative of the heterogeneity of older and adult users of interactive technologies. Further evaluation could indicate if the variability can be related to the morphology (height, hand length) and provide recommendations for more ergonomic interaction.

In order to associate Biomechanics and HCI evaluation methods, participants executed a complex task, composed of several sub-movements. Our choice has been justified by the proposal of a more ecological and realistic situation of use of tactile interaction in comparison to elementary tasks. Elementary tasks, *e.g.* dragging one single puzzle piece at a time and positioning it into its corresponding target, would allow a precise evaluation of the trajectories and articular angles of the wrist and upper limbs during a more numerous repeated series. However, this situation of study would have impoverished the analysis of the interaction performances.

V.3.10. *Perspectives*

The association of HCI and Biomechanics provides an enriching analysis of how users adapt the movements of arms and hands to execute the gestures of interaction as well as the effects of aging, the situations of use of touchscreen and the graphical user interfaces on the interaction performances.

The results presented on this chapter demonstrate that it is possible to enhance ergonomics of tactile interaction by facilitating the interaction. Designers and developers should consider the effects of the supplementary manipulation on the motion range of the articulations involved on tactile interaction. By reducing the number of interactions, particularly the number of targets and the number of errors, interactive systems can support older adults and prevent musculoskeletal disorders so today's users can continue interacting with touchscreens in the future.

V.4. Conclusion and future work

The aim of this chapter was to demonstrate the contribution of the analysis of the movements of the users during interaction with touchscreen devices to try to understand the relationship between the characteristics of the movements related to the execution of the gestures of interaction and the interaction performances.

In this chapter we described the experimental protocol we implemented to assess the movements of the users through motion capture systems and the touch information detected by the interactive system installed on touchscreen devices. In the state-of-the-art presented in Chapter II (II.4.2, p. 74), we discussed about the strategies users apply during interaction, involving movements of head, trunk and upper-limbs. As the wrist is high solicited during interaction with touchscreen (Prattichizzo et al., 2015; Werth and Babski-Reeves, 2014; Young et al., 2013), in the present study, we focused on the postures and movements of this articulation.

Our results demonstrated that older adults and adults assumed a radial deviated, extended and supinated wrist posture during the execution of drag-and-drop interaction on touchscreen devices horizontally fixed on the desk.

The goal of the present study was to identify the differences in movements of interaction between older adults and adults in order to understand their relationship with the decrease of interaction performances related to the aging. Indeed, our results demonstrate that wrist postures of older adults are characterized by increased radial deviation, extension and supination angles in comparison to adults. The movements of older adults are characterized by lower mean wrist elevation, compensated by increased ranges of motion in comparison to adults. Minimal and maximal radial deviation, extension and supination angles are greater for older subjects. Similarly, minimal wrist elevation is lower and maximal wrist elevation was higher for older adults.

The results of the analysis of the interaction performances demonstrated that despite of tactile interaction, particularly drag-and-drop interaction on touchscreen, being ease to use for older adults, older subjects took longer times and made more errors than adults. We were also able to demonstrate that the strategies users employed during interaction result on different relationships between performances and postures of the wrist for each group of subjects. Our analysis contributes to address our Research Question 4 (What are

the differences in movements of interaction between older-aged adults and younger adults that are related to interaction performances?).

Additionally, we also investigated the effects of different screen sizes, input modalities and sizes of targets on the movements and performances. Indeed, the different situations of the study represent physical constraints to movements of the users. Interaction on tablet required bigger travelling distances for positioning the targets drag-and-drop consequently interaction required increased ranges of motion on radial-ulnar deviations for older adults and flexion-extension and pronation-supination for adults. These postures are considered more comfortable than interaction on smartphone from an ergonomic point view, because the restriction of the small screen size related to the smartphone implied increased angular deviations for the two groups of users.

Concerning the input modalities, the users' wrist assumed a greater radial deviated and pronated postures during finger interaction compared to interaction with pen. This posture resulted on increased number of unintentional touches on the screen during interaction due to the proximity of the fingers with the screen. Besides, interaction with fingers is also related to increased range of motion on flexion-extension angles for older adults and radial-ulnar deviation for adults.

In all situations evaluated in this study we observed a big variability in performances and movements of the wrist, particularly to the older group of subjects. This variability could be related to the different user's profiles, such as age and experience of use of technologies, as demonstrated through the analysis we presented in Chapter IV (p. 121). Studies in biomechanics usually evaluate movements of homogeneous groups of users, in order to provide accurate information related to specific gestures or pathologies. One of the main concerns of human-computer interaction, on the other hand, particularly in this thesis work, is the design of interactive systems and interaction techniques that could respond to the specificities of a heterogeneous group of users. From an ergonomic point of view, the variability of performances and movements described in this chapter could be considered representative of actual users of touchscreen devices, outlining the effort required of designers and ergonomists for searching for the most usable and ergonomic interaction.

Even if drag-and-drop has been effective for positioning the targets on the interactive system Puzzle Touch, associating the continuous contact with the screen for improving the accuracy and the constant feedback of the moving puzzle pieces helps older adults to follow the results of their actions, the present study demonstrate that there is still a difference in performances between older adults and adults. Older adults spent

longer times and made more errors than adults. Moreover, the two groups of users performed better times and made fewer errors for positioning large targets, which demonstrate that drag-and-drop can reduce but not cancel the effects of age or targets design. These results are complementary to our previous study, described in Chapter IV (p. 121).

In the present study we focus on the wrist, representing the arrangement of upper-limb articulations and movements during tactile interaction. Future work should evaluate movements of head, trunk, arms and hands in order to provide further information about the effects of aging on the users' movements and the relationship between the motor strategies during interaction and the characteristics of the postures of the wrist.

Besides, the differences on ranges of motion or angular deviations of the wrist observed during interaction on tablet or smartphone as well as during finger or pen interaction should be related to the motor strategy employed by the users during interaction. Restrictive positions for this articulation in regard to the physical constraints of the task (*e.g.* touchscreen device horizontally placed, different screen sizes and input modalities) should be further investigated in relationship to the other articulations of users' upper-limbs.

Chapitre 6 : Conclusion, contributions et perspectives

Résumé

Au cours de cette thèse, nous avons révisé et appliqué des méthodes de conception et d'évaluation afin d'expliquer les problèmes d'utilisabilité que les personnes âgées rencontrent lors de l'interaction avec des écrans tactiles. Nous avons démontré qu'il est nécessaire d'observer et d'essayer de comprendre les difficultés auxquelles les utilisateurs âgés doivent faire face durant l'interaction tactile afin de proposer des systèmes interactifs appropriés. Nous avons aussi démontré que les différents profils d'utilisateur, particulièrement l'âge et l'expérience préalable avec des technologies interactives (ordinateur et écran tactile) peuvent influencer les performances d'interaction, ce qui confirme la facilité d'utilisation de l'interaction drag-and-drop tactile. De plus, les diverses situations d'usage de dispositifs mobiles doivent être considérées et évaluées pour les utilisateurs âgés, et cela en fonction des différentes tailles d'écran (tablettes et smartphones) et modalités d'interaction (doigt ou stylet). Par ailleurs, en complément de ces résultats novateurs qui contribuent à comprendre et encourager l'interaction tactile pour les personnes âgées, l'originalité de cette thèse repose également sur l'apport de l'analyse du mouvement lié à l'exécution du geste d'interaction. Nos résultats démontrent que la posture du poignet des personnes âgées est caractérisée par une plus grande amplitude de déviation radiale, extension et pronation comparé aux sujets adultes pendant l'interaction drag-and-drop avec des écrans tactiles placées horizontalement sur la table. Cela nous a permis de caractériser et différencier les mouvements du poignet (angles articulaires) afin de mieux comprendre l'origine des écarts de performance observés entre les personnes âgées et les adultes.

Nous avons apporté des éléments de réponse pour chacune de nos quatre Questions de Recherche initialement posées. Ils sont décrits en détail dans ce chapitre.

Contributions :

Nous avons proposé des recommandations pour faciliter la participation de personnes âgées lors des phases de conception de systèmes interactifs et de protocoles expérimentaux en tenant compte de facteurs du contexte des utilisateurs (ex. l'interaction sociale) et de leur évaluation subjective des technologies interactives (ex. ludique et facile d'utiliser).

Nous avons démontré que l'analyse et la classification des erreurs observées lors des séances d'évaluation permettent de définir celles qui peuvent être corrigées par la

modification des paramètres des systèmes interactifs et celles qui doivent être considérés lors des protocoles expérimentaux.

Nous avons étudié l'appropriation du drag-and-drop tactile en diverses situations d'usage (tablette et smartphone, doigt et stylet). Le drag-and-drop tactile est facile à apprendre pour les personnes âgées de différents groupes d'âge, ayant de différentes expériences préalables avec des technologies interactives.

L'association de méthodes issues des domaines IHM et Biomécanique a permis l'analyse des mouvements de l'utilisateur durant la réalisation du geste d'interaction sur écran tactile. Nous avons démontré que la posture des sujets âgés et adultes est caractérisée par une déviation radiale, extension et supination du poignet durant l'exécution du geste drag-and-drop sur des écrans tactiles horizontalement fixés sur la table. L'apport de l'analyse du mouvement a été fondamental pour comprendre les différences de performances d'interaction tactile entre les personnes âgées et les adultes à travers la caractérisation de leurs habiletés motrices. Cette différence démontre l'importance de la participation des personnes âgées lors des étapes de conception et d'évaluation des systèmes interactifs et techniques d'interaction.

Perspectives :

L'interaction drag-and-drop sur écran tactile est facile à utiliser par les personnes âgées, même novices, et la contrainte de positionnement des cibles peut être adaptée pour réduire le nombre d'erreurs en diverses situations d'usage de technologies mobiles. Ce geste d'interaction peut être envisagé pour d'autres applications (sélection de menus, saisie d'informations, etc.).

Nous avons réalisé le premier cycle de conception du système « Puzzle Touch » en suivant une méthode itérative. Suite aux résultats encourageants sur l'utilisation du drag-and-drop et de ce système, nous envisageons de continuer le développement des jeux de type puzzle tactile numérique en tant que jeux sérieux pour aider les personnes âgées à apprendre à réaliser l'interaction tactile.

L'analyse des mouvements liés aux gestes d'interaction, associant IHM et Biomécanique, a été effective pour comprendre la relation entre les mouvements et leurs conséquences sur les performances d'interaction. De plus, cette méthode interdisciplinaire peut être envisagée pour l'analyse et la contribution à l'amélioration d'autres situations d'interaction entre humains et technologies.

VI. Conclusion

This thesis has reviewed and applied methods of design and evaluation of tactile interactive systems to bring to the light usability problems older adults face when interacting with touchscreen in order to propose appropriate interaction techniques, better suited to the older users skills and abilities. We demonstrated that the different user profiles, particularly age and previous experience of using interactive technologies (computer and touchscreen) can influence interaction performances. Our results confirm the ease of use of drag-and-drop interaction on touchscreens for novice users. The diverse situations of use of mobile devices have been considered and evaluated from an ergonomic point of view, including different screen sizes (tablet and smartphone) and input modalities (pen and fingers). In addition to these innovative results, that contribute to understand and encourage tactile interaction for older adults, the originality of this thesis lays on the analysis of the movements related to the execution of gestures of interaction. Our results demonstrated that older adults assumed increased ranges of motion and radial deviated, extended and pronated wrist postures compared to adults during the execution of drag-and-drop interaction on touchscreen devices horizontally fixed on the desk. The restrictive postures of the wrist of older adults allowed us to better understand the causes of the decrease of performances usually reported to this group of users. This contribution highlights the importance of including older adults as participants of design and evaluation sessions in order to prevent digital exclusion.

In the following sections, we summarize the contribution of each chapter, the steps and answers to the Research Questions that have been addressed and the main contributions of this thesis work. Then, we present some perspectives and future work.

VI.1. Thesis summary

Chapter I described the context of our research, the thesis statement and the four main research questions that have been addressed as well as the methodology and the organization of our work.

Chapter II presented the state-of-the-art. First, we reviewed the literature on factors predicting the use or rejection of technologies for older adults to identify the problems that could be addressed through design and evaluation methods. We elaborated a classification to identify factors related to the features of technologies and systems that can be addressed during the design of interactive systems and interaction techniques (Table II.1, p. 36). Additionally, we described factors related to the characteristics of the

users' profiles, their context of use and their subjective evaluation. These factors should be considered to facilitate the participation of this group of users during the design phases and experimental protocols and promote the use of technologies (Table II.2, p. 47). Next, the state-of-the-art on evaluation of tactile interaction included HCI research and usability studies to determine the problems that need to be addressed, define the specifications for an interactive system and methods for design and evaluation with older adults (Table II.14, p. 70). In addition to the HCI approach, we reviewed studies about the age effects on the movements of the upper limbs and users' postures during interaction with touchscreen, defining the parameters of our second experimental protocol associating HCI and Biomechanics for evaluating the difference between older adults and adults on the movements for executing the gestures of tactile interaction (Table II.20, p. 85)

Chapter III described the first cycle of an iterative design method for the interactive system Puzzle Touch. The tactile puzzle games were designed to facilitate the inclusion of older adults as participants on the experimental protocols. The design evaluation was made through an exploratory study with 17 older adults (58 to 85 years old). Following an empirical observation, the main contribution of this study is typology of errors that defines errors that can be prevented through the adaptation of the settings of the interactive systems (Table III.6, p. 110). Errors related to the devices, input modalities and user's skills need to be investigated through experimental studies. Aiming to improve the usability of this interactive system to older adults, a new version of the system was designed, delimitating interaction zones to prevent errors related to unintentional touches on the screen.

In Chapter IV, an experimental protocol was implemented to investigate the appropriateness of drag-and-drop interaction on touchscreen for older adults. 24 older adults (aged 65 to 86 years old) executed drag-and-drop interaction with the system Puzzle Touch. We demonstrate that the interactive system we designed and the tactile interaction is easy to use for novice users. Besides, experience of using interactive technologies (computers and touchscreen) can reduce the decrease of performance commonly observed among the oldest subjects. Additionally, we demonstrate that lowering the constraints for positioning the targets is effective for enhancing interaction performances on smartphone and tablet, with pen and fingers.

In Chapter V, we effectuated the analysis of the movements of the user during the execution of the gestures of interaction on touchscreen. After a preliminary study confirming the high mobilization of the wrist during tactile interaction, we implemented

an experimental protocol associating HCI and Biomechanics to evaluate the postures of this articulation and their relationship with the users' performances. 15 older adults (65 to 86 years old) and 15 adults (18 to 43 years old) executed drag-and-drop interaction with the system Puzzle Touch on smartphone and tablet, with pen and fingers on a controlled environment, equipped with motion tracking system. We synchronized the touch information registered by the interactive system to the movements of the users. In this chapter, we described the procedures for extracting spatio-temporal parameters, computing articulatory angles and analyzing the trajectories. We demonstrated that older adults and adults assumed a radial deviated, extended and pronated wrist posture during the execution of drag-and-drop interaction on touchscreen devices horizontally fixed on the desk. Our analysis shows that the increased range of motion that characterizes movements of older adults implies increased number of errors and unintentional touches. Moreover, pen interaction and tablet resulted in reduced extension and pronation angles, which can be considered more comfortable to the users from an ergonomic point of view. Finally, we recommend pen interaction to older adults because this input modality improves the ergonomics and the usability of touchscreen, particularly for this group of users.

VI.1.1. *Thesis statement*

The methods and results of this thesis allow us to affirm our initial statement:

Understanding the difficulties older adults face during interaction with touchscreen is necessary to design appropriate tactile interactive systems, taking into account their different users' profiles and abilities.

Through the design of the tactile interactive system Puzzle Touch following one cycle of iterative design method, we were able to address the main usability problems after the design evaluation, delimitating interaction zones to prevent errors of interaction. Next, we evaluated drag-and-drop interaction on touchscreen devices and we demonstrated that this interaction technique is appropriate to older adults without experience with technologies. Moreover, we demonstrate that lowering the constraints for positioning the targets can facilitate drag-and-drop interaction and improve interaction performances on smartphone and tablet, with pen and fingers. Finally, the analysis of the postures and movements of the users' wrist during interaction with touchscreen evidence the effects of aging on this articulation, allowing us to affirm that older adults wrist assume increased radial deviation, extension and reduced pronation during interaction,

with significant greater ranges of motion on radial-ulnar deviation, flexion-extension and pronation-supination angles. These characteristics are related to the increased number of errors and unintentional touches on the screen especially during finger interaction.

VI.1.2. *Research Questions*

In the foregoing chapters, we have addressed and answered each one of our four Research Questions initially presented.

VI.1.2.1 *Research Question 1*

- What are the factors preventing older adults to use mobile technologies?

This initial question is fundamental to understand the reasons of digital gap on mobile technologies between generations. According to our analysis of Technologies Acceptance and Adoption Models (TAMs) for older people, factors influencing use or rejection of technologies are related to the users' profiles, their context, their subjective evaluation and the features of systems and technologies. By this analysis, we demonstrate that usability problems older users find when interacting with touchscreen are preventing them to use mobile devices. Moreover, we state that improving tactile interaction could effectively reverse the low usage rates of mobile technologies among elderly populations.

Factors related to the users' profiles, their context and their subjective evaluation should be carefully considered to facilitate the participation of older adults on design, evaluation and experimental studies.

VI.1.2.2 *Research Question 2*

- How to design tactile interactive systems to older adults?

In order to identify usability problems since the early stages of the design process, it is necessary to involve representative users during design evaluation sessions. Following an iterative design method, we described the first cycle of design of the tactile interactive system Puzzle Touch. The results of an empirical observation allowed us to identify the main difficulties and errors older participants found when interacting with the system. The classification of the errors according to their causes is helpful to define errors related to the interactive system. These have been addressed through the adaptation of the settings of the system. On the other hand, errors related to the device, input modalities or user skills should not be neglected. In order to prevent usability problems due to the situations of use of mobile devices or to the different user's skills, these factors should be

considered during design evaluation and studied during experimental protocols so designers could provide appropriate support for the users.

VI.1.2.3 *Research Question 3*

- Which aspects of use of touchscreen can affect tactile interaction for older users?

We demonstrated significant effects of the situations of use of touchscreen as well as from the diversity of users' profiles on interaction performances. The main contribution of this question is to state that the different features of mobile technologies as well as the heterogeneity of older user should be considered during design evaluation and experimental protocols in order to enhance usability of tactile interaction. After the results of our experiment associating HCI and Biomechanics (Chapter V, p. 155), there is evidence that users adopt different postures of the wrist in order to adapt their movements according to the screen sizes and the input modalities and this adaptation is directly related to the users' interaction performances.

VI.1.2.4 *Research Question 4*

- What are the differences in movements of interaction between older-aged adults and younger adults that are related to their performances?

As mobile devices are equipped with sensitive touchscreen technologies, executing the gestures of interaction requires fine dexterity of the users. So to answer this question we decided, in a first instance, to evaluate the differences in the movements for executing the gestures of interaction between older adults and adults. In this first study, the biomechanical evaluation of the positions and postures of the wrist demonstrated that the movements of the older adults are characterized by a lower wrist elevation which implies greater radial deviation, greater extension and reduced pronation of this articulation and increased ranges of motion. Ergonomically, the increased deviation angles demonstrate more restrictive posture of the wrist for this group of users compared to adults and our study demonstrated that this characteristic is correlated to the decrease of interaction performances.

The main contribution of the analysis of the effects of aging on the movements related to the execution of the gestures of interaction is to reinforce the argument that the different skills of older adults should be considered for the design and evaluation of

interactive systems and interaction techniques. Additionally, we demonstrate that tablet and pen interaction improve the usability of touchscreen for older adults.

VI.1.3. *Contributions*

In regard of the Research Questions that we addressed, the main contributions of our work are the following.

Through the review and classification of factors predicting acceptance and adoption of technologies by older adults (Table II.1, p. 36), we contributed to identify the features of technologies and systems that have an impact on the acceptance and adoption of technologies by older adults (II.1.4, p. 40). The advantage is that these topics can easily be considered by designers and developers of interactive systems destined to older users to prevent usability problems and consequently, improving acceptance of technologies.

Several times during this thesis research we focus on one key problem of usability that affects the efficiency of an interaction and sometimes even its effectiveness: errors of interaction. Errors increase significantly the cognitive workload of a task for older adults, because users need to implement a strategy to recover from errors (Barnard et al., 2013; Bradley et al., 2011). The analysis and classification of common errors and difficulties older adults find during interaction with mobile devices equipped with touchscreen contributes to define the causes of errors thereby designers can focus on the problems related to interactive systems and interaction techniques.

In order to identify the causes of errors and provide adaptations to prevent them to occur, it is fundamental to include older people as participants in the design process. After a review on the considerations about the participation of older adults in design evaluation and experimental protocols (II.2, p. 44), we addressed a summary of recommendations to facilitate the recruitment and the involvement of older participants (Table II.2, p. 47). Proposing a ludic activity (tactile puzzle games), designing a familiar interaction (drag-and-drop for moving the puzzle pieces) and promoting social interaction during the first experiences with the system and the mobile devices has been showed to be an effective strategy, facilitating the inclusion of older participants in the design evaluation of Puzzle Touch as well as in the experiences. Through the proposed recommendations and the description of the procedures we applied, we contribute to future work of design and evaluation of systems and technologies for older adults.

During the first cycle of an iterative design method, we implemented an exploratory study and the results provide enriching information about the problems older

participants found when interacting with Puzzle Touch and manipulating the mobile devices. All the procedures for specifying the context of use, the users' requirements, the production of our design solution and the evaluation is described in details in Chapter III (p. 93). We hope that this report will contribute to further work on design and evaluation of interactive systems or interaction techniques to older adults.

After the design evaluation, we modified the parameters of the interactive system to prevent errors related to unintentional touches outside the puzzle pieces. This delimitation of interaction zones illustrates how the observation and analysis of errors occurred during the exploratory study is fundamental to propose adequate solutions and improve usability of interaction. We recommend this method to be applied to other design evaluation. Moreover, the evaluation of drag-and-drop interaction described in Chapter IV (p. 121) allows demonstrating how this adaptation of the interactive system was effective, as the unintentional touches did not interrupt the positioning of the targets. Moreover, this adaptation technique can be applied to other interactive system.

The evaluation presented in Chapter IV (p. 121) demonstrates that drag-and-drop interaction is appropriate for older users, allowing the accomplishment of tactile interaction on smartphone and tablet, with pen and fingers. Drag-and-drop interaction was also ease to learn and execute to older adults with different profiles. Our contribution is to propose drag-and-drop interaction as an alternative to other gestures of interaction as tap for increasing the accuracy of interaction.

Reducing the constraints of accuracy for positioning the targets with drag-and-drop interaction significantly reduced the variability of performances on time and errors for older users with different profiles, on smartphone and tablet during pen or finger interaction. This allows us to state that the adaptation of constraints of accuracy of drag-and-drop interaction contributes to improve the usability and the accessibility of tactile interaction.

Another contribution of this thesis is to elaborate and implement and experimental protocol associating methods from HCI and Biomechanics for studying the movements of interaction and their relationship with interaction performances (Table II.20, p. 81, and Chapter V, p. 155).

The originality of this experiment on HCI and Biomechanics is the characterization of the difference of the movements of the wrist of older adults and adults, showing the effects of aging on the execution of drag-and-drop interaction on touchscreen devices (Chapter V, p. 155). This experiment elucidated the relationship between the

movements of the user during tactile interaction, through the biomechanical evaluation of the elevation and articular angles of the wrist, and the interaction performances.

We characterized the postures of the wrist during interaction with touchscreen devices horizontally fixed on the desk as radial deviated, extended and pronated. The angular deviations are increased for older adults, demonstrating that the postures of this articulation are less comfortable and more restrictive for this group of users. The position of the devices (horizontal rather than tilted), the size of the screen (tablet rather than smartphone), the input modality (pen rather than finger) and the gesture of interaction can help users to assume more ergonomic posture of the wrist. Our analysis of the relationship between postures, movements of the wrist and performances shows that improving the ergonomics of touchscreen may help to improve the usability of tactile interaction especially to the older group of users.

VI.2. *Perspectives and future work*

We have demonstrated that drag-and-drop interaction on touchscreen is easy to use for older adults, even novice users, and the constraints for positioning the targets can be adapted to facilitate interaction, reducing the number of errors on different situations of use of mobile technologies. We propose that this gesture of interaction should be applied and evaluated for other applications.

We have completed the first cycle of design of the interactive system Puzzle Touch through an iterative design method. After the encouraging results concerning the drag-and-drop interaction and this tactile interactive system, we would like to pursue the design and development of tactile puzzle games as serious games to help older adults to learn tactile interaction.

We have demonstrated that user profiles, especially experience of using computer and touchscreens, can be used as predictors for interaction performances. This effect might be further evaluated, in order to facilitate interaction for novice users as well as ensure optimized utilization of technologies in a long term for experienced users.

The association of HCI and Biomechanics methods has been effective to understand the relationship between the movements of the user during the execution of the gestures of interaction and the interaction performances. In this first time, we have choose to study the movements of the wrist, but movements of the hands and upper-limb as well as the postures of the users, should be studied in order to propose more ergonomic

interaction. Additionally this interdisciplinary method should be applied to further evaluate and contribute to improve the situations of human-computer interaction.

VI.2.1. *New Research Questions*

In view of the methods, results and discussion presented in this thesis, future work on design and evaluation of tactile interaction for older adults could be undertaken to address some of the new research questions that have emerged.

The Biomechanics evaluation of interaction with touchscreen, associated to HCI evaluation, has provided important information for understanding the effects of aging on the movements of the users. The situations of use of mobile devices and new technologies are diverse: different screen sizes, fixed with special cases and handheld, multiple gestures of interaction and tasks. The movements and positions of the user and its consequences on interaction performances remain unknown. How tactile interaction can be adapted to enhance the ergonomics of mobile devices? What are the consequences of a continuous and long-term use of touchscreen for the users, concerning the overuse of articulations?

We recommend drag-and-drop interaction and familiar interfaces for facilitating the use of touchscreen for novice users. But technologies evolve fast and users get different experiences. Besides, age effects on psychomotor system are individual and can be affected by illnesses and overuse disorders. A new challenge is to follow the dynamic characteristics of the users to continuously propose usable and accessible interaction. How the different skills and disabilities affect the movements of interaction? How to adapt interfaces and interaction techniques to overcome age effects?

Based on the foregoing research, we hope new interaction techniques will be designed to address the variability of users' needs. Design evaluation has shown effective contribution for ease of use and support for interaction for older adults. However, for a long term use, designers should consider to improve user experience and ergonomics.

VII. Appendices

VII.1. Summary of the incidence of age-related disabilities in France

The *Direction de la recherche, des études, de l'évaluation et des statistiques* published in 2015 a report on the incidence of age-related disabilities in France.

Visual impairments are the most common sensorial deficiency, affecting 74% of adults in France. The incidence of visual impairment increases with the age, reaching 96% of people older than 49 years old. Sixteen percent of people older than 74 years old have difficulties to see from close and 4% of them report they are not be able to read after wearing corrective lenses. They are 11% having difficulties to see from far and 4% not able to do it. Severe vision loss touches 2% of people aged 60 to 75 and 8% of people older than 74 years old (DRESS, 2015).

Hearing impairments in adults aged 50 years old or older are mostly due to age-related decline. Fifteen percent of people aged 65 to 79 and 38% older than 79 have hearing loss. Ten percent of people aged 65 to 79 and 26% of people older than 79 years old still report difficult to hear after wearing hearing aids (DRESS, 2015). Hearing impairments can lead to isolation as hearing impaired older adults report avoiding social and familiar activities.

Motor limitations have been reported by 19% of people aged 60 to 79 years old. For people older than 79, the prevalence of motor limitation is 54% (Bouvier, 2011). Arthritis, for instance, can prevent older adults for executing many daily life activities that require fine dexterity or force. This illness, like Osteoporosis, is more common among women (Bouvier, 2011).

Concerning cognitive decline, Alzheimer's disease is the most common neurodegenerative disease in France, followed by Parkinson's disease. Seven percent of people aged 60 to 79 years old report having cognitive limitations. The proportion increases to 25% among people older than 79 years old (Bouvier, 2011).

Ten percent of people aged 60 to 79 reports having a functional limitation with a sensorial predominance (hearing and/or visual impairments). Among people older than 79 years old the prevalence of sensorial limitation is 29%.

Among people older than 69 years old, functional limitations are more common and often multidimensional. 70% of the men and 80% of the women aged 85 years old or older have reported at least one functional limitation. Half of the people older than 69 years old reported two or three forms of limitation combined (DRESS, 2015). 10% of people older than 79 years old report having sensorial, motor and cognitive limitations combined (Bouvier, 2011).

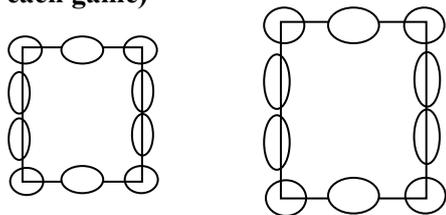
VII.2. Tools for empirical observation

We elaborated the following grid and questionnaires as tools for empirical observation and assessing the user strategies and difficulties during the experiments.

- The observation grid was filled by the experimenter during the task, according to the observations of the interaction between the subject and the tactile interactive system displayed on the touchscreen devices.
- The initial questionnaire present the questions asked to the subjects before the experiment, filled by the experimenter.
- The final questionnaire present the questions asked to the subjects after the experiment, also filled by the experimenter.

VII.2.1. Observation grid

Table VII.1 Observation grid for the experimenter

<p>Order of the games:</p> <p>1) C1 C3 C2 C4 C6 C8 C5 C7</p> <p>2) C5 C7 C6 C8 C2 C4 C1 C3</p>	
<p>(For each game)</p>  <p>Position of the device</p> <p><input type="checkbox"/> table, <input type="checkbox"/> other :</p> <p>Interaction</p> <p>Hand : <input type="checkbox"/> right, <input type="checkbox"/> left <input type="checkbox"/> both</p> <p>Comments:</p> <p>Finger interaction:</p> <p>- preferentially used <input type="checkbox"/> index, <input type="checkbox"/> thumb, <input type="checkbox"/> middle, <input type="checkbox"/> ring, <input type="checkbox"/> tiny, - others: <input type="checkbox"/> index, <input type="checkbox"/> thumb, <input type="checkbox"/> middle, <input type="checkbox"/> ring, <input type="checkbox"/> tiny, Comments:</p> <p>Pen interaction :</p>	<p>Difficulties perceived by the experimenter</p> <p>Dues to the device:</p> <p><input type="checkbox"/> holding, <input type="checkbox"/> reflection, <input type="checkbox"/> fingerprints , <input type="checkbox"/> buttons: <input type="checkbox"/> menu, <input type="checkbox"/> volume, <input type="checkbox"/> home, <input type="checkbox"/> stand up, <input type="checkbox"/> power, <input type="checkbox"/> other</p> <p>Interaction techniques:</p> <p><input type="checkbox"/> accidental touches <input type="checkbox"/> finger, <input type="checkbox"/> palm, <input type="checkbox"/> forearm, <input type="checkbox"/> game zone <input type="checkbox"/> menu, <input type="checkbox"/> unregistered touches, <input type="checkbox"/> unsupported action : <input type="checkbox"/> other</p> <p>Dexterity : <input type="checkbox"/> tremor, <input type="checkbox"/> accuracy <input type="checkbox"/> pain <input type="checkbox"/> fatigue, <input type="checkbox"/> sensitivity, <input type="checkbox"/> control <input type="checkbox"/> other</p> <p>Interactive system :</p> <p><input type="checkbox"/> similar pieces</p>

<ul style="list-style-type: none"> - couple of fingers holding the pen: <ul style="list-style-type: none"> <input type="checkbox"/> index, <input type="checkbox"/> thumb, <input type="checkbox"/> middle, <input type="checkbox"/> ring, <input type="checkbox"/> tiny, - if changing, others: <ul style="list-style-type: none"> <input type="checkbox"/> index, <input type="checkbox"/> thumb, <input type="checkbox"/> middle, <input type="checkbox"/> ring, <input type="checkbox"/> tiny, <input type="checkbox"/> touches with a finger too <p>Interaction :</p> <ul style="list-style-type: none"> <input type="checkbox"/> dragging the pieces until de target, <input type="checkbox"/> dragging fast, <input type="checkbox"/> dragging slow, <input type="checkbox"/> jerky movement, <input type="checkbox"/> other strategies <p>Multi-touch :</p> <ul style="list-style-type: none"> <input type="checkbox"/> do not move more than one piece at a time, <input type="checkbox"/> tried to move more than one piece at a time, <input type="checkbox"/> effective dragging more than one piece at a time <input type="checkbox"/> failure dragging more than one piece at a time <p>Comments:</p>	<ul style="list-style-type: none"> <input type="checkbox"/> legibility of colors <input type="checkbox"/> contrast <ul style="list-style-type: none"> <input type="checkbox"/> targets too small <input type="checkbox"/> low contrast <input type="checkbox"/> lack of feedback, <input type="checkbox"/> insufficient feedback <input type="checkbox"/> during dragging <input type="checkbox"/> final positioning <input type="checkbox"/> legibility of background image <input type="checkbox"/> other <p>Comments</p> <p>Perceived user skills :</p> <ul style="list-style-type: none"> <input type="checkbox"/> understanding of the interaction, <input type="checkbox"/> understanding of the game
---	--

VII.2.2. Initial questionnaire

The following questionnaire is filled by the experimenter before the experiment and after the written consent of participants.

Questionnaire initial
Identifiant :
Age :
Sexe :
Métier exercé, activité professionnelle :
Mesure d'acuité visuelle à titre indicatif (résultats du test healthcare4mobile):

Score vérification vue			
Perception de couleurs			
Perception de grilles			
Sensibilité au contraste (%)			

Scolarité :

1 <input type="checkbox"/> pas de	2 <input type="checkbox"/> école	3 <input type="checkbox"/> collège	4 <input type="checkbox"/> lycée	5 <input type="checkbox"/> enseignement supérieur
-----------------------------------	----------------------------------	------------------------------------	----------------------------------	---

scolarité	primaire			
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Jouez-vous à des puzzles ? Je ne sais pas ce qu'est c'est

1 <input type="checkbox"/> Jamais	2 <input type="checkbox"/> Rarement	3 <input type="checkbox"/> Au moins une fois par mois (pas toutes les semaines)	4 <input type="checkbox"/> Au moins une fois par semaine (mais pas tous les jours)	5 <input type="checkbox"/> Tous les jours ou presque
--------------------------------------	--	---	--	--

Jouez-vous à des jeux électroniques ? Je ne sais pas ce que c'est

1 <input type="checkbox"/> Jamais	2 <input type="checkbox"/> Rarement	3 <input type="checkbox"/> Au moins une fois par mois (pas toutes les semaines)	4 <input type="checkbox"/> Au moins une fois par semaine (mais pas tous les jours)	5 <input type="checkbox"/> Tous les jours ou presque
--------------------------------------	--	---	--	--

Avec quelle fréquence utilisez-vous :
- Ordinateur

1 <input type="checkbox"/> Jamais Précisez pourquoi : <input type="checkbox"/> Je n'en possède pas <input type="checkbox"/> Je ne connais pas <input type="checkbox"/> Je n'aime pas	2 <input type="checkbox"/> Rarement	3 <input type="checkbox"/> Au moins une fois par mois (mais pas toutes les semaines)	4 <input type="checkbox"/> Au moins une fois par semaine (mais pas tous les jours)	5 <input type="checkbox"/> Tous les jours ou presque
---	-------------------------------------	---	--	--

- Téléphone portable

1 <input type="checkbox"/> Jamais Précisez pourquoi : <input type="checkbox"/> Je n'en possède pas <input type="checkbox"/> Je ne connais pas <input type="checkbox"/> Je n'aime pas	2 <input type="checkbox"/> Rarement	3 <input type="checkbox"/> Au moins une fois par mois (mais pas toutes les semaines)	4 <input type="checkbox"/> Au moins une fois par semaine (mais pas tous les jours)	5 <input type="checkbox"/> Tous les jours ou presque
---	-------------------------------------	---	--	--

- Tablette tactile (Je ne sais pas ce que c'est)

1 <input type="checkbox"/> Jamais Précisez pourquoi : <input type="checkbox"/> Je n'en possède pas <input type="checkbox"/> Je ne connais pas <input type="checkbox"/> Je n'aime pas	2 <input type="checkbox"/> Rarement	3 <input type="checkbox"/> Au moins une fois par mois (mais pas toutes les semaines)	4 <input type="checkbox"/> Au moins une fois par semaine (mais pas tous les jours)	5 <input type="checkbox"/> Tous les jours ou presque
---	-------------------------------------	---	--	--

- Smartphone (Je ne sais pas ce que c'est)

1 <input type="checkbox"/> Jamais	2 <input type="checkbox"/> Rarement	3 <input type="checkbox"/> Au moins une fois par mois (mais pas toutes les semaines)	4 <input type="checkbox"/> Au moins une fois par semaine (mais pas tous les jours)	5 <input type="checkbox"/> Tous les jours ou presque
Précisez pourquoi : <input type="checkbox"/> Je n'en possède pas <input type="checkbox"/> Je ne connais pas <input type="checkbox"/> Je n'aime pas				

Informations complémentaire

Main dominante : Je suis droitier Je suis gaucher Je suis ambidextre

J'ai des problèmes de vue Corrigés (je porte des lunettes) Non-corrigés

Typologie des altérations visuelles :

Champ visuel Perception des couleurs Vue de près Vue de loin Déformation

J'ai des difficultés motrices

Typologie des altérations motrices :

J'ai de l'arthrite sur les mains J'ai de l'arthrose sur les mains J'ai des tremblements

J'ai des troubles musculo-squelettiques sur les mains

J'ai des troubles musculo-squelettiques au niveau du bras

Autres, précisez.

Commentaires :

VII.2.3. *Final questionnaire*

Questionnaire final

Avez-vous une préférence pour l'interaction avec le doigt ou le stylet ? Doigt Stylet

Avez-vous une préférence pour la tablette ou le smartphone ? Tablette Smartphone

Avez-vous des difficultés particulières ?

Que pensez-vous sur des jeux de type puzzle sur les tablettes ?

Cette activité vous a plu ?

VII.3. *Evaluation of users' profiles*

The following tests were selected to verify the homogeneity of the participants of the experiments.

VII.3.1. *Eye-sight tests*

Examples of images of the test developed by healthcare4mobile (<https://play.google.com/store/apps/developer?id=healthcare4mobile>) are presented below. The test designed to identify color deficiency presents 6 colored images and subjects should identify the number inside the pattern (Figure VII.1). The other test was designed to reveal visual impairment on a person's central visual field (which could reveal age-related macular degeneration). Subjects should cover one eye and describe two images displayed on the screen, presenting a small dot in the center of a grid (Figure VII.2). They repeated the procedure covering the other eye. The third test was designed to test contrast sensitivity. Eight images presenting numbers were displayed on the screen and subjects should read them, covering one eye then the other (Figure VII.3). The size and the contrast of the numbers reduced from one image to the following.

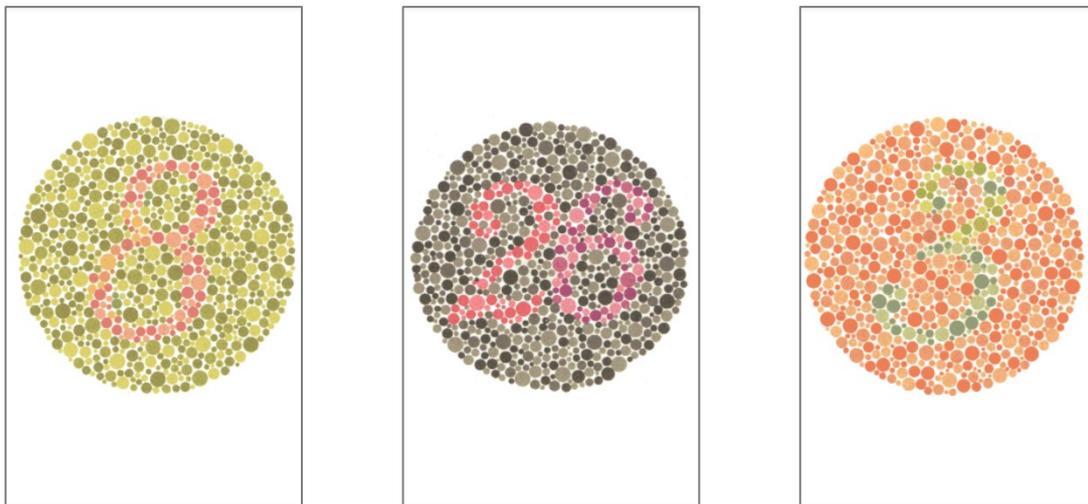


Figure VII.1 Example of images for Color Perception test

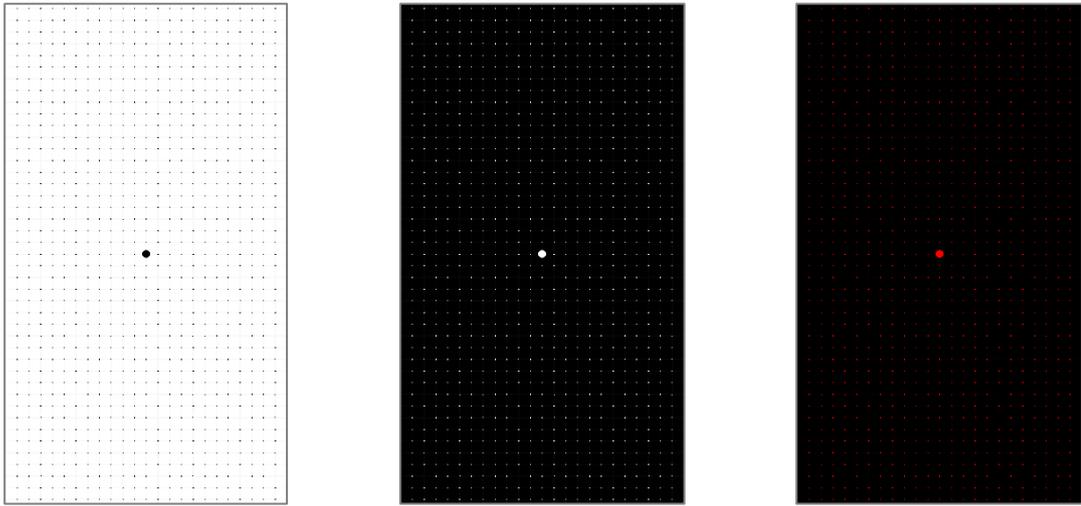


Figure VII.2 Example of images for Central Vision Acuity test

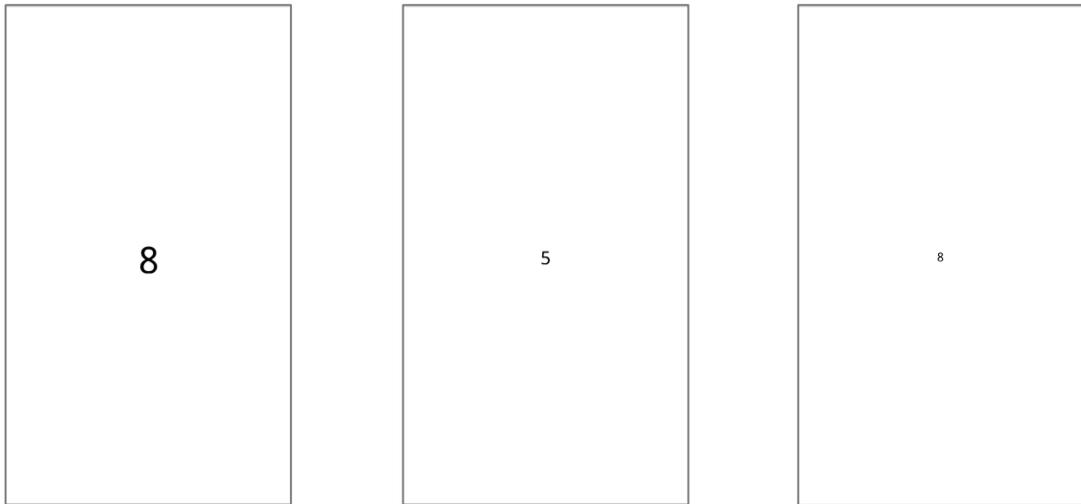


Figure VII.3 Example of images for Contrast Sensitivity from Near test

VII.3.2. *Questionnaire for assessing motor control profile*

The following questions are an example of motor control assessment questionnaire **Abilhand Rasch analysis for rheumatoid and arthritis patients** in French.

Source:

<http://www.rehab-scales.org/abilhand-rasch-analysis-rheumatoid-arthritis.html?scale=abilhand-ra&language=fr&order=1>

N	Questions	Impossible	Difficile	Facile	?
1.	Prendre une canette				
2.	Utiliser une agrafeuse				
3.	Ecrire une phrase				
4.	Utiliser un tournevis				
5.	Serrer un boulon				
6.	Remplacer une ampoule				
7.	Couper de la viande				
8.	Peler des pommes de terre avec un couteau				
9.	Prendre de la monnaie dans la poche				
10.	Tailler un crayon				
11.	Se limer les ongles				
12.	Utiliser un stylo à 4 couleurs d'une seule main				
13.	Prendre une pièce de monnaie sur une table				
14.	Emballer des cadeaux				
15.	Tourner une clé dans une serrure				
16.	Eplucher des oignons				
17.	Se brosser les cheveux				
18.	Ouvrir un paquet de chips				
19.	Fermer un robinet				
20.	Fermer la tirette d'une veste				
21.	Ouvrir un bocal				

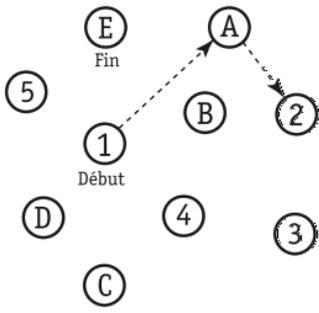
22.	Enfoncer un clou avec un marteau				
23.	Fermer une pression (veste, sac, ...)				
24.	Enfiler une aiguille				
25.	Décapsuler une bouteille				
26.	Se couper les ongles				
27.	Se peigner les cheveux				

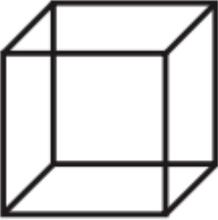
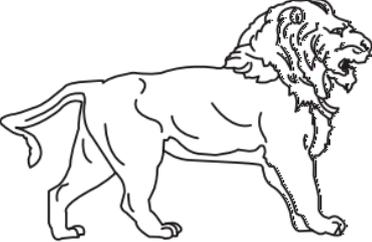
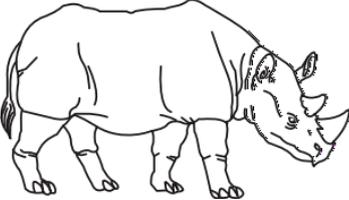
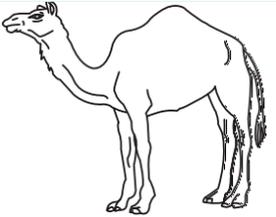
VII.3.3. Questionnaire for assessing cognitive profile

The following questions and exercises are an extract of the questionnaire cognitive assessment **Montréal Cognitive Assessment - MoCa** in French.

Source:

[http://www.cofemer.fr/UserFiles/File/EHELLES%20ADULTES%20TOME%202_page_30\(1\).pdf](http://www.cofemer.fr/UserFiles/File/EHELLES%20ADULTES%20TOME%202_page_30(1).pdf)

N	Questions	Points
1.	Scolarité	Ajouter 1 point si scolarité égale ou supérieure à 12 ans
2.	Relier les points. 	1 point
3.	Copier le cube.	1 point

		
4.	Dessiner l'horloge et les aiguilles pour indiquer : onze heures dix.	3 points
5.	Nommer : <div style="text-align: center;">    </div>	3 points
6.	Lire la liste de mots. Mémoriser et répéter. Faire un rappel 5 minutes après. Visage Velour Église Marguerite Rouge	1er essai (5 points) 2e essai (5 points)
7.	Lire la série de chiffres (1 chiffre/seconde) et répéter. <ul style="list-style-type: none"> • Répéter : 21854 • Répéter à l'envers : 742 	1 point (répétition) 1 point (répétition à l'envers)
8.	Lire la série de lettres. Taper de la main à chaque lettre A. F B A C M N A A J K L B A F A K D E A A A J A M O F A A B	1 point (pas de point si 2 erreurs)
9.	Soustraire série de 7 à partir de 100.	3 points (4 ou 5 soustractions)

		correctes) ou 2 points (2 ou 3 correctes) ou 1 point (1 correcte)
10.	Répéter : “Le colibri a déposé ses œufs sur la table.” “L’argument de l’avocat les a convaincus.”	2 points
11.	Nommer un maximum de mots commençant par la lettre “F” en 1 minute.	1 point (11 mots)
12.	Similitude (ex. : banane, orange = fruit). <ul style="list-style-type: none"> • train - bicyclette • montre - règle 	2 points
13.	Doit se souvenir des mots : Visage Velours Église Marguerite Rouge	5 points pour rappel sans indices
14.	1) Orientation <ul style="list-style-type: none"> • Date • Mois • Année • Jour • Endroit • Ville 	6 points

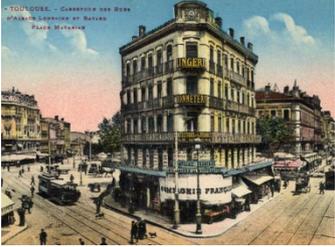
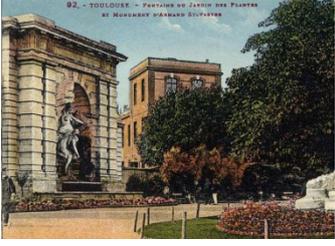
VII.4. Appendix for Chapter IV

In order to better understand the variability of performances between subjects, we investigated the effects of the users' profiles. First, we verified for significant effects of gender, education, dexterity or sight.

VII.4.1. Images used to generate the tactile puzzle games

Eight images were selected generating one puzzle game for each condition, as shown on Table VII.2.

Table VII.2 Images selected for the experimental study

Input technique and accuracy requirements	Smartphone	Tablet
Finger, low accuracy		
Pen, low accuracy		
Finger, high accuracy		
Pen, high accuracy		

VII.4.2. *Effects of different user' profiles on performances*

Data is not normally distributed according to the results of Shapiro Wilk test (for all subjects, time: $W = 0.88$, $p\text{-value} = 2.59e-11$; errors: $W = 0.79$, $p\text{-value} = 2.202e-15$). Consequently, Mann-Whitney U test has been used to look for significant effects of participants' profile (gender, educational level, dexterity, sight) or Kruskal-Wallis test for age effects (four age-ranges). Data distribution curve time and errors is skewed left. For this reason we detailed the median values to indicate tendencies and inter-quartile values to indicate deviations

Concerning the effects of participant's profiles, there is no significant effect of gender ($Z = 6.13$, $W = 4005$, $p\text{-value} = 0.80$) on mean time of movement per target neither on number of errors ($Z = 4.68$, $W = 3609$, $p\text{-value} = 0.18$).

Educational level revealed significant on time ($Z = 2.07$, $W = 2895.5$, $p\text{-value} = 1.19e-05$) but not on errors ($Z = 6.27$, $W = 4045$, $p\text{-value} = 0.17$). Subjects who had higher education problems spent shorter movement times: 2.30 ± 0.9 seconds while subjects with primary education spent 2.95 ± 2 seconds.

Dexterity had significant effect on time ($Z = 10.99$, $W = 5336$, $p\text{-value} = 0.008$) and on errors ($Z = 10.31$, $W = 5148$, $p\text{-value} = 0.03$). Subjects who reported dexterity problems spent longer movement times: 2.76 ± 1.7 seconds and made more errors (0.67 ± 1.41) than subjects with normal dexterity, who spent 2.39 ± 1.4 seconds and made a median number of errors per target of 0.42 ± 0.95

Sight also showed significant on time ($Z = -4.32$, $W = 1146$, $p\text{-value} = 1.40e-09$) and errors ($Z = -1.95$, $W = 1795$, $p\text{-value} = 6.7e-05$). Subjects with insufficient eyesight correction spent longer movement times: 3.98 ± 2.8 seconds than subjects corrected view (2.37 ± 1.2). The first made 1.42 ± 1.94 errors of accuracy per target while subjects with sufficient eyesight correction made 0.42 ± 0.85 errors.

The number of participants doesn't allow stating the effects of dexterity or sight on different levels of accuracy required.

Table IV.4 and Table IV.5 describe interaction performances for age-groups and groups of subjects with different profiles (dexterity, sight, use of computers and use of touchscreen).

Table VII.3 Effects of subjects' profiles on time and number of errors on high and low accuracy levels

Users' profiles	Time		Errors	
	High levels	Low levels	High levels	Low levels
Age	2.5e-3*	0.07	2.0e-4*	8.23e-3*
Sight	2.08e-7*	5.0e-05*	3.5e-5*	1.58e-3*
Dexterity (self-reported)	0.08	0.04	0.11	0.02731
Use of computer (self-reported)	3.77e-4*	4.37e-4*	0.004*	0.26
Use of touchscreen (self-reported)	0.07	5.86e-3*	0.50	0.25

* Significant effects P-value < 0.025

Table VII.4 Mean time per target and mean number of errors per target on high and low accuracy levels according to the subjects' profiles: sight (medians and inter- quartiles)

Subjects' profile **	Time		Errors	
	High levels	Low levels	High levels	Low levels
Corrected sight	2.59 (1.19)*	1.81 (1.00)*	0.96 (1.29)*	0.17 (0.27)*
Not corrected sight	5.57 (3.26)*	3.26 (1.46)*	2.45 (1.88)*	0.54 (0.69)*

* Significant effects, p-value < 0.025 ** According to the answers to the pre-experiment eyesight verification

Table VII.5 Mean time per target and mean number of errors per target on high and low accuracy levels according to the subjects' profiles: dexterity (medians and inter- quartiles)

Subjects' profile *	Time for high levels	Time for low levels	Errors for high levels	Errors for low levels
Normal dexterity	2.65 (1.61)	1.91 (1.06)	1.17 (1.42)	0.17 (0.42)
Low dexterity (self-reported)	3.04 (2.66)	2.44 (1.53)	1.58 (1.67)	0.33 (0.44)

* Subjects having reported any illness or disorder affecting the accuracy of the movements of the hand that could cause any difficulty for executing the gestures of interaction, without disturbing the accomplishment of the task

VII.5. Appendix for Chapter V

VII.5.1. Preliminary study: Analysis of movements of the users during interaction with touchscreen:

The aim of this preliminary study is to assess Biomechanics and kinematics of upper-limb to evaluate joints positions and articular angles employed during tactile interaction. The upper-limb is a multi-joint system with redundancy: different combinations of joints positions and articular angles are possible to lead to the same movement (Jacquier-Bret et al., 2009). In this study, the analysis is focused on the motion angles of elbow and wrist to identify the strategies users employed during interaction with touchscreen.

VII.5.1.1 Experimental design and methods

Settings of the interactive system Puzzle Touch

Taking into consideration the possibilities of use of touchscreen devices, we chose to set the interactive system to generate tactile puzzle games with three sizes of targets (small, medium and large, as described in Chapter III, Table V.1, p. 158) displayed on mobile devices with different screen sizes, a smartphone and a tablet, allowing pen and finger interaction.

For this preliminary study, the settings of the interactive system have been modified to create different situations of interaction as described in Table VII.6. In order to facilitate the task, the accuracy requirements have been set to 50%. Twelve different images have been selected for the games. The game play as described in the design evaluation is maintained (Chapter III, III.3.1, p. 101).

Table VII.6 Preliminary study: Settings of the interactive system

Parameter	Characteristics of the devices and development choices
Targets sizes	Small, medium and large according to the number of targets on each device
Targets number	16, 12 and 9 pieces
Accuracy requirement	50 %
Interaction technique	Drag-and-drop
Number of pieces that can be dragged simultaneously	One. The games are single-touch.

Task

The task is the same as described in V.1.3 (p.159).

Apparatus and equipment

The apparatus and equipment is the same as described in V.1.4 (p.159).

Procedures

11 able-bodied adults were recruited for the experiment. After a detailed explanation of the procedures, subjects had a demonstration of the game and executed some practice trials (one or two games with both devices and both input techniques). During the practice trials, we verified the visibility of the background image and the luminosity of the screen. Then, subjects signed a written consent form. We collected subjects' weight and size, dominant hand size and they were questioned about previous injuries or motor difficult on right hands, arms or upper-limb. They were also questioned about previous experience and use of computers and touchscreen, puzzle games, video and electronic games and level of education. Measures of their hands are taken by drawing the open hand placed over a paper sheet. Then they were equipped with the reflective markers as described in 0.

During the experiment, subjects were seated on a chair and the devices were horizontally placed on a desk in front of them, in portrait orientation. The smartphone was placed at 10 cm from the border of the desk and the tablet at 10 cm. Before each game, subjects were told to respect the same initial position with back on the seat and arms resting on the table alongside the device. If the situation of the study required pen interaction, subjects kept the pen in their hands. When the game is finished, subjects got back to the initial position. Subjects were told to move one piece at a time, with accuracy.

In order to have enough data to measure body movements, measures have to be repeated so the average position for each marker could be calculated. During the experiment, subjects played five series of 12 puzzle games. Each subject played 60 games; the experiment lasts approximately 3 hours. The 12 games of each sequence correspond to the different situations of the study: 2 screen sizes (smartphone and tablet), 2 input modalities (pen or finger) and the 3 sizes of targets (9 large, 12 medium and 16 small targets). The 12 situations have been sorted randomly for each series. At the end of each series, they were questioned about motor and visual fatigue and they were invited to take a 10 minutes break. Subjects were informed that they could ask for more breaks anytime.

Data analysis

In this study, we report the results of the evaluation of the twenty two reflective markers placed on head, trunk and right upper limb of each subject. The chosen situations of the experiment for this analysis concern nine large and sixteen small targets and interaction with finger in smartphone and tablet.

VII.5.1.2 Results

Participants

11 able-bodied adults (10 male) were recruited for this study. They are aged between 18 and 42 years old (mean age 28.63 +/-5.97). Mean weight for subjects is 73.27 +/-12.4 kg; mean height 178.18 +/-7.14 cm; mean length for the dominant hand is 19.5 +/-0.71 cm and mean length for the major finger is 8.57 +/-0.52 cm.

All subjects were right handed. According to the self-reported information, subjects had no motor control problems that could disturb the execution of the gestures of interaction. All have corrected vision or no visual deficiency. All of them are university students or have higher education and they use a computer every day or almost every day. All of them except one (T11) have a smartphone with a tactile screen. 5 of them play video games frequently. Table VII.7 summarizes the characteristics of the participants.

Table VII.7 Preliminary study: Subject's profiles

Id	Age	G	W	S	Hand	F	Puzzle games	Video games	Use of computer	Use of touchscreen
T1	18	M	65	185	18.7	8.7	1	4	5	5
T2	24	M	75	183	19.8	9	1	2	5	5
T3	25	M	96	190	20.4	9.5	1	2	5	5
T4	27	M	82	176	18.6	8.2	3	2	5	5
T5	27	M	78	177	18.4	8	3	3	5	5
T6	29	M	70	176	20	9	2	4	5	5
T7	29	F	49	164	17.7	8	1	3	5	5
T8	30	M	70	183	18.5	8	1	4	5	5
T9	32	M	86	175	19.8	9	3	1	5	5
T10	32	M	65	180	19	9	4	4	5	5
T11	42	M	70	171	18.5	8.5	1	3	5	1

*G= gender; W= weight (kg); S= high (cm); Hand= dominant hand length (cm); F= major finger length (cm). Frequency of use: 1) I never use it, 2) I have already used or I rarely use it, 3) I use it at least once a month, 4) At least once a week, 5) Every day or almost every day

Articular angles of upper limb and motion strategies

The distance of the head and the center of the devices remained constant, about 52.2 +3.7 cm. For all the situations of the experiment, an advancement of the head has been detected, the mean distance was 26.3 +-5.7 cm (Jacquier-Bret et al., 2014b).

Jacquier-Bret *et al.* (2014) report a significant effect of the size of the screen and the number of the targets on the wrist displacement (Jacquier-Bret et al., 2014b).

In order to analyze the upper-limbs interaction strategy, the wrist flexion-extension trajectories were plotted against the elbow flexion-extension (Jacquier-Bret et al., 2014a). A 95% confidence ellipse was also plotted and the equation of the major axis was calculated. The range of motion of the elbow flexion-extension is larger than the one of the wrist.

After determining the slope of the major axis of the linear equation, Jacquier-Bret *et al.* (2014) identified the strategies of the interaction. Subjects assuming a slope of 1 have been considered as adopting a strategy that mobilizes equally the elbow and the wrist (Mixed Strategy, MS). Subjects whose movements are represented by an increased slope adopt a strategy characterized by a more important mobilization of the wrist in relation to the elbow (Wrist Strategy, WS). On the other hand, subjects whose movements are represented by a decreased slope adopt a strategy interpreted by a larger solicitation of the elbow (Elbow Strategy, ES) (Jacquier-Bret et al., 2014a).

Following this assumptions, three groups of subjects have been identified (Jacquier-Bret et al., 2014c). Six subjects executed interaction movements with a “proximal strategy” organization, characterized by an important solicitation of the proximal joints (shoulder and elbow) and low implication of the wrist. Five subjects employed a “wrist strategy” organization, corresponding to an important solicitation of the wrist and low mobilization of the proximal joints. One subject adopted a “neutral strategy”, employing a mixed organization.

VII.5.1.3 Discussion

In line with previous studies, the screen sizes and the targets number directly affected the traveling distance of the wrist and the range of motion of the upper-limb. Kim *et al.* (2013) evaluated the effects of key sizes during typing tasks on virtual keyboards. They found that smaller keys (13 mm width) implied higher static muscle activity of the shoulder probably due to the increased visual demand (Kim et al., 2013). HCI studies have already reported significant effects of screen sizes and graphical user

interfaces on interaction performances, as bigger screen sizes require more movements and bigger travelling distances (Harada et al., 2013; Kobayashi et al., 2011; Stöbel et al., 2010).

The analysis of the motion angles of the elbow and the wrist allow the identification of the strategies adopted by the users to accomplish interaction, an important solicitation of the proximal joints (shoulder and elbow) and low implication of the wrist or an important solicitation of the wrist and low mobilization of the proximal joints. Interacting with touchscreen devices horizontally placed on a desk resulted on elevation of arms and hands and variation of angles in relation to the neutral positions. These postures, associated to the duration and the frequency of mobilization, could present a risk factor for musculoskeletal injuries due to the repeatability of the movements of the same combination of upper-limb joints (Gustafsson et al., 2011). After a prolonged use of touchscreen, subjects employing a “proximal strategy” could overcharge the shoulder and elbow articulations and subjects adopting a “wrist strategy” would be risking fatigue and injuries for the wrist. From an ergonomic point of view, a “neutral strategy”, balancing the mobilization of elbow and wrist articulations, should be prioritized for prolonged use of touchscreen.

The implication of this results for the design of interactive systems is that reducing the number of supplementary manipulation (*e.g.*, reducing errors of interaction, helping the user to recover from errors, simplify the steps for executing the task) could enhance the ergonomics of tactile interaction.

VII.5.1.4 *Conclusion*

The results of the evaluation of elbow and wrist positions during tactile interaction confirm that a prolonged use of touchscreen could present the risk of developing musculoskeletal disorders for subjects adopting a “proximal strategy” or a “wrist strategy” for adults. Designers should facilitate the interaction by increasing performances and reducing the number of manipulations. This preliminary study confirms the interest in associating Biomechanics research methods to better understand the kinematics of tactile interaction in order to enhance ergonomics. Future work should investigate the different strategies of movements of upper-limb during interaction with touchscreen for older users.

VII.6. Procedures for filtering and clipping data

VII.6.1. Procedures for filtering and clipping data with Matlab.

```
% Butterworth filter

fnorm= 6*2/200*pi;
order=2;
[b, a]= butter(order, fnorm, 'low');
tofilter(any(isnan(tofilter),2),:)=[];
filtered=filtfilt(b,a,tofilter);
```

```
%Finding peaks and valleys for clipping

[pks, locs, ~, ~]= findpeaks(filtered-z,
'MinPeakDistance',50, 'MinPeakProminence',1);
row=locs(1);
z1=filtered(row);
z2= filtered(row+1);
while z2<z1 %going down after first "tap"
row= row+1;
z1=filtered(row);
z2= filtered(row+1);
end
firstvalleyloc=row;
valley=filtered(firstvalleyloc);
```

```
%Procedure for clipping X,Y,RU, FE and PS

task_z= filtered_z(firstvalleyloc_z:lastvalleyloc_z);
task_x= filtered_x(firstvalleyloc_z:lastvalleyloc_z);
task_y= filtered_y(firstvalleyloc_z:lastvalleyloc_z);
task_RU= filtered_RU(firstvalleyloc_z:lastvalleyloc_z);
task_FE= filtered_FE(firstvalleyloc_z:lastvalleyloc_z);
task_PS= filtered_PS(firstvalleyloc_z:lastvalleyloc_z);
```

VII.6.2. *Procedures for clipping data and normalizing with R.*

```
# find the dragging moves for positioning one puzzle
piece at its corresponding target
subset=subset_touchmove[subset_touchmove$target==my_targ
et,]
list_touches_target=
levels(as.factor(subset$nb_touches))
dragging= subset[subset$nb_touches==
list_touches_target[1],]
```

```
#select only one gesture for this target (ignore multi-
touch)
onegesture= dragging[dragging$touch_id==my_touch_id,]
```

```
#create curve from coordinates and timestamp for time x
distance
spl<-
smooth.spline(onegesture$duration,onegesture$distance)
pred<-predict(spl)
```

```
#calculate derivative (speed)
pred$y.prime<-diff(pred$y)/diff(pred$x)
dx <- rowMeans(embed(pred$x,2))
```

```
# normalize X axis (time) to 100 points
normalize=spline(dx, pred$y.prime, n=100)
```

VII.7. Complementary results for the experimental study described in Chapter V

The following analysis presents a finer description of the subjects' performances and wrist postures during the different situations of the study. First, we searched for the combinations of device, input modalities and targets sizes more suitable to each group of user. Then we verified learning effects through the differences in performances across the iteration series.

VII.7.1. Differences in performances and postures and movements of the wrist for the two groups of subjects in the eight situations of the study

Table VII.8 Results of Shapiro Wilk's test: P-values

Dependent variables	All subjects		Only older (3 iterations)		Only adults (5 iterations)	
	Time	0.832	<2.2e-16	0.799	<2.2e-16	0.882
Errors	0.701	<2.2e-16	0.751	<2.2e-16	0.710	<2.2e-16
Unintentional touches	0.236	< 2.2e-16	0.382	< 2.2e-16	0.300	< 2.2e-16
Mean PS	0.948	6.742e-16	0.921	8.604e-13	0.970	9.338e-10
Mean FE	0.986	6.535e-08	0.971	1.409e-06	0.985	9.37e-06
Mean RU	0.990	0.000141 6	0.973	3.039e-06	0.995	0.03051*
Mean wrist elevation	0.966	2.849e-15	0.986	0.001395	0.962	2.436e-11
Range of motion PS	0.882	<2.2e-16	0.965	1.551e-07	0.846	<2.2e-16
Range of motion FE	0.858	<2.2e-16	0.870	<2.2e-16	0.905	<2.2e-16
Range of motion RU	0.911	<2.2e-16	0.908	5.506e-14	0.950	2.096e-13
Range of motion on wrist elevation	0.786	<2.2e-16	0.798	<2.2e-16	0.946	4.899e-14

VII.7.1.1 Interaction performances

The following tables describes interaction performances for the two groups of subjects for the two input modalities and two sizes of targets on smartphone, in Table VII.9, and on tablet, in Table VII.10 . These differences are statistically significant, as showed in Table VII.11.

Table VII.9 Interaction performances on different situations for groups of subjects on smartphone (medians)

Situation	group	Time	Errors	Unintentional touches
Large targets, finger	Adults	2.24 +/-0.65	0.56 +/-0.17	0.11 +/-0.78
	Older adults	4.95 +/-1.09	1.11 +/-1.04	0 +/-0
Large targets, pen	Adults	1.92 +/-0.40	0.44 +/-0.50	0 +/-0
	Older adults	3.74 +/-1.47	0.85 +/-0.43	0 +/-0
Small targets, finger	Adults	2.64 +/-0.43	0.73 +/-0.51	0.56 +/-2.25
	Older adults	5.84 +/-2.15	1.96 +/-1.31	0.06 +/-0.13
Small targets, pen	Adults	2.20 +/-0.39	0.54 +/-0.34	0 +/-0.06
	Older adults	4.84 +/-1.89	1.60 +/-0.83	0 +/-0
	Older adults	4.33 +/-1.15	0.37 +/-0.91	0.11 +/-0.78

Table VII.10 Interaction performances on different situations for groups of subjects on tablet (medians)

Situation	group	Time	Errors	Unintentional touches
Large targets, finger	Adults	2.76 +/-0.95	0.15 +/-0.30	0.22 +/-0.33
	Older adults	4.33 +/-1.15	0.37 +/-0.91	0 +/-0
Large targets, pen	Adults	2.37 +/-0.63	0.15 +/-0.31	0 +/-0
	Older adults	4.00 +/-1.40	0.44 +/-0.54	0 +/-0
Small targets, finger	Adults	2.69 +/-0.68	0.25 +/-0.29	0.31 +/-0.81
	Older adults	4.52 +/-1.08	0.60 +/-0.82	0 +/-0.06
Small targets, pen	Adults	2.50 +/-0.65	0.19 +/-0.19	0.06 +/-0.13
	Older adults	4.63 +/-1.98	0.77 +/-0.59	0 +/-0

Table VII.11. Results of Friedman test for significant differences between the eight situations of the study in interaction performances

Dependent variables	Group	χ^2	DF	P-values
Time	Older adults	82.825	14	8.438e-12*
	Adults	85.825	14	2.318e-12*
Errors	Older adults	75.0673	14	2.3e-10*
	Adults	77.2279	14	9.212e-11*
Unintentional touches	Older adults	59.602	14	1.378e-07*
	Adults	28.4801	14	0.01228*

* Significant effects: p-value < 0.05 Postures and movements of the wrist

The following tables describe interaction postures and movements of the wrist for the two groups of subjects for the two input modalities and two sizes of targets on smartphone and tablet. Radial-ulnar deviations are described in Table VII.12, flexion-extension angles are described in Table VII.13, pronation-supination angles are described in Table VII.14 and mean wrist elevation described in Table VII.15.

Table VII.12 Mean angles and range of motion on radial -ulnar deviation of the wrist for the different situations of the experiment (medians and inter-quartiles)

Device	Target size	Input modality	Group	Mean RU	Range of motion RU
Smartphone	Large	Finger	Adults	21.23+/-9.48	27.3+/-11.36
			Older	27.87+/-10.35	50.93+/-20.08
		Pen	Adults	14.84+/-10.16	28.34+/-11.89
			Older	25.47+/-11.51	45.02+/-16.09
	Small	Finger	Adults	20.03+/-9.41	29.94+/-12.9
			Older	28.35+/-9.01	59.04+/-16.83
		Pen	Adults	14.2+/-10.36	28.06+/-8.81
			Older	25.87+/-11.49	53.48+/-20.3
Tablet	Large	Finger	Adults	18.04+/-9.11	35.31+/-9.44
			Older	24.74+/-10.97	53.78+/-20.37
		Pen	Adults	14.36+/-9.36	34.59+/-11.27
			Older	24.39+/-10.71	50.5+/-13.88
	Small	Finger	Adults	16.89+/-8.23	35.08+/-9.21
			Older	25.67+/-10.35	64.04+/-22.13
		Pen	Adults	12.92+/-8.85	36.25+/-7.49
			Older	24.6+/-9.75	56.07+/-18.55

Table VII.13 Mean angles and range of motion on flexion-extension of the wrist for the different situations of the experiment (medians and inter-quartiles)

Device	Target size	Input modality	Group	Mean FE	Range of motion FE
Smartphone	Large	Finger	Adults	8.58+/-5.99	19.42+/-7.71
			Older	8.99+/-6.38	37.21+/-19.5
		Pen	Adults	11.15+/-6.22	15.99+/-6.08
			Older	13.74+/-5.7	31.63+/-15.14
	Small	Finger	Adults	8.58+/-5.86	22.78+/-9.58
			Older	9.49+/-6.84	39.58+/-14.11
		Pen	Adults	10.61+/-6.56	16.6+/-5.92
			Older	13.96+/-5.59	35.64+/-13.84
Tablet	Large	Finger	Adults	3.14+/-5.58	23.63+/-11.53

			Older	6.36+/-6.78	37.76+/-20.63
		Pen	Adults	9.07+/-5.34	20.85+/-9.64
			Older	12.34+/-5.72	34.32+/-13.04
	Small	Finger	Adults	2.78+/-5.95	27.28+/-10.44
			Older	5.34+/-7.41	46.27+/-19.5
		Pen	Adults	8.4+/-5.08	20.43+/-5.94
			Older	11.57+/-6.11	41.72+/-20.44

Table VII.14 Mean angles and range of motion on pronation-supination of the wrist for the different situations of the experiment (medians and inter-quartiles)

Device	Target size	Input modality	Group	Mean PS	Range of motion PS
Smartphone	Large	Finger	Adults	20.56+/-7.84	24.21+/-13
			Older	22.76+/-6.01	59.01+/-31
		Pen	Adults	49.71+/-8.29	25.43+/-9.01
			Older	56.49+/-8.05	63.99+/-27.37
	Small	Finger	Adults	22.32+/-8.2	31.54+/-19.4
			Older	23.39+/-6.72	71.57+/-28.14
		Pen	Adults	49.71+/-8.71	26.28+/-10.51
			Older	56.67+/-7.11	70.4+/-22.68
Tablet	Large	Finger	Adults	16.03+/-6.98	30.31+/-14.09
			Older	15.65+/-5.85	55.12+/-27.77
		Pen	Adults	42.64+/-9.84	29.66+/-10.92
			Older	50.25+/-5.67	67.45+/-29.36
	Small	Finger	Adults	16.18+/-7.38	30.5+/-10
			Older	16.87+/-5.99	73.26+/-30.68
		Pen	Adults	43.34+/-7.02	29.22+/-10.22
			Older	50.61+/-6.15	70.38+/-31.21

Table VII.15 Mean wrist elevation and range of motions for the different situations of the experiment (medians and inter-quartiles)

Device	Target size	Input modality	Group	Mean Z	Range of motion Z
Smartphone	Large	Finger	Adults	28.43+/-16.17	28.68+/-24.25
			Older	23.67+/-10.35	70.88+/-66.95
		Pen	Adults	27.67+/-11.66	29.84+/-18.3
			Older	22+/-9.79	53.91+/-43.61
	Small	Finger	Adults	27.82+/-15.9	32.52+/-29.68
			Older	24.05+/-11.12	85.07+/-50.18
		Pen	Adults	28.95+/-13.41	30.18+/-18.79
			Older	22.04+/-8.65	83.6+/-76.08
Tablet	Large	Finger	Adults	45.97+/-15.49	57.47+/-23.06

			Older	34.12+/-10.36	83.49+/-45
		Pen	Adults	43.71+/-13.32	51.33+/-23.39
			Older	35.57+/-8.48	82.41+/-44.32
		Small	Finger	Adults	47.18+/-16.75
	Older			36.21+/-10.75	113.51+/-72.97
	Pen		Adults	44.26+/-13.21	55.02+/-18.94
			Older	37.34+/-9.28	96.4+/-48.86

The eight situations of the study have significant effects on interaction performances and postures and movements of the wrist for the two groups of subjects, as described in Table VII.16.

Table VII.16. Results of Friedman test for significant differences between the eight situations of the study in postures and movements of the wrist

Dependent variables	Group	x²	DF	P-values
RU	Older adults	73.925	14	3.724e-10*
	Adults	97.0375	14	1.748e-14*
Range of motion RU	Older adults	60.175	14	1.093e-07*
	Adults	80.0125	14	2.815e-11*
FE	Older adults	85.7625	14	2.381e-12*
	Adults	55.2375	14	7.881e-07*
Range of motion FE	Older adults	73.25	14	4.948e-10*
	Adults	85.2875	14	2.923e-12*
PS	Older adults	57.725	14	2.928e-07*
	Adults	97.4	14	1.491e-14*
Range of motion PS	Older adults	67.925	14	4.574e-09*
	Adults	90.75	14	2.738e-13*
Mean wrist elevation	Older adults	68.7	14	3.316e-09*
	Adults	87.8375	14	9.705e-13*
Range of motion on wrist elevation	Older adults	59.95	14	1.197e-07*
	Adults	74.0875	14	3.478e-10*

* Significant differences: p-value < 0.05

VII.7.1.2 Effects of the size of the targets on smartphone and tablet

The effects of the targets sizes during interaction on smartphone and on tablet were verified on interaction performances and postures of the wrist for the two groups of subjects.

Interaction performances

Older adults and adults spent longer times for positioning small targets than large targets, on both touchscreen devices (Figure VII.4). The two groups also made more errors with small targets on smartphone (Figure VII.5). Older adults only made more errors for positioning small targets than large targets on tablet. Concerning the number of unintentional touches, it also increased during interaction with small targets on tablet and smartphone for older adults. The effects of the different sizes of targets on smartphone and on tablet were significant for older adults on time, errors and unintentional touches. These effects also produced significant differences in time, errors and unintentional touches for adults. However, during interaction on tablet, the size of the targets only affected the mean time of movement per target for adults. Details are presented in Table VII.17.

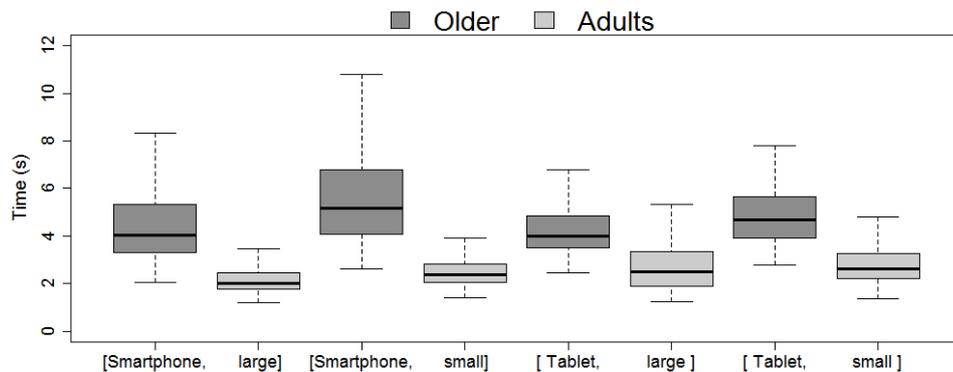


Figure VII.4 Time of movement per target (s) for the two groups on smartphone and tablet, for large and small targets.

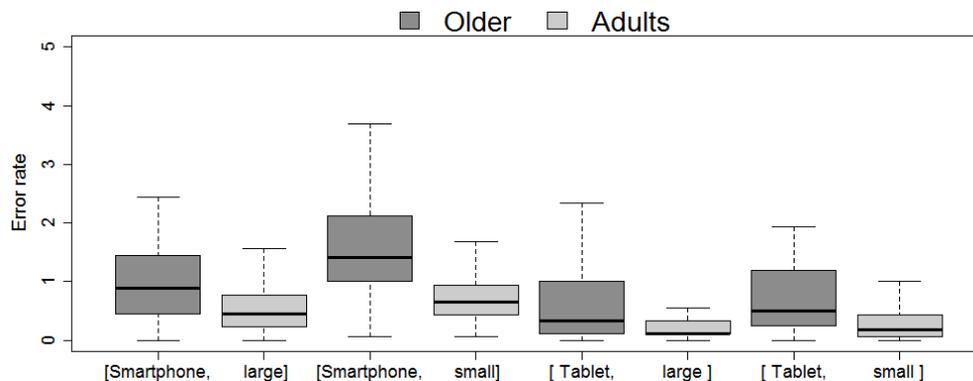


Figure VII.5 Number of errors per target for the two groups on smartphone and tablet, for large and small targets.

Table VII.17. Results of Wilcoxon test for significant differences of targets sizes in interaction performances during interaction on smartphone and tablet

		Older adults			Adults		
		Z	V	P-values	Z	V	P-values
Smartphone	Time	-5.410	703	6.379e-08*	-5.615	652	1.988e-08*
	Errors	-5.261	740	1.448e-07*	-3.362	1212	0.0008*
	Unintentional touches	-7.394	210	3.526e-07*	-7.844	98	0.002*
Tablet	Time	-4.770	862	1.86e-06*	-3.555	1164	0.0004*
	Errors	-2.778	1357	0.012*	-0.453	1935	0.784
	Unintentional touches	-6.062	541	0.0008*	-7.558	169	0.637

* Significant differences of size of targets: p-values < 0.025

Postures and movements of the wrist

The size and number of targets affected postures and ranges of motion of older adults' wrist during interaction on smartphone. During interaction on tablet, the different sizes of targets affected only mean FE and mean PS for this group of subjects. Figure VII.6 and Figure VII.7 illustrate the effects of ranges of motion during interaction on smartphone and tablet respectively. Concerning the group of adults, different sizes and number of targets on smartphone or tablet affected mean RU, FE and PS angles as well as ranges of motion on FE and PS.

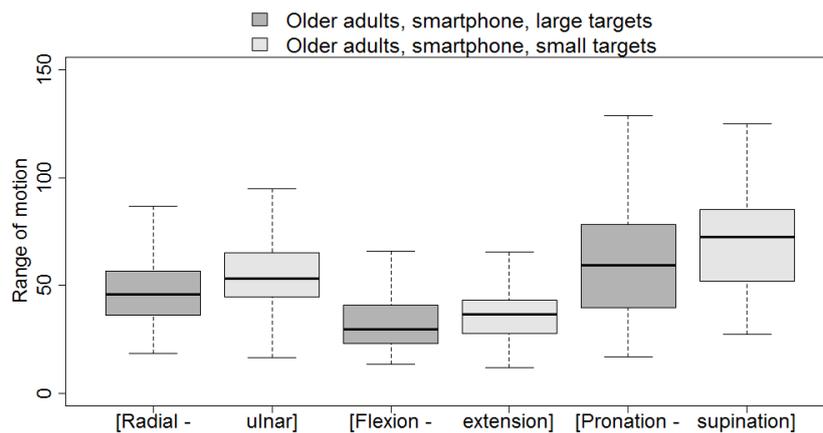


Figure VII.6 Range of motion (in angles) on radial-ulnar deviation, flexion-extension and pronation-supination of the wrist of older adults during interaction on smartphone with large and small targets. Sixteen small targets required greater ranges of motion for this group of users than nine large targets.

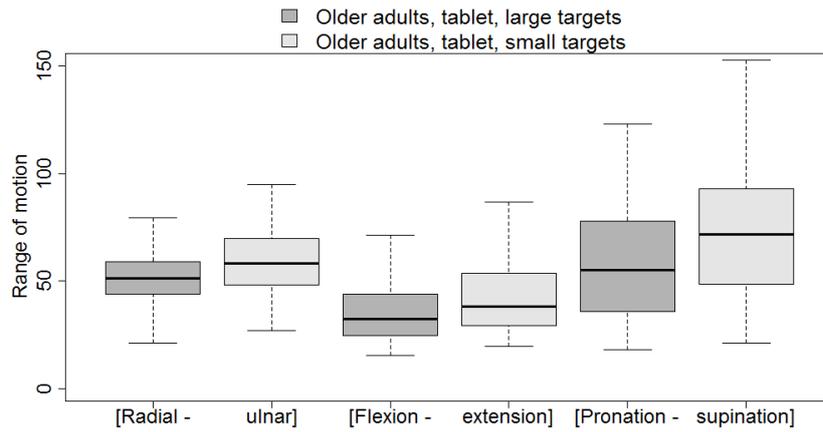


Figure VII.7 Range of motion (in angles) on radial-ulnar deviation, flexion-extension and pronation-supination of the wrist of older adults during interaction on tablet with large and small targets. Similarly to interaction on tablet, sixteen small targets required greater ranges of motion for this group of users than nine large targets.

Table VII.18 presents mean angular deviations of the wrist and ranges of motion for older adults and adults, for positioning small and large targets on smartphone and tablet. Table VII.19 describes wrist elevation and motion features during the task for the two sizes of targets. The verification of significance for interaction on smartphone is described in Table VII.20 and on tablet in Table VII.21.

Table VII.18 Motion features with two sizes of targets for groups of subjects on smartphone (medians and inter-quartiles)

		Group	Mean RU	Range of motion RU	Mean FE	Range of motion FE	Mean PS	Range of motion PS
Smartphone	Large targets	Older adults	28 +/-17	46 +/-20	12 +/-9	30 +/-17	48 +/-35	59 +/-39
		Adults	18 +/-15	23 +/-11	10 +/-10	17 +/-9	54 +/-29	22 +/-10
	Small targets	Older adults	29 +/-14	53 +/-20	13 +/-8	37 +/-15	50 +/-34	72 +/-33
		Adults	16 +/-13	26 +/-10	10 +/-9	19 +/-11	53 +/-26	25 +/-11
Tablet	Large targets	Older adults	26 +/-15	51 +/-15	11 +/-8	32 +/-19	56 +/-33	55 +/-42
		Adults	15 +/-14	33 +/-13	6 +/-9	21 +/-13	62 +/-26	26 +/-12
	Small targets	Older adults	27 +/-14	58 +/-21	10 +/-9	38 +/-24	56 +/-33	72 +/-44
		Adults	14 +/-11	34 +/-12	6 +/-9	21 +/-10	61 +/-25	27 +/-13

Table VII.19 Mean wrist elevation and range of motions with two sizes of targets for groups of subjects (medians and inter-quartiles)

Device	Situations	Group	Mean Z	Range of motion Z
Smartphone	Large targets	Older adults	21.64 +/-14.85	49.04 +/-28.43
		Adults	23.79 +/-18.43	26.96 +/-27.92
	Small targets	Older adults	21.5 +/-15.85	62.31 +/-45.23
		Adults	22.58 +/-20.97	27.27 +/-27.77
Tablet	Large targets	Older adults	34.5 +/-10.51	73.09 +/-41.36
		Adults	43.6 +/-21.68	48.73 +/-22.78
	Small targets	Older adults	35.77 +/-11.3	87.66 +/-71.01
		Adults	45.74 +/-22.59	50.17 +/-30.95

Table VII.20. Results of Wilcoxon test for significant differences of targets sizes in postures and movements of the wrist on smartphone

	Older adults			Adults		
	Z	V	P-values	Z	V	P-values
RU	2.646	2705	0.008*	9.388	10666	2.2e-16*
Range of motion RU	2.835	2752	0.005*	0.566	5964	0.572
FE	-6.585	411	4.618e-11*	-4.637	3191	3.549e-06*
Range of motion FE	2.404	2645	0.016	6.966	9375	3.293e-12*
PS	8.239	4095	2.2e-16*	10.624	11325	2.2e-16*
Range of motion PS	-0.384	1952	0.702	0.204	5771	0.839
Mean wrist elevation	1.451	2408	0.14	-3.217	3948	0.001*
Range of motion on wrist elevation	1.966	2536	0.05	-1.222	5011	0.222

* Significant differences of size of targets on smartphone: p-values < 0.0125

Table VII.21 Results of Wilcoxon test for significant differences of targets sizes in postures and movements of the wrist on tablet

	Older adults			Adults		
	Z	V	P-values	Z	V	P-values
RU	0.561	2187	0.576	6.885	9332	5.823e-12*
Range of motion RU	2.163	2585	0.031	-0.894	5186	0.372
FE	-7.434	200	1.072e-13*	-8.752	998	2.2e-16*

Range of motion FE	1.793	2493	0.074	6.326	9034	2.536e-10*
PS	8.239	4095	2.2e-16*	10.622	11324	2.2e-16*
Range of motion PS	-0.879	1829	0.380	1.245	6326	0.214
Mean wrist elevation	-1.559	1660	0.119	1.399	6408	0.162
Range of motion on wrist elevation	1.322	2376	0.187	3.202	7369	0.001*

* Significant differences of size of targets on tablet: p-values < 0.0125

VII.7.2. *Effects of the iterations*

In this section, we investigate the appropriation of the interactive system for adults and older adults across three iteration series. First we describe the differences in performances between older and adults during the first three iterations. Then in order to try to understand the variability of performances among older adults, we verified effects of age and previous experience with touchscreen across the iterations.

VII.7.2.1 *Effects of iterations on interaction performances for older and adults' subjects*

There is a significant effect of iteration on time for both groups ($\chi^2= 13.32$, $DF= 2$, $p\text{-value}= 0.001$), for adults ($\chi^2= 20.96$, $p\text{-value}=2.81e-05$) and for older adults ($\chi^2= 10.13$, $p\text{-value} 0.003642$). No significant effects were found for iteration on errors for both groups ($\chi^2= 4.33$, $DF= 2$, $p\text{-value}= 0.11$) or for adults ($\chi^2= 0.06$, $DF= 2$, $p\text{-value}= 0.98$) but there is a significant effect on error rates for older adults ($\chi^2= 9.96$, $DF= 2$, $p\text{-value}= 0.007$).

Mean time and errors for older adults and adults across the three iterations are described on Table VII.22 and Table VII.23.

Table VII.22 Time (s) for groups of subjects per iteration series (medians and inter-quartiles)

Group	Time 1st	Time 2nd	Time 3rd
Older adults	4.83 +/-2.46	4.29 +/-1.10	4.12 +/-1.12
Adults	2.99 +/-1.08	2.56 +/-0.92	2.37 +/-0.91

Table VII.23 Error for groups of subjects per iteration (medians and inter-quartiles)

Group	Errors 1st	Errors 2nd	Errors 3rd
Older adults	1.45 +/-1.56	1.10 +/-1.22	0.93 +/-0.95
Adults	0.53 +/-0.54	0.53 +/-0.58	0.62 +/-0.86

VII.7.2.2 *Effects of user profiles on interaction performances for older subjects*

For the analysis of the effects of the subjects' profiles, older adults have been divided into groups according to

- Four groups for age range: 4 subjects are aged 65 to 69 years old, 7 subjects are aged 70 to 74 years old, subjects are aged 75 to 79 years old and one subject is aged 80 years old or older.
- Two groups for use of touchscreen: 9 subjects never used or rarely use a touchscreen (mean age 73 +/-2.93) and six subjects with experience of using touchscreen (using it at least once a month, mean age 73 +/-6.43).

There is a significant effect of age ranges on time ($x^2= 35.11$, $DF= 3$, $p\text{-value}= 1.15e-07$) and errors ($x^2= 32.74$, $DF= 3$, $p\text{-value}= 3.65e-07$). Table VII.24 describes mean times of movements and mean number of errors per target for each age group.

Table VII.24 Interaction performances for older subjects according to age-ranges (medians and inter-quartiles)

Age range	Number of subjects	Time	Errors
65-69	4	4.04 (1.62)	0.94 (1.00)
70-74	7	4.40 (1.58)	0.56 (0.97)
75-79	3	4.68 (4.03)	1.15 (2.09)
80 plus	1	6.54 (2.27)	1.65 (1.57)

There is a significant effect of experience of using touchscreen on time ($Z= 16.51$, $W= 19702$, $p\text{-value}= 1.80e-05$) but no significant effects were found on errors ($Z= 12.12$, $W= 16629.5$, $p\text{-value}= 0.27$).

Table VII.25 show the different performances on time and errors for the four groups of subjects according to the experience.

Table VII.25 Time (s) and errors for groups of subjects by experience with touchscreen (medians and inter-quartiles)

Group	Time	Errors
Experienced users	4.41 +/-1.70	0.94 +/-0.81
Novice users	5.43 +/-2.38	1.31 +/-1.51

VII.7.2.3 *Iterations and experience of touchscreen on interaction performances*

For experienced older adults, no significant effects of iteration were found on time ($x^2= 3.65$, $DF= 2$, $p\text{-value}= 0.16$) neither on errors ($x^2= 4.91$, $DF= 2$, $p\text{-value}= 0.09$). Even if the effects are not significant for experienced subjects, there is a decrease in mean time

of movement per target between the first and the third iteration as well as an increase of the accuracy.

For novice older adults, there is a significant effect of iteration on time ($\chi^2= 8.65$, $DF= 2$, $p\text{-value}= 0.01$) and no significant effects on errors ($\chi^2= 5.22$, $DF= 2$, $p\text{-value}= 0.07$). Novice older adults spent 14% less time on the second iteration and then 6% at the third iteration.

Evaluating each iteration series separately, there are significant differences between this two group of older users in time for the first ($Z= 10.16$, $r= 1.311048$, $W= 2294.5$, $p\text{-value}= 0.002$) and the second iteration ($Z= 9.31$, $r= 1.20$, $W= 2179$, $p\text{-value}= 0.02$). However, there is no significant difference between experienced and novice users on time at the third iteration ($Z= 9.01$, $r= 1.16$, $W= 2139$, $p\text{-value}= 0.03$).

There are no significant differences between this two group of older users in errors for the first ($Z= 7.12$, $r= 0.92$, $W= 1882$, $p\text{-value}= 0.41$), neither at the second ($Z= 6.89$, $r= 0.89$, $W= 1850.5$, $p\text{-value}= 0.51$) nor the third iteration ($Z= 6.91$, $r= 0.89$, $W= 1853.5$, $p\text{-value}= 0.50$).

This indicates a rapid appropriation of the interactive system and drag-and-drop on time of movement for novice older users. Values for time and errors for these groups of subjects are detailed on Table VII.26 and Table VII.27.

Table VII.26 Time (s) for groups of subjects by experience with touchscreen per iteration (medians and inter-quartiles)

Group	Time 1st	Time 2nd	Time 3rd
Experienced users	4.33 +/-2.46	4.29 +/-1.10	4.12 +/-1.12
Novice users	6.13 +/-2.88	5.25 +/-2.20	4.91 +/-1.80

Table VII.27 Errors for groups of subjects by experience with touchscreen per iteration (medians and inter-quartiles)

Group	Errors 1st	Errors 2nd	Errors 3rd
Experienced users	1.12 +/-0.90	0.91 +/-0.85	0.78 +/-0.62
Novice users	1.68 +/-1.84	1.22 +/-1.40	1.03 +/-1.11

VII.7.2.4 Discussion about iteration effects on interaction performances

Time of movement reduced across the three iterations for older adults and adults. Mean time of movement per target of adults reduced 17% between the first and the third iteration: 11% the second iteration and 6% the third iteration. Older adults, they spent 22% less time per target: 13% less between the first and the second iteration and 5% less between the second and the third iteration.

The accuracy of the gestures is improved only for older adults, who made 25% then 12% fewer errors of accuracy. Adults made the same mean number of errors of accuracy (0.53) during the first and the second iteration and 17% fewer errors between the second and the third iteration. They spent less time but made some more errors at the third iteration (17% faster but 10% less accurate).

Globally, the analysis of the effects of three iteration series confirms the rapid appropriation of tactile interaction for older adults. Mertens and Jochems (2010) have observed that older adults show better performances and stabilization after the 20th trial (Mertens and Jochems, 2010). Our results also confirm that the accuracy of drag-and-drop increases with practice (Kobayashi et al., 2011).

Across the iterations, adults and older adults executed significant shorter times but the accuracy is improved only for older adults, showing a rapid appropriation of drag-and-drop interaction for this group.

Evaluating the performances across iterations allow to assessing information about the appropriation of interaction. The appropriation is the process by which users adopt an interaction or an interactive system and adapt their abilities and experience in order to accomplish the interaction (Dourish, 2003). The effects of iterations on time show that novice older users appropriate tactile interaction rapidly, confirming the results of previous studies (Mertens and Jochems, 2010). The effects of experience of using touchscreen disappear at the third iteration. This demonstrated that novice older users acquire the same level of appropriation of experienced older users after more than 100 positioned targets.

VII.7.2.5 Postures of the hand

In the study described in Chapter V (p. 155), the devices were horizontally fixed on the desk and subjects were told to execute the gestures of interaction accurately but naturally. They were free to adapt their movements in order to accomplish interaction.

In the previous experiment, described in Chapter IV (p. 121), had showed a great variability on interaction performances of older subjects (time of movement and error rates). The present experiment allow us to state that the variability of performances is also observed on the variability of the positions of the wrist among the participants, adults and older, as well as the range of motions of the movements. This variability can be related to

- The six degrees of freedom of the movements of the wrist and the wrist position determined by the articular positions of the elbow, shoulder and trunk during the task;
- The individual adaptation of the users and the strategy of movements adopted for accomplishing the gestures of interaction, as already described on the results of the preliminary study (V.2);
- The parameters of the interactive system: in order to create an engaging activity, the initial positions of the puzzle pieces are randomly placed on the bottom of the screen;
- The position of the hands and the choice of the fingers used for dragging were not controlled. Across the interaction series, it has been observed that participants used mainly index finger but also middle finger. The positions of the hand were observed with open palm, parallel to the device, or closed fingers, which imply higher wrist elevation. Figure VII.8 illustrates some of the common hand positions observed during this experiment.

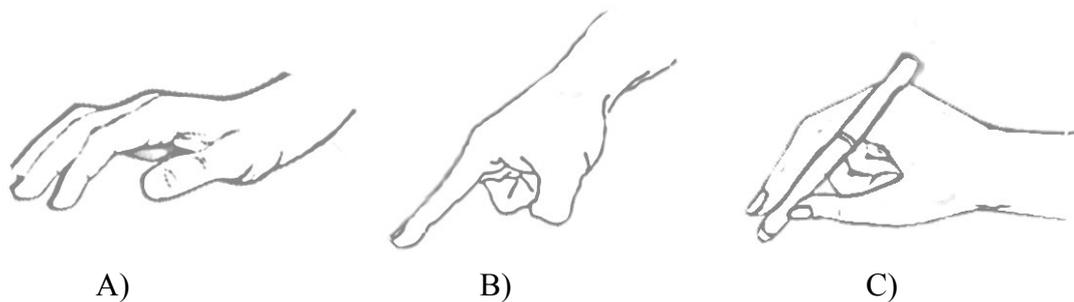


Figure VII.8 Hands positions observed during dragging: A) open hand touching with index or middle finger, B) closed hand touching with index finger, C) holding the pen

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Index of figures

Figure I.1 Example of tactile interaction on touchscreen: user interacting with pen on a tablet.....	17
Figure I.2 Example of tactile interaction on touchscreen: user interacting with finger on a smartphone.....	17
Figure I.3 World population aged 65 or older between 1950 and 2015 and estimative by 2060. In 2015, older population represents approximately 603,986 thousand people and this number is expected to increase in the next years.	21
Figure I.4 Populations aged 65 or older in France (red) and in Brazil (black) between 1950 and 2015 and estimative until 2060. In 2015, populations older than 64 represent approximately 12,171 thousand people in France and 16,330 thousand people in Brazil.....	21
Figure I.5 Percentage of French population according to four specific age groups (15 to 29, 30 to 44, 45 to 59 and 60 or older) and, for each group, percentage of people that had used mobile web in 2012 in France.....	22
Figure I.6 Percentage of Brazilian population according to four specific age groups (15 to 29, 30 to 44, 45 to 59 and 60 or older) and, for each group, percentage of people that had used mobile web in 2012.....	22
Figure III.1 One piece of the puzzle and the black border.	99
Figure III.2 Screenshot of the puzzle game at the initial state. The targets are randomly placed at the bottom and the grid with a watermark is displayed at the top.	99
Figure III.3 Screenshot showing an instance of the game.	99
Figure III.4 Picture: users interacting together. One user holds a tablet by the side on portrait mode and another user touches the screen with a middle finger.....	108
Figure III.5 Picture: one user holds a tablet by the side, but some devices have power and volume button at this emplacement. The user uses the middle finger to interact.....	108
Figure III.6 Picture: one user holds a smartphone on the hand and interacts with the index finger.....	108
Figure III.7 Picture: during a collaborative situation, one user shows the screen to the others and uses the small finger to interact. The device is hold by the bottom	108
Figure III.8 Picture: during an individual interaction, the tablet is placed on a desk and the user places the hands to avoid reflection of the light on the bright screen	108
Figure III.9 Picture: one user holds a smartphone with his left hand and his thumb touches the volume button	108

Figure III.10 Picture: the pen is laid down. The screen does not recognize the interaction	108
Figure III.11 Picture: the user holds the pen but interacts with her fingers.....	108
Figure III.12 Picture: the user touches a puzzle piece with index finger	109
Figure III.13 Picture: the user drags the piece to its corresponding position	109
Figure III.14 Picture: the user's hand (palm) touches the bottom of the screen and the pieces appears on this second touch emplacement	109
Figure III.15 Screenshot of an initial state of a puzzle game of the system Puzzle Touch after the modification of the parameters: multi-touch interaction and prioritization of interaction zones (puzzle pieces)	113
Figure III.16 Screenshot of an initial state of a puzzle game of the system Puzzle Touch highlighting the filtered zones (orange colored), where accidental touches does not interfere on the users' interaction	113
Figure IV.1 A screenshot of the system Puzzle Touch.....	124
Figure IV.2 Example of positioning: the piece is covering less than 95% of its emplacement and should be correctly positioned	124
Figure IV.3 Example of positioning:) the piece is covering at least 95% of its emplacement and the positioning is validated	124
Figure IV.4 Picture: older adult playing a tactile puzzle on a tablet during a recruitment meeting.....	125
Figure IV.5 Time of movement per target (s) according to the device and input modality for both accuracy requirements. Longer times of movement during finger interaction on tablet.....	132
Figure IV.6 Mean number of errors per target according to the device and input modality for both accuracy requirements. Bigger variability on error rates on smartphone and more errors during finger interaction.....	132
Figure IV.7 Time of movement per target (in seconds) according to the device, input modality and constraint of accuracy. Lower constraint of accuracy reduces time of movement during finger and pen interaction on smartphone and tablet.....	134
Figure IV.8 Mean number of errors per target according to the device, input modality and constraint of accuracy. Lower constraint of accuracy reduces number of errors during finger and pen interaction on smartphone and tablet.	134
Figure IV.9 Number of subjects according to their age range.....	135
Figure IV.10 Time of movement per target (in seconds) according to the age-groups. Time of movement increases with age but oldest group have bigger variability.	136

Figure IV.11 Mean number of errors per target according to the age-groups. Number of errors increases with age but oldest group have bigger variability.	136
Figure IV.12 Subjects with experience of using touchscreen spent shorter times of movement.....	137
Figure IV.13 Novice and experienced users were able to execute drag-and-drop interaction accurately.....	137
Figure IV.14 Subjects with experience of using computers spent shorter times of movement.....	137
Figure IV.15 Subjects with experience of using computers made fewer errors.....	137
Figure IV.16 Representation of areas of bigger density of unintentional touches during finger interaction on smartphone	141
Figure IV.17 Representation of areas of bigger density of unintentional touches during pen interaction on smartphone	141
Figure IV.18 Representation of areas of bigger density of unintentional touches during finger interaction on tablet.....	141
Figure IV.19 Representation of areas of bigger density of unintentional touches during pen interaction on smartphone	141
Figure V.1 Screenshot of an instance of the game set for nine puzzle pieces on smartphone.....	159
Figure V.2 Screenshot of an instance of the game set for sixteen puzzle pieces on smartphone.....	159
Figure V.3 Picture: equipment for motion capture, pan from the subject's position.....	160
Figure V.4 Illustration of the reflective markers positions.....	163
Figure V.5 Picture: initial and final position of the subject for the experiment, with the arms resting on the desk.....	164
Figure V.6 Picture: position of the subject during pen interaction with a tablet, horizontally fixed on the desk.....	164
Figure V.7 Illustration of reconstruction of body segments according to the emplacement of the markers on the subjects' body	164
Figure V.8 Detail (zoom) on the markers placed on subjects' wrist and hand (right side)	164
Figure V.9 Illustration: radial deviation (adapted from ISO 9241-400:2007).....	166
Figure V.10 Illustration: ulnar deviation (adapted from ISO 9241-400:2007)	166
Figure V.11 Representation of the orientation of the hand and device for the estimative of radial-ulnar angular deviation of the wrist.....	166

Figure V.12 Illustration: flexion (adapted from ISO 9241-400:2007)	167
Figure V.13 Illustration: extension (adapted from ISO 9241-400:2007)	167
Figure V.14 Representation of the orientation of the hand and the device for the estimative of the flexion-extension angular deviation of the wrist.....	167
Figure V.15 Illustration: supination (adapted from ISO 9241-400:2007).....	168
Figure V.16 Illustration: pronation (adapted from ISO 9241-400:2007)	168
Figure V.17 Representation of the orientation of the hand and the device for the estimative of the pronation-supination angular deviation of the wrist	168
Figure V.18 Illustration: dorsal view of the right hand and emplacement of reflective markers used for estimating elevation and articular angles of the wrist (adapted from ISO 9241-400:2007)	170
Figure V.19 Representation of the experimental setup for the analysis of the movements of the wrist during interaction with touchscreen devices.....	171
Figure V.20 3D representation of device and hands markers positions and orientation .	171
Figure V.21 Representation of wrist trajectory on Z axis (elevation). Peaks have been identified on filtered signal and start and end positions defined after first valley and before las valley, respectively.....	175
Figure V.22 Representation of the wrist trajectory on 3D (X, Y, Z) for the task before clipping	176
Figure V.23 Representation of the wrist trajectory on 3D (X, Y, Z) for the task (filtered and clipped).....	176
Figure V.24 Representation of wrist trajectory on Z axis (elevation).....	177
Figure V.25 Representation of wrist radial-ulnar deviation angles through time	178
Figure V.26 Representation of the flexion-extension angular variations of the wrist through time	178
Figure V.27 Representation of the pronation-supination angular variations of the wrist through time	179
Figure V.28 Time of movement per target (s) for the two groups. Older adults spent longer times than adults.	184
Figure V.29 Number of errors per target. Older adults made more errors than adults.....	184
Figure V.30 Number of unintentional touches per target. Adults pratically did not touch outside interaction zones.....	184
Figure V.31 Mean radial deviation for the two groups. Older adults assumed increased radial deviated wrist postures compared to adults.	185

Figure V.32 Mean extension angles for the two groups. Older adults assumed increased extended postures of the wrist compared to adults.	185
Figure V.33 Mean pronation angles for the two groups. Older adults assumed reduced prone rotation angles compared to adults.	185
Figure V.34 Ranges of motion on radial-ulnar deviation for the two groups. Older adults executed greater ranges of motion.	186
Figure V.35 Ranges of motion on flexion-extension angles for the two groups. Older adults executed greater ranges of motion.	186
Figure V.36 Ranges of motion on pronation-supination angles for the two groups. Older adults executed greater ranges of motion.	186
Figure V.37 Time of movement per target (s) for the two groups of subjects on smartphone and on tablet. Adults spent longer times for positioning the targets on tablet.	190
Figure V.38 Number of errors per target for the two groups of subjects on smartphone and on tablet. Both groups made more errors on smartphone, where targets are smaller than those on tablet.	190
Figure V.39 Mean radial deviation of the wrist of older adults and adults for interaction on smartphone and tablet	191
Figure V.40 Mean extension angle of the wrist of older adults and adults for interaction on smartphone and tablet	191
Figure V.41 Mean pronation angles of the wrist of older adults and adults for interaction on smartphone and tablet	191
Figure V.42 Range of motion on RU deviation of the wrist of older adults and adults for interaction on smartphone and tablet	191
Figure V.43 Range of motion on FE of the wrist of older adults and adults for interaction on smartphone and tablet	191
Figure V.44 Range of motion on PS of the wrist of older adults and adults for interaction on smartphone and tablet	191
Figure V.45 Mean wrist elevation (mm) for the two groups of subjects on smartphone and tablet. Mean wrist elevation is higher during interaction on tablet.	192
Figure V.46 Range of motion of wrist elevation (mm) for the two groups of subjects on smartphone and tablet. The range of motion increased during interaction on tablet. .	192
Figure V.47 Time of movement per target (s) for the two groups for finger and pen interaction. Both groups spent shorter times during pen interaction.	194

Figure V.48 Number of errors per target for the two groups of subjects for finger and pen interaction. Older adults made fewer errors using a pen.	194
Figure V.49 Number of unintentional touches per target for the two groups of subjects. Both groups made fewer unintentional touches using a pen.....	194
Figure V.50 Mean radial deviation of the wrist of older adults and adults for finger and pen interaction.....	195
Figure V.51 Mean flexion angle of the wrist of older adults and adults for finger and pen interaction	195
Figure V.52 Mean pronation angles of the wrist of older adults and adults for finger and pen interaction.....	195
Figure V.53 Range of motion on RU deviation of the wrist of older adults and adults for finger and pen interaction	195
Figure V.54 Range of motion on FE of the wrist of older adults and adults for finger and pen interaction.....	195
Figure V.55 Range of motion on PS of the wrist of older adults and adults for finger and pen interaction.....	195
Figure V.56 Mean wrist elevation (mm) for the two groups of subjects during finger and pen interaction.....	196
Figure V.57 Range of motion of wrist elevation (mm) for the two groups of subjects during finger and pen interaction.	196
Figure VII.1 Example of images for Color Perception test.....	231
Figure VII.2 Example of images for Central Vision Acuity test.....	232
Figure VII.3 Example of images for Contrast Sensitivity from Near test.....	232
Figure VII.4 Time of movement per target (s) for the two groups on smartphone and tablet, for large and small targets.	252
Figure VII.5 Number of errors per target for the two groups on smartphone and tablet, for large and small targets.	252
Figure VII.6 Range of motion (in angles) on radial-ulnar deviation, flexion-extension and pronation-supination of the wrist of older adults during interaction on smartphone with large and small targets. Sixteen small targets required greater ranges of motion for this group of users than nine large targets.	253
Figure VII.7 Range of motion (in angles) on radial-ulnar deviation, flexion-extension and pronation-supination of the wrist of older adults during interaction on tablet with large and small targets. Similarly to interaction on tablet, sixteen small targets required greater ranges of motion for this group of users than nine large targets.....	254

Figure VII.8 Hands positions observed during dragging: A) open hand touching with index or middle finger, B) closed hand touching with index finger, C) holding the pen 261

Index of tables

Table II.1 Factors determining the use of technologies for older adults	36
Table II.2 Recommendations for including older participants during the design and evaluation of interactive systems, interaction techniques and experimental studies in order to promote the use of technologies	47
Table II.3 HCI studies: Subjects' skills assessed for the experiments, assessment tests and inclusion criteria in the studies analyzed	49
Table II.4 HCI studies: Users' previous experience with ICTs and interactive technologies and the inclusion criteria adopted in the studies analyzed	50
Table II.5 HCI studies: Apparatus and configuration in the studies analyzed	53
Table II.6 HCI studies: Training tasks in the studies analyzed	54
Table II.7 HCI studies: Elementary tasks in the studies analyzed.....	55
Table II.8 HCI studies: Complex tasks in the studies analyzed	57
Table II.9 HCI studies: Main gestures of interaction in the studies analyzed	60
Table II.10 HCI studies: Kind of provided feedback in the studies analyzed	63
Table II.11 HCI studies: Evaluation criteria in the studies analyzed	64
Table II.12 HCI studies: Measures for time criteria in the studies analyzed.....	65
Table II.13 HCI studies: Measures for errors and typology in the studies analyzed.....	66
Table II.14 Specifications and recommendations for the design and evaluation of interactive systems in order to improve the usability of tactile interaction for older adults	70
Table II.15 Biomechanics studies: Population in the studies analyzed	75
Table II.16 Biomechanics studies: Apparatus and configuration in the studies analyzed.	76
Table II.17 Biomechanics studies: Tasks and interaction techniques in the studies analyzed	78
Table II.18 Biomechanics studies: Equipment employed in the studies analyzed	80
Table II.19 Biomechanics studies: Subjects instrumentation for assessing bodies' postures and movements in the studies analyzed	81
Table II.20 Specification and recommendations for the Biomechanics evaluation of tactile interaction of older adults	85
Table III.1 User requirements for the design of Puzzle Touch system	98
Table III.2 Options and default settings of the Puzzle Touch system	100
Table III.3 Settings of the interactive system for design evaluation	103
Table III.4 Subject's profiles	105

Table III.5 Strategies of interaction on touchscreen of older users observed in the present study.....	109
Table III.6 Common difficulties users find during interaction with touchscreen devices and tactile interaction, common errors that occur and proposals for solution	110
Table IV.1 Settings of the interactive system.....	123
Table IV.2 Subject's profiles.....	130
Table IV.3 Time and errors on both accuracy requirements for the different situations (medians and inter - quartiles)	133
Table IV.4 Time and errors on high and low accuracy levels according to age groups (medians and inter - quartiles)	138
Table IV.5 Time and errors during high and low accuracy levels according to the experience of using touchscreen (medians and inter - quartiles).....	139
Table IV.6 Time and errors during high and low accuracy levels according to the subjects' profiles: use of computer (medians and inter - quartiles)	139
Table IV.7 Number of unintentional touches per target for pen and finger interaction on smartphone and tablet (medians and inter - quartiles).....	140
Table V.1. Target sizes according to the screen sizes (tablet and smartphone)	158
Table V.2 Settings of the interactive system	158
Table V.3 Anatomical positions for reflective markers during motion capture	162
Table V.4 Emplacement of technical reflective markers during motion capture	162
Table V.5 Summary of dependent variables for performances and data distribution	174
Table V.6 Summary of dependent variables for analysis of postures of the wrist and data distribution	179
Table V.7 Summary of participants' characteristics (means and standard deviations)...	180
Table V.8 Subjects' profiles (A= Adults, B= Older adults).....	181
Table V.9 Interaction performances for older adults and adults (medians and inter-quartiles)	184
Table V.10. Results of Mann-Whitney test for significant differences in performances between the two groups	185
Table V.11 Angular deviations and ranges of motions of the wrist for older adults and adults (medians and inter-quartiles).....	186
Table V.12 Mean elevation of the wrist and range of motion for older adults and adults (cm) (medians and inter-quartiles).....	187
Table V.13. Results of Mann-Whitney test for significant differences in postures and movements of the wrist between the two groups.....	187

Table V.14 Spearman's coefficient of correlation between interaction performances and postures and movements of interaction for older adults	188
Table V.15 Spearman's coefficient of correlation between interaction performances and postures and movements of interaction for adults	189
Table V.16 Interaction performances on smartphone and tablet for groups of subjects (medians and inter-quartiles)	190
Table V.17. Results of Wilcoxon test for significant differences of screen sizes in interaction performances.....	190
Table V.18 Motion features on smartphone and tablet for groups of subjects (medians and inter-quartiles).....	191
Table V.19 Mean wrist elevation and range of motions on smartphone and tablet for groups of subjects (medians and inter-quartiles)	192
Table V.20. Results of Wilcoxon test for significant differences of screen sizes in postures and movements of the wrist	193
Table V.21 Performances with two input modalities for groups of subjects (medians and inter-quartiles).....	194
Table V.22. Results of Wilcoxon test for significant differences of input modalities in interaction performances.....	194
Table V.23 Motion features with two input modalities for groups of subjects (medians and inter-quartiles).....	196
Table V.24 Wrist elevation and range of motion with two input modalities for groups of subjects (medians and inter-quartiles)	196
Table V.25. Results of Wilcoxon test for significant differences of input modalities in postures and movements of the wrist.....	196
Table V.26 Interaction performances with two sizes of targets for groups of subjects on smartphone (medians and inter-quartiles).....	198
Table VII.1 Observation grid for the experimenter	227
Table VII.2 Images selected for the experimental study	237
Table VII.3 Effects of subjects' profiles on time and number of errors on high and low accuracy levels	239
Table VII. VII.4 Mean time per target and mean number of errors per target on high and low accuracy levels according to the subjects' profiles: sight (medians and inter-quartiles)	239

Table VII. VII.5 Mean time per target and mean number of errors per target on high and low accuracy levels according to the subjects' profiles: dexterity (medians and inter-quartiles)	239
Table VII.6 Preliminary study: Settings of the interactive system	240
Table VII.7 Preliminary study: Subject's profiles	242
Table VII.8 Results of Shapiro Wilk's test: P-values	247
Table VII.9 Interaction performances on different situations for groups of subjects on smartphone (medians).....	248
Table VII.10 Interaction performances on different situations for groups of subjects on tablet (medians).....	248
Table VII.11. Results of Friedman test for significant differences between the eight situations of the study in interaction performances	248
Table VII.12 Mean angles and range of motion on radial -ulnar deviation of the wrist for the different situations of the experiment (medians and inter-quartiles).....	249
Table VII.13 Mean angles and range of motion on flexion-extension of the wrist for the different situations of the experiment (medians and inter-quartiles).....	249
Table VII.14 Mean angles and range of motion on pronation-supination of the wrist for the different situations of the experiment (medians and inter-quartiles).....	250
Table VII.15 Mean wrist elevation and range of motions for the different situations of the experiment (medians and inter-quartiles)	250
Table VII.16. Results of Friedman test for significant differences between the eight situations of the study in postures and movements of the wrist	251
Table VII.17. Results of Wilcoxon test for significant differences of targets sizes in interaction performances during interaction on smartphone and tablet.....	253
Table VII.18 Motion features with two sizes of targets for groups of subjects on smartphone (medians and inter-quartiles).....	254
Table VII.19 Mean wrist elevation and range of motions with two sizes of targets for groups of subjects (medians and inter-quartiles).....	255
Table VII.20. Results of Wilcoxon test for significant differences of targets sizes in postures and movements of the wrist on smartphone	255
Table VII.21 Results of Wilcoxon test for significant differences of targets sizes in postures and movements of the wrist on tablet.....	255
Table VII.22 Time (s) for groups of subjects per iteration series (medians and inter-quartiles)	257
Table VII.23 Error for groups of subjects per iteration (medians and inter-quartiles)....	257

Table VII.24 Interaction performances for older subjects according to age-ranges (medians and inter-quartiles)	258
Table VII.25 Time (s) and errors for groups of subjects by experience with touchscreen (medians and inter-quartiles)	258
Table VII.26 Time (s) for groups of subjects by experience with touchscreen per iteration (medians and inter-quartiles)	259
Table VII.27 Errors for groups of subjects by experience with touchscreen per iteration (medians and inter-quartiles)	259

Attachment: Technical documentation of the system Puzzle Touch

VII.1. Design and development.....	286
VII.1.1. State-of the art on web accessibility guidelines	286
VII.1.2. Procedures for registering touch information with HTML5 and JavaScript.....	288
VII.1.3. Procedures for enabling tactile interaction on Puzzle Touch system..	290
VII.1.4. Description of the log files	292
VII.2. Future design of Puzzle Touch	294
VII.2.1. Proposal for future design: dynamical adaptation of the settings	294
VII.2.2. Specifications	296
VII.2.3. Adaptive settings	300
VII.3. References for the attachment.....	301

The thesis work described the first cycle of an iterative design method for the tactile interactive system Puzzle Touch. The results of his thesis work confirm the appropriateness of this interactive system to older adults and experimental studies. For this reason, Puzzle Touch could become a serious game for helping older users to learn tactile interaction.

The present documentation is divided into two main sections. The first details the development of the current version of Puzzle Touch. The second presents the specifications we propose for the future development of this interactive system.

VII.1. *Design and development*

The following sections describe the technical documentation for the present version of the interactive system. First, we present the analysis of the current mobile web accessibility guidelines and how they were considered during the design and development of the interactive system. Then, we detail the procedures for registering touch information and enabling tactile interaction. Next, we explain the collected data (log files). We hope this documentation would contribute to further experimental studies evaluating interaction of users with different profiles and touchscreen devices.

VII.1.1. *State-of the art on web accessibility guidelines*

For the design of the interactive system Puzzle Touch, we reviewed the standard of accessibility guidelines for web content, user agents and authoring tools are defined by the World Wide Web Consortium - W3C:

- The Web Accessibility Initiative –WAI and the Web Content Accessibility Guidelines – WCAG (<http://www.w3.org/TR/WCAG20/>)
- The Mobile Web Best Practices – MWBP (<http://www.w3.org/TR/mobile-bp/>), a specific WCAG covering web pages and applications so they can be accessed on mobile devices
- The Mobile Web Application Best Practices – MWABP (<http://www.w3.org/TR/mwabp/>)
- And the Accessible Rich Internet Applications Suite – ARIA (<http://www.w3.org/TR/wai-aria/>).

Table 1 presents a selection of the current guidelines directly related to our user requirements concerning the use of mobile touchscreen devices. The other guidelines have also been taken into account to the development of our web-application.

Table 1 Examples of accessibility guidelines from W3C MWBP, MWABP and WAI-ARIA concerning user requirements for the Puzzle Touch system

MWBP	MWABP	WAI-ARIA
<p>G8 Navigation: Provide consistent navigation mechanisms.</p> <p>G18 Clarity: Use clear and simple language</p> <p>G19 Limited: Limit content to what the user has requested.</p> <p>G20 Page size usable: Divide pages into usable but limited size portions.</p> <p>G22 Scrolling Limit scrolling to one direction, unless secondary scrolling cannot be avoided.</p> <p>G42 Style sheets use: Use style sheets to control layout and presentation, unless the device is known not to support them.</p> <p>G50 Error messages: Provide informative error messages and a means of navigating away from an error message back to useful information.</p> <p>G54: Minimize keystrokes: Keep the number of keystrokes to a minimum.</p>	<p>G2: Use appropriate client-side storage technologies for local data</p> <p>G5: Ensure the user is informed about use of personal and device information</p> <p>G13: Use background images inline in CSS style sheets</p> <p>G17: Keep DOM (Document Object Model) size reasonable</p> <p>G20: Design for multiple interaction methods</p> <p>G27: Use meta viewport element to identify desired screen size</p> <p>G31: Support a non-JavaScript variant if appropriate</p> <p>G32: Offer users a choice of interfaces</p> <p>AN1: Consider use of canvas element or SVG for dynamic graphics</p> <p>AN2: Inform the user about automatic network access</p> <p>AN3: Provide sufficient means to control automatic network access</p>	<p>GS1: Pick the widget type (role) from the WAI-ARIA taxonomy</p> <p>GS2: From the role, get the list of supported states and properties</p> <p>GS3: Establish the widget structure in the markup (parent/child)</p> <p>GS5: Establish keyboard navigation of the widget and plan for how it will be navigated to within the document</p> <p>GS9: Support basic accessibility, such as alternative text on images</p> <p>GS13: Test with user agent, assistive technology, and people with disabilities</p>

VII.1.2. *Procedures for registering touch information with HTML5 and JavaScript*

HTML5, CSS3, JavaScript, JQuery, and PHP provide all the functionalities for developing web based puzzle games supporting tactile interaction.

HTML (Hyper Text Markup Language) describes elements to be displayed on the web browser. The 5th edition of HTML includes semantic, attributes, multimedia and graphics elements and APIs (Application Programming Interfaces). For example, images are defined inside an attribute ``, `<canvas>` are used as a graphic container and `localStorage` is an API for store information within the browser.

CSS (Cascading Style Sheets) defines how the HTML elements will be displayed. The 3th edition includes modules for selecting elements, modifying values and properties as well as specifying user interfaces in order to adapt the content display to different media (*e.g.*, small screen sizes or portrait orientation).

JavaScript is a programming language adapted to control HTML DOM (Document Object Model) elements and events, generating interaction. Current versions of mobile browsers support touch events that can be detected by JavaScript such as:

- `Touchstart`: the user touches a DOM element
- `Touchmove`: the user maintains the touch and moves through the DOM element
- `Touchend`: the user lifts the touch of the screen, releasing the DOM element

Every point of contact detected on the screen generates a `Touch` object, whose properties are described in the following attributes:

- `Touch.identifier`: a unique identifier tracking the same contact point
- `Touch.screenX`: the X coordinate relative to the left edge of the screen
- `Touch.screenY`: the Y coordinate relative to the top of the screen
- `Touch.pageX`: the X coordinate relative to the left edge of the web page
- `Touch.pageY`: the Y coordinate relative to the top edge of the web page
- `Touch.target`: element on which the touch started

These attributes depend on the hardware and software features, versions and available tools. They can be completed by `Touch.clientX`, `Touch.clientY`, `Touch.radiusX`, `Touch.radiusY`, `Touch.rotationAngle` and `Touch.Force`.

Each touch object is included in an array, called `TouchList`, containing a length attribute and two methods, an identifier and an index:

- `TouchList.length`: the number of touch objects, corresponding to each point of contact
- `TouchList.IdentifiedTouch()`: returns the first item in the list matching the specified value
- `TouchList.item()` or `(touchList([x]))`: returns the object of the specified index

Each touch event has three properties:

- `Touchevent.touches`: a `TouchList` with all the touch objects describing current points of contact with the screen
- `Touchevent.targetTouches`: a `TouchList` with all the touch objects describing current points of contact with the screen that started on the same target and that are
- `Touchevent.changedTouches`: a `TouchList` with all the touch objects describing points of contact with the screen and their current state

Puzzle games are generated from the selected images displayed on the HTML DOM and following CSS style. Images had different colors (grayscale, soft colors chart or color photography) and represented different subjects (landscapes, portraits, statues, objects, maps). According to the defined options, images will be cut into specific number and sizes of pieces. For generating the pieces and create the interaction, we use JavaScript and JQuery, a JavaScript Library. The game play is made as a JQuery plugin. Therefore, games are loaded when one image is selected:

```
$(selector).jqpuzzletouch(options)
```

JQuery plugin architecture is based on Implicit Invocation: once it is initialized, controls and listeners are instantiated on the web browser ready to receive event notifications. Events can be the user's actions (*e.g.*, touch events) or systems features (*e.g.*, task completed). When the event notification is received, the system triggers the corresponding procedures.

Additionally our system will register all touch information so we can evaluate interaction. Some information will be registered on `localStorage` but there is a memory limit (about 5 Mo). For this reason, we also use PHP (Hypertext Preprocessor). It is an open source scripting language used to generate dynamic web content. PHP scripts

are executed on the server and they will be used to generate the log files. We can send data to a remote server via Wi-Fi connection. For more reliability, we transformed the mobile devices for the experimental studies in order to install a local server and storing log files directly on the devices.

VII.1.3. *Procedures for enabling tactile interaction on Puzzle Touch system*

A simple web page is designed to present the images and the options for the puzzle games. Once the user (or the experimenter) selects an image, the Puzzle Touch creates the game following the selected or default options. The image selected in the HTML DOM `` element is identified. The Puzzle Touch JQuery plugin will dynamically generates the puzzle pieces inside the `<canvas>` elements and they are displayed at the bottom of the screen. The user should move the pieces into their corresponding emplacement on the grid, displayed according to the visibility settings.

When the finger or the pen touches a piece, the `Touchstart` event is detected and generates a `Touch` object. If the `Touch.target` is a puzzle piece, the touched piece appears on the top of the others and it can be dragged. As long as the contact with the screen is maintained, this `Touch` object will be identified by its unique `Touch.identifier`.

If the point of contact is moved, a `Touchmove` event is detected and the puzzle piece's position will be actualized to follow the coordinates of the event (`Touch.pageX` and `Touch.pageY`).

When the finger or pen leaves the screen, a `Touchend` event is detected. The `Touch` object lost its corresponding `Touch.identifier`. If a puzzle piece was moving, it stops according to the last coordinates of the point of contact, it means the puzzle piece is dropped.

If the game is defined to be single-touch, `TouchList.length` is set to only accept one `Touch` object at a time. Otherwise, many puzzle pieces can be moved at the same time.

If the `Touchstart` event takes place outside a puzzle piece, the event is registered into the log file but there is no interaction with the user.

When the puzzle piece is dropped, the position of the piece is verified. If it is correctly placed on its corresponding emplacement of the grid, meeting the accuracy

requirements set for the game, the puzzle piece is fixed. The position will be adjusted if necessary to match exactly the corresponding emplacement. There is a visual feedback (flash effect) and the piece cannot be moved anymore.

If the piece is dropped elsewhere, it should be moved again until it is dropped on its corresponding target on the grid.

The game is over when all the pieces are correctly placed. A congratulations message appears on the screen.

The log files keep a track of all touch information on the screen. On each event detected, the system registers information about the game, its current state and the event itself. Based on log files, games can be replayed if necessary. At the end of the game, a summary of this information is also registered. The description of the data collected in the log files is presented on Table 2.

Table 2 Data collected in the log files of the Puzzle Touch system

Kind of registered data	Content
Game information	User identifier, device information, game options
Game play state	Positions and properties of the pieces
Touch event	Touchstart, Touchmove, Touchend
Touch information	Target, coordinates, timestamp
End of the game	Duration, number of moves, number of touches inside targets and the positions

VII.1.4. Description of the log files

VII.1.4.1 Log files content and description

Table 3 describes the content of a log file with the collected data for each puzzle game after event detection.

Table 3 Description of the content of a log file

Columns headings	Data type	Content
game_id	Text	Date and start time (converted into text)
log_index	Number	Number of the game on the same device
subject_id	Text	Subject Identification
age	Number	User age
gender	Text	F= female, M= male
nb_condition	Number	Condition id number
nb_iteration	Number	Iteration number
device	Number: 5 or 10	Screen size
input_tech	Text: pen or finger	Input technique
nb_pieces	Number: 12	Number of pieces for the puzzle
accuracy_req	Number: 1 to 99	Define the accuracy requirement
opacity_help	Number: 0 to 100	Opacity of the background
img_src	Text	Name of the image file
time	Time: (hh:mm:ss:000)	Elapsed time since the start time
row_nb	Number	0= columns headers, 1 to the end= row counting
event	Text	Kind of touch events registered
event_x	Number	X position of the touch event
event_y	Number	Y position of the touch event
radius_x	Number	Touch radius width
radius_y	Number	Touch radius height
force	Number: 0 to 1	Pressure (not available on every browser)
touch_id	Text	Target id and touch count (i.e., 1_1_3)
touches_length	Number	Number of concomitant touches
target_id	Text: piece id (0_0, 0_1...), no_piece or placed_piece	Target identification
target_left	Number	Target position X
target_top	Number	Target position Y
distance	Number	Distance of the trajectory in pixels
duration	Time	Duration of the movement

VII.1.4.2 Log table with summary of results at the end of a game

Table 4 describes the summary of results registered at the end of each game.

Table 4 Description of the content of the summary of results registered at the end of each game

Columns headings	Values	Content
game_id	Text	Date and start time (converted into text)
log_index	Number	Number of the game on the same device
total_rows	Number	Number of the rows for this log
subject_id	Text	Subject Identification
age	Number	User age
gender	Text	F= female, M= male
nb_condition	Number	Condition id number
nb_iteration	Number	Iteration number
device	Number: 5 or 10	Screen size
input_tech	Text: pen or finger	Input technique
nb_pieces	Number: 12	Number of pieces for the puzzle
accuracy_req	Number: 1 to 99	Define the accuracy requirement
opacity_help	Number: 0 to 100	Opacity of the background
img_src	Text	Name of the image file
total_distance	Number	Distance of all the trajectories in pixels
total_duration	Time	Duration of all contacts and movements
total_time	Time	Elapsed time for the whole game
nb_touches	Number	Total number of registered touches
nb_tgt_touches	Number	Total number of registered touches on pieces/targets
nb_no_tgt_touches	Number	Total number of registered touches outside pieces/targets
nb_placed_tgt_touches	Number	Total number of registered touches on already placed pieces/targets
nb_errors_placement	Number	Number of pieces placed on a bad emplacement on the grid
nb_errors_accuracy	Number	Number of times pieces were replaced before validation
nb_strategy_moves	Number	Number of touchend out of the grid

VII.2. *Future design of Puzzle Touch*

After the first cycle of design, results showed that the iterative design method described in this thesis work is important to identify and address some usability problems observed during interaction of older adults on touchscreen devices.

A second cycle of design could take place for improving user experience. The main advantage of touchscreen is the possibility of adapting graphical user interfaces and interaction techniques for supporting users with different abilities and special needs. A new version of Puzzle Touch should be dynamically modified to facilitate interaction or increase the challenge of the activity according to the results of the previous games. The following sections present our proposal and the specifications we elaborate for the future development of Puzzle Touch. Finally, we review the literature to propose support techniques that could facilitate drag-and-drop interaction for older adults and could be applied to the Puzzle Touch system.

VII.2.1. *Proposal for future design: dynamical adaptation of the settings*

Puzzle Touch could become a serious game for helping older users to learn tactile interaction. The future versions of the Puzzle Touch could dynamically adapt graphical elements (e.g. targets sizes, positions, colors) and settings related to the interaction technique (e.g. constraints of accuracy) according to the scores (time, error rates and number of unintentional touches on the screen) set by default or registered during the previous games.

An interesting example is the experiences of multi-layered interfaces, where novice older adults accede first to a reduced-functionality layer to perform basic tasks before progressing into an interface allow access to all the functionalities. This adaptation proposed by Leung *et al.* (2010) demonstrate positive effects on learnability (Leung *et al.*, 2010).

Hocine *et al.* (2015) developed a game adaptation technique that allows the generation of customized game levels aiming to dynamically adjust the difficulties of the game play to the user's abilities and performances (Hocine *et al.*, 2015). They proposed a series of questions related to the design of this adaptive system.

- **What is the objective of the adaptation technique?**
- **When are adaptation decisions made?**
- **What are the inputs for the adaptation process?**

- **What are the game elements affected by the adaptation process?**
- **What is the model used for adaptation?**

Serious games interfaces should be adaptive to respond to older user's special needs and support interaction (Ijsselsteijn et al., 2007). For this purpose, the system should be appropriate; it means we need to design intuitive systems and interactions helping the users to understand the effects of their actions, providing cues for correct or incorrect performances and recovering after undesirable actions are appropriate. Adapting the interfaces and /or the interaction techniques can be used to improve usability and accessibility for users with different skills as well as to encourage them to continue to use technologies for longer times. Besides, as emphasized by Dourish (2003): "People need to be able to understand how a system works in order to understand how to make it work for them. So, we need to allow them to see not just the opportunities for action (the affordances that characterize traditional user interface design), but also the consequences of those actions." (Dourish, 2003)

The main goal of the dynamic adaptation of the settings is to allow a better user experience based on the touch information that can be tracked and evaluated by the interactive system on touchscreen devices. To do so, based on the evaluation indexes elaborated in this thesis work, particularly the ratio between the number of errors of accuracy and the number of targets, we create an adaptive interactive system capable of adapting targets number and sizes, accuracy requirements and feedback in order to support older adults, users with low dexterity or novices users.

The diagram presented in Figure 1 illustrates the possibilities for adaptations of graphical interfaces and interaction for the tactile puzzle games.

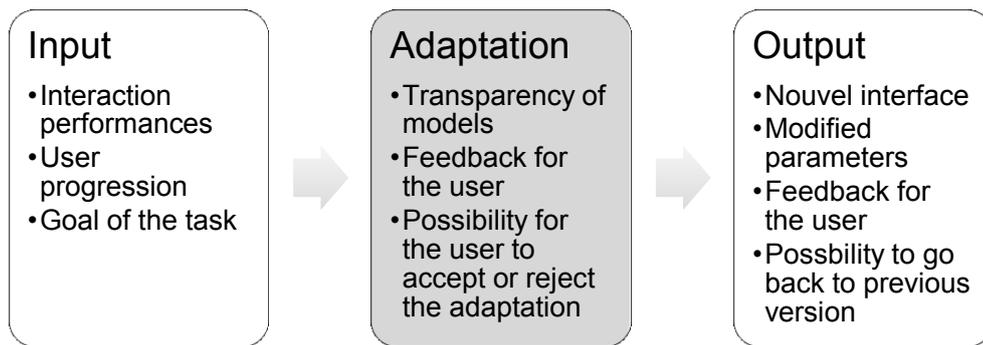


Figure 1 Possibilities to adaptable interfaces and interaction for tactile puzzle games

Additionally, usability testing should identify errors related to the devices and input modalities thereby solutions can be designed to help the users to recover from errors, *e.g.*, keep track of current interactions, get back to previous state, and automatically saving changes of the state of the system.

VII.2.2. *Specifications*

- Users: older adults, including
 - Novice or experienced users of touchscreen,
 - with normal or low dexterity because of age-related changes on muscular force and accuracy of movements, musculoskeletal disorders, past injuries affecting hands and upper-limb movements and/or tremor
 - with sufficient or insufficient eyesight correction
 - willing to learn and use tactile interaction
- Product: Puzzle Touch system
 - a series of tactile puzzle games
- Goals and applications:
 - Help novice users to learn tactile interaction, encourage and motivate users
 - Asses interaction information and provide data to interactive systems and interaction techniques in order to adapt interaction to the user's needs
 - Demonstrate the possibilities of adaptation to further applications
 - Facilitate social and cognitive stimulation through memorization and puzzle solving activities
- Functions and constraints related to the usage context:

- A1: Allow users with different profiles, abilities and special needs to accomplish the interaction
- B1: Fit to different screen sizes and orientation
- B2: Be usable on different devices and operating systems
- C1: Allow pen and finger interaction
- D1: Allow both individual and social interaction
- D2: Be usable with and without internet connection
- D3: Games can be played with devices on a desk, on the lap, in a case or handheld

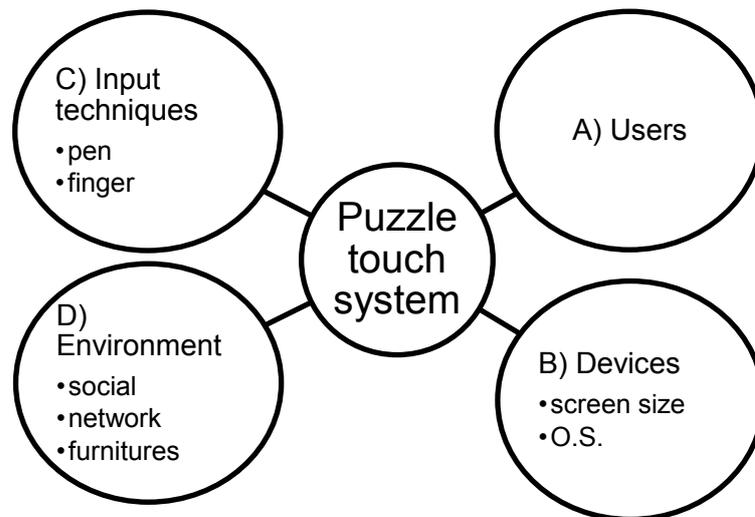


Figure 2 Functions and constraints related to elements outside the system

VII.2.2.1 *Game play*

- Initial screen
 - About the game
 - Textual description
 - Play!
 - If no ongoing game, show a list of images or selection (*)
 - Back button on the bottom or about/score options
 - If a game was paused, show dialog box: continue or restart
 - Once the image is selected:

- If no previous score: 12 pieces game, 80% accuracy
- Else: the game is set according to the previous score
- Score
 - Listing of main score: number of games accomplished, mean ratio time/number of targets, mean ratio number of errors of accuracy/number of targets, mean ratio number of errors of placement/number of targets, a graphic presenting the evolution across the iteration
 - Back button on the bottom or about/score options
 - Erase button
-
- Game screen
 - Set the game play according to previous score
 - Display grid of targets on top
 - Display puzzle pieces on random order on the bottom of the grid
 - The user should drag the pieces and drop on their corresponding target on the grid
 - The game is over when all the pieces are correctly placed
 - A congratulation message appears
 - Display current settings
 - Show score
 - Propose game adaptation on dialog box
 - If accepted, the settings will be automatically adjusted
 - If no, current settings will be kept
 - Show list of images (*)

VII.2.2.2 Requirements

Requirements for the new version of the Puzzle Touch system are described in Table 5..

Table 5 Requirements for the new version of the Puzzle Touch system

Type	Specification	Mandatory
Graphical	Size and number of the targets can be initially set by the user	Open
Graphical	Size and number of the targets adjusted according to previous results, but demand	Closed

	confirmation	
Graphical	Block the limitations of the game play zone, i. e. the puzzle pieces cannot exceed the game play zone	
Support	Adaptation of: <ul style="list-style-type: none"> • Number and size of targets • Accuracy requirements 	Closed
Support	Adaptation of: <ul style="list-style-type: none"> • Piece position for touch offset according to target position • Color balance • Contrast 	Open
Feedback	Highlighting selected case before dropping	Open
Feedback	Highlighting selected puzzle piece before dragging	Open
Feedback	Display performance information and scores	Open
Feedback	Display accidental touches positions	Open
Technical	Assessing private pictures for puzzle games (require O.S. permission and privacy policy)	Open
Technical	Keep targets and pieces positions so the user can pause the game and continue later	Closed
Technical	Register three past games for define game adaptation	Closed
Technical	Keep settings from previous games for adapting the next game to the user's personal needs	Closed
Technical	Create a homepage, including <ul style="list-style-type: none"> • Presentation • Settings • History and scores 	Closed
Technical	Add a function to set games by default <ul style="list-style-type: none"> • 12 medium targets • 80 % accuracy requirements 	Closed
Technical	Add a function to erase history and scores	Closed

VII.2.3. *Adaptive settings*

First game: 12 targets, 80% accuracy requirement

Calculate First_REA

If First_REA \geq 2

Propose new settings:

- 9 targets
- 60% accuracy
- Or keep settings

If First_REA $<$ 2

Propose new settings:

- 16 targets
- 95% accuracy
- Or keep settings

2nd iteration: user-defined settings

Calculate Second_REA

If Second_REA \geq First_REA

Propose new settings:

- 9 targets
- 60% accuracy
- Or keep settings

If Second_REA $<$ First_REA

Propose new settings:

- 16 targets
- 95% accuracy
- Or keep settings

3rd iteration: user-defined settings

Calculate Third_REA

Calculate Referential_REA

If Third_REA \geq Second_REA

Propose new settings:

- 9 targets
- 60% accuracy
- Or keep settings

If Third_REA $<$ Second_REA

Propose new settings:

- 16 targets
- 95% accuracy
- Or keep settings

Following iterations: user-defined settings

Calculate Last_REA

Re-calculate Referential_REA

If Last_REA \geq Referential_REA

Propose new settings:

- 9 or 12 targets
- 60 to 80 % accuracy
- Or keep settings

If Last_REA $<$ Referential_REA

Propose new settings:

- 12 to 16 targets
- 80 to 95% accuracy
- Or keep settings

VII.3. *References for the attachment*

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