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HUMAN FACTORS AND PSYCHOSOCIAL CHALLENGES IN THE DESIGN AND USE OF ASSISTIVE TECHNOLOGY FOR OLDER ADULTS WITH COGNITIVE IMPAIRMENT

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FACTEURS HUMAINS ET DEFIS PSYCHOSOCIAUX DANS LA CONCEPTION ET UTILISATION DES TECHNOLOGIES D'ASSISTANCE DESTINEES AUX PERSONNES AGEES PRESENTANT DES TROUBLES COGNITIFS

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Abstract

Technology-based products and services are increasingly used to meet the needs of older adults in terms of healthcare, safety, and autonomy. In addition, many forms of assistive technology to support people living with Alzheimer's disease in everyday life are either already on the market or undergoing testing within various research projects in Europe and worldwide. These recent trends explain the growing interest in human factors research in this area. So far, however, there has been little discussion about how theoretical models of disability, dementia care, and assistive technology might influence the choice of design approaches for the conception and development of these technological solutions. This is particularly critical when considering that assistive technology could represent the most cost-effective way of dealing with the pressing demand for home care that results from the rising number of older adults living with dementia. The present work investigates the design and development lifecycle of assistive technology for older adults with mild cognitive impairment or Alzheimer's disease from a human factors and psychosocial perspective. As part of this thesis, a series of studies corresponding to the different phases of the design and development cycle were carried out: (1) *Gathering user needs and requirements*: assessment of attitudes and opinions of older adults towards social assistive robots, (2) *Product assessment:* usability testing of two software applications for an assistive robot for older adults with cognitive impairment, (3) *Iterative product development and assessment:* iterative design and usability testing of a software application for cognitive training for older adults with cognitive impairment, (4) *Final product assessment:* literature review on the effectiveness of computer-based cognitive interventions for older adults, and (5) *Ethical analysis process*: analysis of ethical issues related to the design and use of assistive technology for older adults with cognitive impairment and the advantages of living lab methodologies in this context. After highlighting key findings and limitations for each study, some recommendations for the design and evaluation of these technological solutions are provided. Finally, based on the overall analysis of these results we discuss our two main theoretical contributions: first, an extension of the *Comprehensive Assistive Technology* model (CAT) proposed by Hersh & Johnson (2008a) for its use in the context of dementia, and second, a conceptual network to analyze the relationship existing between the concepts of disability, dementia, dementia care, assistive technology, and the choice of design approaches for the development of assistive technologies in this area.

Key words: Aging, cognitive impairment, assistive technology, design lifecycle, human factors/ergonomics, psychosocial approaches

Résumé

L'utilisation des Technologies de l'information et de la Communication pour favoriser l'autonomie et la qualité de vie des personnes âgées a pris une importance grandissante dans les dernières années. De plus, de très nombreuses technologies d'assistance qui ciblent particulièrement les personnes âgées présentant une maladie d'Alzheimer ou apparentée sont déjà sur le marché ou font l'objet de différents projets de recherche en Europe et dans le monde. Ces tendances expliquent l'intérêt qui est actuellement accordé à l'étude des facteurs humains dans ce domaine. Néanmoins, peu de travaux ont abordé la façon dont les modèles du handicap, de la prise en charge de la démence et des technologies d'assistance peuvent influencer le choix des méthodes pour la conception de ces solutions technologiques. Ce point est particulièrement critique si l'on considère que les technologies d'assistance représentent potentiellement la piste la plus prometteuse pour répondre dans des coûts accessibles à la demande grandissante de solutions permettant aux personnes atteintes de cette maladie de rester au domicile le plus longtemps possible. Ce travail de thèse porte donc sur l'étude du cycle de conception et de développement des technologies d'assistance pour des personnes âgées atteintes de troubles cognitifs légers ou de la maladie d'Alzheimer dans une perspective psychosociale. Dans le cadre de ce projet, plusieurs études correspondant aux différentes phases du cycle de design et développement ont été conduites: (1) *Recueil des besoins des utilisateurs :* évaluation des attitudes et des opinions des personnes âgées à l'égard des robots sociaux d'assistance, (2) *Evaluation du produit* : tests d'utilisabilité de deux applications logicielles pour un robot d'assistance destiné aux personnes âgées souffrant de troubles cognitifs, (3) *Evaluation du produit et développement itératif :* évaluation de l'utilisabilité et conception itérative d'un logiciel d'entraînement cognitif pour des personnes âgées souffrant de troubles cognitifs, (4) *Evaluation du produit final :* revue de la littérature sur l'efficacité des interventions cognitives informatisées chez des personnes âgées, et (5) *Démarche d'analyse éthique :* analyse des questions éthiques liées à la conception et à l'utilisation des technologies d'assistance pour des personnes âgées souffrant de la maladie d'Alzheimer, et discussion sur les avantages de la méthodologie du living lab dans ce contexte. Après en avoir restitué les principaux résultats et discuté les limites, une série de recommandations pour la conception et l'évaluation de ces solutions technologiques est présentée. Enfin, en s'appuyant sur l'analyse générale de nos résultats nous discutons nos deux contributions principales. D'une part, la proposition d'une extension du modèle Compréhensif de Technologies d'Assistance (CAT) proposé par Hersh & Johnson (2008a) pour une utilisation dans le cadre de la prise en charge de la démence. D'autre part, la suggestion d'un réseau conceptuel pour analyser la relation qui existe entre les concepts de handicap, de démence, de la prise en charge de la démence et des technologies d'assistance, et le choix des méthodes de conception pour le développement de technologies d'assistance dans ce contexte.

Mots-clés: vieillissement, troubles cognitifs, technologies d'assistance, cycle de conception et développement, approches psychosociales

Preface

This dissertation, "Human Factors and Psychosocial Challenges in the Design and Use of Assistive Technology for Older Adults with Cognitive Impairment", sets out to explore human factors issues related to the design and assessment of assistive technology for older adults with cognitive impairment within a psychosocial perspective. A set of empirical studies involving elderly with cognitive impairment, and their caregivers, illustrates the different phases of user research. Furthermore, we review existing disability, dementia care, and assistive technology models with the aim of discussing the specificities of providing support through technological systems when dealing with a progressive disability such as Alzheimer's disease.

All the studies reported in this dissertation were carried out at LUSAGE, a living lab specialized in older adults with cognitive impairment. These experiences were conducted under the supervision of Pr. François Jouen (EPHE) and the co-supervision of Pr. Anne Sophie Rigaud, head of department of the Geriatrics Department at Broca Hospital (APHP, University Paris Descartes).

This research was supported by the following research projects conducted at LUSAGE, Companionable (FP7, 2008-2012), QuoVADIS (ANR 2008-2011), PRAMAD (2011-2013), LUSAGE (France Alzheimer, 2009-2011) and by a doctoral grant from the Fundation Médéric Alzheimer, Paris (2009-2011).

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From the Broca hospital I want to thank also Jocelyne de Rotrou for her support and encouragement in the initial steps of this project. Further, it is a great pleasure to thank all my colleagues LUSAGE team, in particular Mélodie Boulay and Jean-Sébastien Vidal, for their contributions in the conducting of the experiments and for their support during these last months. I would also like to express my sincere thanks to all the persons, patients from Broca Hospital and families that took part in the studies conducted within this thesis project. Thank you for the generosity with which you shared your experiences.

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Least but not last, I would like to thank my parents Rosa Elena and Ramon Elias, and my dearest sister and brothers for their support and encouragement during all these years. I dedicate this work to the memory of my dad who would have been very proud and happy to see that I have reached the end of this journey.

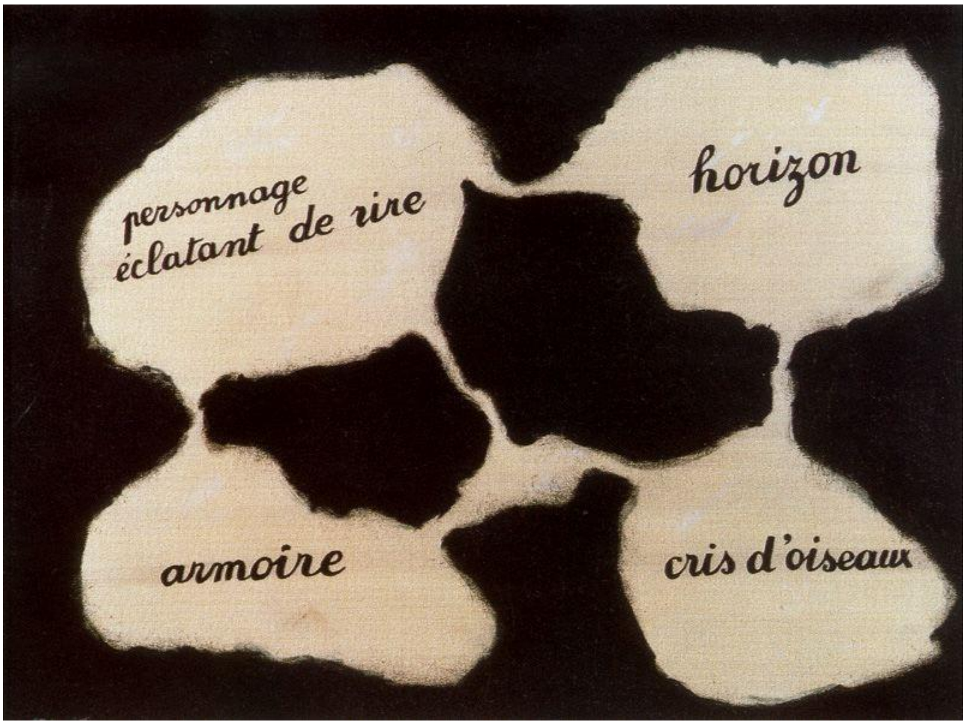
"It is obvious that the memory loss and the spatial temporal alterations in dementia detach the self from the past and isolate it in the limited time of the present, without further perspectives for the future.

However, we do not know the dimensions of the interior aspect of time, the subjective personal time in patients who suffer from dementia, which may play an important role in the sense of duration and integration of the self"

Stavros J. Baloyannis
The Philosophy of Dementia (2010)

"*One can travel the world and see nothing. To achieve understanding it is necessary not to see many things, but to look hard at what you do see"*

Girorgio Morandi



Le miroir vivant (The Living Mirror)
René Magritte (1928)

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Acronymes

AD	Alzheimer’s disease
ADI	Alzheimer’s Disease International
ADL	Activities of Daily Living
aMCI	amnestic Mild Cognitive Impairment
AT	Assistive Technology
CAT	Comprehensive Assistive Technology (model)
GUI	Graphical User Interface
GT	Gerontechnology
HAAT	Human Activity Assistive Technology (model)
HF/E	Human factors/ergonomics
IADL	Instrumental Activities of Daily Living
IEA	International Ergonomics Association
ICF	International Classification of Functioning, Disability and Health
ICT	Information and Communication Technology
ISO	International Organization for Standardization
IT	Information Technology
MCI	Mild Cognitive Impairment
na-MCI	non amnestic Mild Cognitive Impairment
NIA	National Institut on Aging
NHP	Nursing Home Placement
OCDE	Organization for Economic Co-operation and Development
SAR	Socially Assistive Robotics
UN	United Nations
WHO	World Health Organization

1 INTRODUCTION

1.1 Motivation

Information and Communication Technologies (ICT) surround us. Internet is omnipresent, network and sensors systems, mobile phones, instant messaging, social networks, and many others ICT based systems are part of everyday life. Wearable computing devices can follow people everywhere they go. Objects can communicate between themselves and gather data about different events. Context-awareness technologies allow us to locate and track objects and human beings, to predict some of our behaviors, and offer us individualized services satisfying our needs, personality, and preferences. Information can be shared almost instantaneously around the world contributing to a feeling of global connectedness. Intelligent environments and robotic systems are no longer part of a science-fiction universe. Indeed, these systems are gradually entering our homes and personal lives. In summary, new technologies are transforming the way we communicate and participate in society.

Working with older adults who have Alzheimer's disease (AD), or any other dementia, can give the feeling that this population is not part of the global connectedness and that it is not at speed with the world, especially with regard to information processing. This perception is clearly influenced by the age of the patients, their memory loss, poor communication skills, and reduced mobility, as well as their generally slower pace of life. In most cases, persons with AD can cope with one thing at a time, and live within the limits of the present moment. This kind of environment is not one in which society conceives recent advances in ICT as playing a significant role. Furthermore, the general opinion is that elderly individuals will hardly be interested in looking for support in high-tech solutions because of their limited experience with technology.

However, governments, along with health professionals and employees of the private sector are turning to technology to find alternative methods to deal with the increasing need for healthcare due to aging demographics[1]. From this context, an important question arises: *how should assistive technology be conceived and implemented successfully and ethically, while addressing the unique challenges of older adults living with a progressive condition such as AD?* This topic is profoundly interesting and challenging, and is at the center of this work.

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[1] For an analysis from the European Commission about assistive technologies industry in Europe see Stack et al. (2009)

Assistive Technology (AT) has the potential to promote autonomy, quality of life, and social participation of older adults with cognitive impairment, for example related to dementia. In addition, AT devices and services, offer several opportunities to assist caregivers with tasks related to the managing of the person with cognitive impairment. By doing so, AT can help to diminish caregivers' workload and relieve their stress. The increasing number of research and development projects conducted on AT provides compelling evidence for its importance. Many persons with cognitive impairment and their caregivers are eager to participate in the design of AT solutions and to use them in their daily lives. Besides, interest in AT concerns many stakeholders: potential primary users (i.e., care recipients and caregivers), health professionals, academic researchers, entrepreneurs, and decision makers. The issue also generates debate in the medical, psychosocial, ethical, political, and economic fields.

Over the last years, a reasonable number of exploratory studies on AT for older adults with cognitive impairment has been conducted. These studies were primarily concerned with the assessment of users' needs and usability of advanced AT prototypes. Most of them have been carried out in laboratory settings showing encouraging results. However, several limitations that require further examination have been identified: usability, acceptance, and usefulness for people with dementia are not always clear or have not been studied, long-term adherence, AT prescription, follow-up procedures, and ethical and societal issues. This thesis project aims to address some of these topics from a Human Factors/Ergonomics (HF/E) perspective. Therefore, this works covers traditional HF/E areas, such as the study of users' abilities, limitations, and the demands placed upon them when interacting with AT devices, as well as acceptance issues, in particular, the attitudes and expectations of elderly persons with cognitive impairment and their caregivers towards the use of AT. The theoretical models predominant in the area of disability, dementia care, and AT, and their influence on the choice of a design approach for the conception and development of AT products are also examined.

This thesis presents an innovative and valuable perspective on AT. Its major contribution lies in the adoption of a global perspective on the entire process of design, development, and assessment of AT solutions for older adults with cognitive impairment. As part of this thesis, a series of studies, corresponding to different phases of the lifecycle of product design, were carried out (Figure 1). In this sense, this work contributes to a broader reflection on the AT design process and the conceptual framework that underpins it. Instead of using an analytical approach that breaks the research problem into smaller parts, this thesis looks at the "big picture". Focusing on the process also permits to consider AT solutions as a system and allows closer examination of the interactions between its components. It is hoped that this comprehensive view will be useful for designers, health professionals, and all the different actors seeking to have a better understanding of the psychosocial challenges raised by the design and implemention of AT products and services for elderly people with AD and their caregivers.

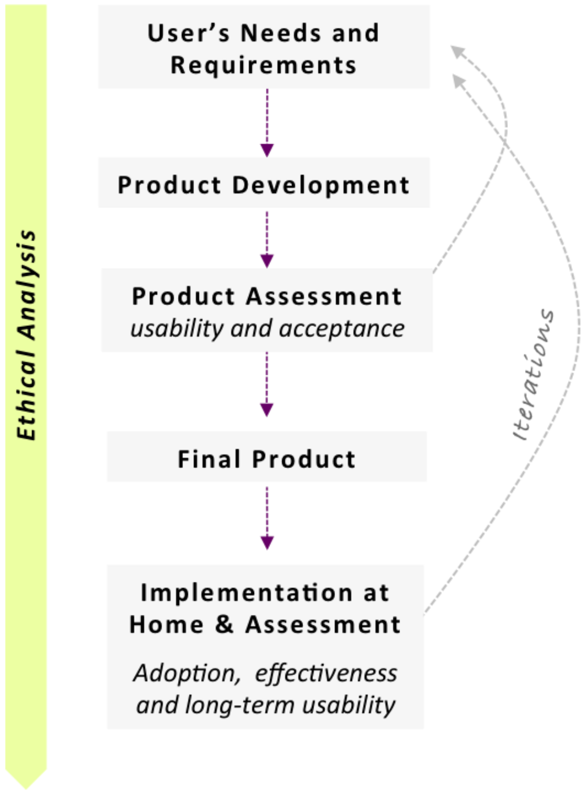

Figure 1 AT design, development, and implementation cycle

1.2 General Framework

Technological applications are increasingly used in healthcare. For instance, in the field of geriatrics, Information and Communication Technology (ICT) offers several opportunities for supporting older adults with cognitive impairment and their caregivers. In this context, a number of devices and services that fall under the category of AT (e.g., telehealth, memory support devices, locomotion sensors, social assistive robots, etc.) are commercially available or under development. The first aim of AT solutions is to help older adults achieve greater independence and quality of life by supporting their cognitive, functional, and social abilities. AT has also the potential to help formal and informal caregivers better cope with the caregiving situation. From a societal perspective, health-enabling and AT represent an interesting alternative to deal with the increasing number of elderly people with disabilities resulting from an aging population.

However, even if it is a rapidly growing area, the use of AT to support older adults with cognitive impairment remains a relatively recent field of research. Indeed, despite the advantages that AT offers, many questions related to its development and implementation merit further consideration, such as:

a) Which are the underlying concepts of disability, dementia care, and AT that support AT solutions?

b) Which are the most suitable design approaches and methods for involving end-users in the design and development process?

c) How to implement and assess AT solutions in the context of AD, taking into consideration some particular features of this condition, such as its progressive nature, the interaction between preserved and impaired capacities, the high inter- and intraindividual variability observed among individuals with AD, and the important role played by informal caregivers?

d) Which are the best predictors of compliance with AT and how to ensure long-term adherence?

e) How to balance interests among the different stakeholders (end-users, health professionals, policy makers, etc.) and create acceptable production and distribution strategies of AT?

All these factors mentioned above are considered to establish the framework of this thesis. This project intends to provide empirical evidence of how traditional HF/E methods can be adapted to the field of AT for elderly people with cognitive impairment. The possible application of existing AT models in the context of dementia care, ethical and societal issues related to the design and use of AT, and the advantages of using living lab methods for this endeavor are also discussed in this document.

1.3 Research Goals

The general objectives of this thesis are:

- To present an overview of the use of AT to support elderly people with Mild Cognitive Impairment (MCI), AD, and their caregivers.

- To illustrate the different stages of the AT design and development cycle (Figure 1) for older adults with cognitive impairment and the most commonly used techniques (e.g., focus groups, questionnaires, user tests, final product assessment) with a number of studies.
- To discuss ethical and societal issues related to the use of AT in geriatric settings and the advantages and implications of using a living lab approach in this context.
- To examine the relationship existing between the models of disability, dementia care, AT systems, and design approaches used for developing AT products.
- To provide a set of recommendations for the execution of projects focused on the design and evaluation of AT for older adults with cognitive impairment.

1.4 Projects, Publications, and Communications

Studies reported in this dissertation are based on the following research projects carried out at LUSAGE:

- *Social assistive robotics:* Companionable (CE FP6 2008-2012); QuoVADis (ANR-TECSAN 2007-2011); PRAMAD (OSEO and Region Ile-de-France, 2011-2014).

- *Graphical user-interfaces:* Agenda and Shopping list applications, and cognitive training software PRIMO developed for the QuoVADis project (ANR-TECSAN 2007-2011).

- *Living Labs methodologies:* LUSAGE (France Alzheimer, 2009-2011), Working group of Living Labs for healthcare and autonomy, Minister of the Economy, Finances and Industry (France) (2011-2012), ENoLL labeling procedure (2012).

Publications and communications resulting from this thesis include:

Peer-reviewed journals

Pino, M., Cristancho-Lacroix V., Kerhervé H., et al. (2012). LUSAGE: An example of Living Lab in the gerontechnology field [In french]. *Les cahiers de l'année gérontologique*, 4(3), doi: 10.1007/s12612-012-0311-9

Pino, M., Granata, C., Legouverneur G., Boulay M., Rigaud, A.S. (2012) Assessing design features of a graphical user interface for a social assistive robot for older adults with cognitive impairment. *Gerontechnology,*11(2): 383; doi:10.4017/gt.2012.11.02.490.00

Granata, C., **Pino, M.**, Legouverneur G., Boulay M., Rigaud, A.S. (2012) Robot services for elderly with cognitive impairment: testing usability of graphical user interfaces with target end-users. *Technology and Healthcare. xxxxx. (accepted)*

Rigaud A.S., **Pino M.,** Wu Y.H., et al. (2011). Support for patients with Alzheimer's disease and their caregivers by gerontechnology. *Gériatrie et psychologie neuropsychiatrie du vieillissement,* 9, 91-100.

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Pino M., Boulay M., Legouverneur G., Wu Y.H., Cristancho-Lacroix V., Rigaud A.S. (2011). Assessing the uses of assistive technologies by elderly people with Alzheimer's disease. *Proceedings of the* ASSISTH'2011, Paris, France, 17-19 January.

Pino M., Boulay M., Faucounau V., Wu Y.H., Riguet M., & Rigaud A.S. (2009). Performing usability testing with older adults suffering from Alzheimer's disease: example of a software application for cognitive training. In Weghorn H., & Isaías, P., (Eds.), *Proceedings of the IADIS (International Association for Development of the Information Society) applied computing conference*, Rome, 11- 21 nov, 2009, (2)2, 303-307.

Book chapters

Pino, M., Boulay, M., Rigaud, A.S. (2012). "New technologies and non pharmacological interventions in Alzheimer's Disease" [In French, Nouvelles technologies et interventions non médicamenteuses dans la maladie d'Alzheimer : Quels enjeux éthiques ?] In, Gzil, F., Hirsch E., (eds). *Alzheimer, éthique et société* (pp. 489-506). Paris: érès.

Pino, M., Kerhervé, H., Legouverneur, G., Rigaud, A.S. (2012). "Gerontechnology and Alzheimer's Disease" [In French, Gérontechnologies et Maladie d'Alzheimer]. In, A. Michon, Dubois B., *Démences.* Collection Traité de Neurologie. Paris: Doin. (In press)

Conference abstracts (oral communications)

Pino, M., Boulay, M., Legouverneur, G., Wu, Y. H., Cristancho-Lacroix, V., & Rigaud, A.S. (2011). Assistive technologies for older adults with Alzheimer's disease: the LUSAGE user-lab experience. *Alzheimer's and Dementia,* 7(4), S442. doi:10.1016/j.jalz.2011.05.1282

Pino, M., Faucounau, V., Wu, Y. H. Boulay, M. et al. (2009). The LUSAGE Usability laboratory for elderly people with cognitive impairment. *Gerontechnology*, 8(3): 185.

Pino, M., Boulay, M., Faucounau, V., Wu, Y-H., & Rigaud, A.S. (2010). Usability assessment methodology for elderly people with cognitive impairment: the LUSAGE laboratory experience. *Gerontechnology,* 9(2): 347.

Pino, M., de Rotrou J., Jouen, F., Rigaud A.S. (2010). Spatial attention and eye movement behavior during visual task performance in early Alzheimer's disease. Contribution of eye tracking monitoring systems. *25th International Conference of Alzheimer's Disease International (ADI)*, Thésalonique, Greece, 9-12 March, 2010.

1.5 Thesis Organization

This thesis is structured as follows:

Chapter 2 presents the context of the dissertation within the broader literature on population aging, age and disability, cognitive impairment, and the use of AT to promote health, well-being, autonomy, and social inclusion among elderly individuals.

Chapter 3 provides an overview of the scope of human factors/ergonomics. It describes some of the key concepts of the discipline, the stages of the design and development product cycle, core methods in user-research, and design approaches. Some theoretical models for the description and evaluation of AT are also reviewed in this section.

Chapter 4 presents the results of five studies on AT for older adults with cognitive impairment and discusses main findings. Each study corresponds to a different phase of the design and development lifecycle (Figure 2). The first study focuses on the assessment of attitudes and opinions of older adults towards social assistive robotics (*User's needs and requirements phase*). The second study concerns usability testing of two software applications for an assistive robot for older adults with cognitive impairment (*Product assessment phase*). The third study presents iterative design and usability testing of a software application for cognitive training for older adults with cognitive impairment (*Product assessment and development phases*). The fourth study presents a literature review on the effectiveness of computer-based cognitive interventions for older adults (*Final product assessment phase*). The last study presents an analysis of ethical issues related to the design and implementation of AT products and services for older adults with cognitive impairment (*Ethical analysis process*).

Chapter 5 provides a general discussion on the use of AT models in the context of dementia care and suggests a conceptual network as a way of understanding the relationship between disability, dementia care and AT models, and suitable design approaches. This chapter also presents a recommendation summary for the execution of design projects focused on the development and assessment of AT solutions derived from the studies conducted within this thesis.

Chapter 6 presents the conclusions of this thesis, and recommendations for future work.

Figure 2 Studies conducted within this thesis and corresponding phases of AT design and development cycle

2 BACKGROUND: POPULATION AGING, DISABILITY AND ASSISTIVE TECHNOLOGY

This chapter examines background and context of the use of Assistive Technology (AT) to support older adults with cognitive impairment. Topics include socio-demographic data related to population aging and trends for the next decades, conceptual approaches for defining and measuring "old age" and life expectancy, and economic indicators for the prediction of disability. General issues related to health status and disability in later life, as well as common age-related conditions such as mild cognitive impairment (MCI) and Alzheimer's disease (AD), will be presented. In the final part of this section, non-pharmacological approaches for AD care will be briefly reviewed, with special emphasis on gerontechnology and AT.

2.1 Facing the Demographic Changes

Demographic dynamics have changed profoundly over recent decades. Low birth rates and improvement in longevity of life have resulted in population aging around the world. In this trend while the proportion of older adults (60 years old or over) increases, the proportion of children (15 years or less) declines (United Nations, 2009). In the developed regions of the world, the number of children dropped below that of elderly individuals in 1998. This process will occur in the entire world by 2045 (UN, 2009). On that account, the number of older adults will rise significantly compared to the number of people of working age.

The dynamics of population aging is expected to endure for the coming decades. In the Organization for Economic Co-operation and Development (OCDE) countries the share of individuals aged 65 years or older will double from 2000 to 2050 (Table 1). This means that by 2050, more than one person in four is expected to be 65 years and older (Lafortune & Balestat, 2007). In the process of population aging, the segment of "oldest-old" adults (aged 85 years or older) is expected to grow the fastest. This group will grow from 1.4% to 5.2% of the entire population in OECD countries, concerning primarily Japan (10.2 %) followed by Italy (7.9 %) and France (7.6 %). Nevertheless, it must be acknowledged that most demographic indicators define aging based on *chronological age*, a backward-looking measure of age. Analyses that use this measure, chronological age, categorize "older adults" all the individuals aged 65 or over, without taking into account changes observed over time in *life expectancy*[2]. Within this

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[2] Average number of years of life a person can expect to live at a certain age.

analysis a 60-year-old person in 1900 would behave similarly to a 60-year-old person today, whereas people today live longer and in healthier conditions (Lutz, Sanderson, & Scherbov, 2008)

Table 1 Share of the population aged 65 and 85 and over in OECD countries, 2000 to 2050

Country	**2000 % ≥ 65**	**2000 % ≥ 85**	**2005 % ≥ 65**	**2005 % ≥ 85**	**2030 % ≥ 65**	**2030 % ≥ 85**	**2050 % ≥ 65**	**2050 % ≥ 85**
Australia	12.4	1.3	13.1	1.5	22.2	3.2	27.7	5.7
Austria	15.4	1.8	16.2	1.6	23.4	3.4	27.4	5.8
Belgium	16.8	1.8	17.3	1.7	24.1	3.1	26.5	5.8
Canada	12.6	1.3	13.1	1.5	23.0	2.7	24.9	5.1
Czech Republic	13.8	1.2	14.1	0.9	22.7	2.7	31.2	5.2
Denmark	14.8	1.8	14.9	1.8	21.3	2.5	22.2	3.7
Finland	14.9	1.5	15.9	1.6	26.0	3.2	27.1	5.5
France	**16.1**	**2.1**	**16.6**	**1.9**	**25.1**	**3.8**	**29.2**	**7.6**
Germany	16.4	2.0	18.8	1.7	26.3	3.9	29.6	6.5
Greece	16.6	1.3	18.3	1.3	24.8	2.9	32.5	4.9
Hungary	15.1	1.3	15.7	1.2	21.5	2.6	26.9	3.5
Iceland	11.6	1.2	11.7	1.3	19.2	1.8	21.5	3.2
Ireland	11.2	1.0	11.2	1.1	18.5	2.2	26.3	4.4
Italy	18.3	2.1	19.7	2.1	27.3	4.7	33.7	7.9
Japan	17.3	1.8	20.2	2.3	31.8	7.4	39.6	10.2
Korea	7.2	0.4	9.0	0.5	23.1	2.5	34.4	7.0
Luxembourg	14.1	1.5	14.2	1.3	20.0	2.5	22.1	4.5
Mexico	4.8	0.4	5.3	0.4	11.7	1.2	21.1	2.8
Netherlands	13.6	1.4	14.1	1.5	22.4	2.3	21.8	3.7
New Zeland	11.8	1.2	12.1	1.4	21.9	3.1	26.2	6.3
Norway	15.2	1.9	14.7	2.1	20.6	2.6	23.2	4.5
Poland	12.2	0.9	13.2	0.9	22.7	2.3	29.6	5.1
Portugal	16.2	1.4	16.8	1.4	23.9	2.7	31.6	4.6
Slovak Republic	11.4	1.0	12.0	0.8	21.6	2.0	30.1	4.3
Spain	16.8	1.7	16.8	1.9	25.1	3.7	35.7	6.9
Sweden	17.3	2.3	17.3	2.5	22.8	3.5	23.6	4.5
Switzerland	15.3	2.0	15.9	2.0	24.2	3.9	27.9	6.8
Turkey	5.5	0.3	5.4	0.2	10.1	0.4	17.0	1.3
United Kingdom	15.8	1.9	16.0	2.0	22.5	3.7	25.3	6.0
United States	12.4	1.5	12.4	1.7	19.6	2.6	20.6	5.0
OCDE	**13.0**	**1.4**	**13.8**	**1.5**	**21.1**	**3.0**	**25.2**	**5.2**

Source: Edited from OECD (2007)

If policy makers focus on chronological age to define options to finance pensions and healthcare costs, old-age dependency would be at risk of overestimation. In order to provide more accurate estimations of the dependency ratio[3] Sanderson and Scherbov (2005, 2007) proposed two other forward-looking measures that include life expectancy as a variable: *prospective age* and *expected remaining years of life*. By using these measures, the proportion of older adults in the general population would not be calculated based on a fixed number of years lived, but on a fixed remaining life expectancy. Their analysis showed that the speed of aging will increase in the entire world over the coming decades, but at a slower pace of change than the one predicted when the life expectancy variable is not included. These new indicators permit a more precise estimation of the speed of population aging at a global level and to establish short and long-term policies to cope with it (Lutz et al., 2008).

2.1.1 Aging, Life Expectancy, and Functional Status

Population aging has important implications in many aspects of society: economy, politics, social affairs, public health, etc. The rapid growth of the “oldest-old” adults raises important questions concerning disability and long-term care needs. Indeed, living longer does not mean that extra years of life are always lived in good health. Consequently the concept of life expectancy must be carefully examined.

In 2004, life expectancy at birth for women was 81.1 years and 75 years for men from OECD countries. This means a gain of 10.1 years of life expectancy for women, and 9.4 years for men since 1960. Life expectancy at age 65 has also increased over the past decades, reaching 19.5 years for women, and 16.1 years for men in 2004 (Lafortune & Balestat, 2007). Countries with the highest life expectancy at age 65 were in 2004 Japan (23.3 years), followed by France, Australia and Switzerland (Table 2).

Table 2 Life expectancy at age 65, men and women in OECD countries, 1960 to 2004

Country	**Men**				**Women**			
	1960	**1980**	**2000**	**2004**	**1960**	**1980**	**2000**	**2004**
Australia	12.5	13.7	16.9	**17.8**	15.6	17.9	20.4	**21.1**
Austria	12	12.9	16	16.9	14.7	16.3	19.4	20.3
Belgium	12.4	13	15.5	15.8	14.8	16.9	19.5	19.7
Canada	13.5	14.5	16.8	17.4	16.1	18.9	20.4	20.8
Czech Republic	12.5	11.2	13.7	13.9	14.5	14.3	17.1	17.3

[3] This indicator is defined as the projected number of persons aged 65 and over expressed as a percentage of the projected number of persons aged between 15 and 64 (EUROSTAT)

Country	Men				Women			
	1960	**1980**	**2000**	**2004**	**1960**	**1980**	**2000**	**2004**
Denmark	13.7	13.6	15.2	15.5	15.3	17.6	18.3	18.6
Finland	11.5	12.5	15.5	15.8	13.7	16.5	19.3	19.6
France	**12.5**	**13.6**	**16.7**	**17.1**	**15.6**	**18.2**	**21.2**	**21.4**
Germany	12.4	13	15.7	16.1	14.6	16.7	19.4	19.6
Greece	13.4	14.6	16.3	16.8	14.6	16.8	18.3	18.9
Hungary	12.3	11.6	12.7	13.1	13.8	14.6	16.5	16.9
Iceland	15	15.8	18.1	17.9	16.8	19.1	19.7	20.5
Ireland	12.6	12.6	14.6	15.7	14.4	15.7	17.8	18.9
Italy	13.4	13.3	16.5	16.7	15.3	17.1	20.4	20.7
Japan	11.6	14.6	17.5	**18.2**	14.1	17.7	22.4	**23.3**
Korea	--	10.4	14.1	15.1	--	15.1	18	19
Luxembourg	12.5	12.3	15.5	15.5	14.5	16	19.7	19
Mexico	14.2	15.4	16.8	17.1	14.6	17	18.3	18.6
Netherlands	13.9	13.7	15.3	16.3	15.3	18	19.2	19.8
New Zeland	13	13.2	16.7	17.1	15.6	17	20	20.1
Norway	14.5	14.3	16	16.7	16	18	19.7	20.1
Poland	12.7	12	13.6	14.2	14.9	15.5	17.3	18.4
Portugal	13	12.9	15.3	15.6	15.3	16.5	18.7	18.9
Slovak Republic	13.2	12.3	12.9	13.3	14.6	15.4	16.5	16.9
Spain	13.1	14.8	16.6	16.8	15.3	17.9	20.4	20.7
Sweden	13.7	14.3	16.7	17.4	15.3	17.9	20	20.6
Switzerland	--	14.6	16.9	**17.5**	--	18.3	20.7	**21**
Turkey	11.2	11.7	12.9	13.1	12.1	12.8	14.6	14.9
United Kingdom	11.9	12.6	15.7	16.1	15.1	16.6	18.9	19.1
United States	12.8	14.1	16.3	16.8	15.8	18.3	19.2	19.8
OCDE	**12.9**	**13.3**	**15.6**	**16.1**	**14.9**	**16.8**	**19**	**19.5**

Source: Edited from OECD (2007)

However, most current estimates of life expectancy for the general population are calculated by using only age, gender, or race, without contemplating other characteristics. A recent approach consists in estimating life expectancy including functional status as a variable (Keeler, Guralnik, Tian, Wallace, & Reuben, 2010). This method would contribute to a more precise prognostic estimate of life expectancy, in particular with regard to older adults. Keeler et al. (2010) found that estimates for life expectancy could vary by 50% within a specific age and gender group when considering individual self-reported functional status and predictable transitions between the following functional states: a) autonomy in mobility and activities of daily living; b) limitations in mobility but autonomy in ADL, and c) limitations in both domains. Within this approach a 75-years-old person will have five years more of life expectancy than an individual of the same age with ADL limitations, and a little more than one year longer than another who is limited only in mobility (p. 730). Authors concluded that this method could help to improve the estimation of life expectancy in older adults and supply valuable information for the planning of healthcare programs.

2.1.2 Gender Differences

Because of the differences in mortality rates and average life spans, women, nowadays, constitute the majority of the world's elderly population. Women outnumber men by an estimated 66 million among the persons aged 60 years or over (UN, 2009). Furthermore, it is expected that by 2050 nearly 60% of the population aged 65 and older in OECD countries will be women. The ratio of women to men increases with age, for instance, more than 70% of the persons in the group of people aged 85 and older will be women (Figure 3).

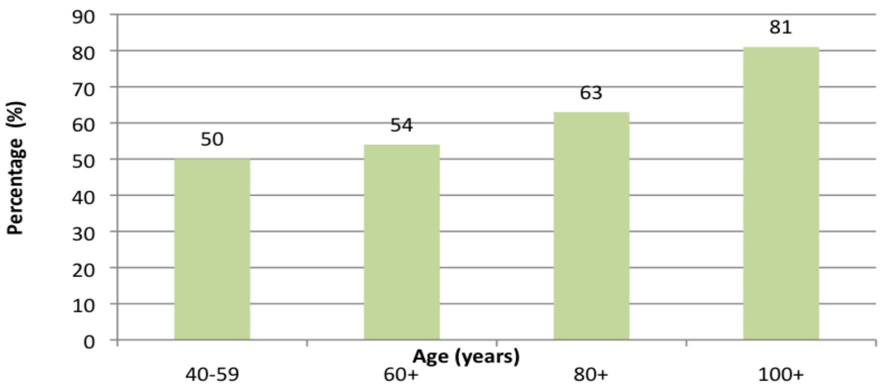


Figure 3 Proportion of number of women in the world population in 2009 (UN, 2009)

Nevertheless, these projections depend also on the reliability of prediction in trends of life expectancy. Gender gaps in longevity at age 65 have narrowed in several OECD countries since the mid-1980s. On the one hand, lifestyle factors such as obesity, smoking and stress seem to be limiting the gains in life expectancy for women. On the other hand, the number and rate of deaths from cardiovascular disease among men have fallen considerably (World Health Organization [WHO], 2009).

Still, gender differences associated to aging have a number of implications on public policy regarding healthcare and social systems. Adult women face a range of health challenges including growing risks for chronic diseases and disability (Chappell & Cooke, 2012). For instance, more women than men have a diagnosis of AD (Alzheimer's Association, 2012). In France, according to the PAQUID study, the prevalence of dementia was globally estimated at

17.8%, being significantly higher among women (20.5%) than among men (13.2%)(Direction Générale de la Cohésion Sociale [DGCS], 2010). Moreover, this difference increases dramatically with age (Table 3). These statistics should encourage the planning of dementia prevention strategies, early detection, and care (WHO, 2012).

Table 3 Prevalence of AD in regards to age and gender in France

Age (years)	**Women (%)**	**Men (%)**
75-79	5,7	7,7
80-84	16,6	12,5
85 or more	38,4	23,9

Source: Paquid study (DGCS, 2010)

2.1.3 Disability in Older Adults

One of the critical consequences of advances in survival to old age is the increase in chronic conditions that can lead to *disability*. But before going any further it is important to understand what is meant by disability and to precise the theoretical model that will be used throughout this work. This choice is important since the definition, assessment, policy formulations, and solutions for disability depend on this conceptual framework.In fact, a number of models of disability have been defined over the last few years (Bickenbach, Chatterji, Badley, & Üstün, 1999). But three of the most frequently used models are the social, the medical, and the biopsychosocial (Figure 4).

1) The *medical model* views disability as a direct consequence of a disease, trauma or other health condition, which requires medical care in the form of individual treatment provided by health professionals. Disability, on this model, calls for medical or other treatment or intervention, which can lead if possible, to correct the problem, cure the disease or treat its symptoms (Dröes, van Mierlo, van der Roest, Meiland, 2010; WHO, 2002, p.9).

2) The *social model* of disability considers disability as a socially created problem and not at all an attribute of an individual. The focus is thus on the way that disability is socially defined and on barriers to social participation that result from this labeling (e.g., attitudes and rights, laws, regulations concerning physical and social environments). In this model, the

problem of disability resides in society, not in the person, and consequently demands a sociopolitical response (Hersh & Johnson, 2008; WHO, 2002, p.9).

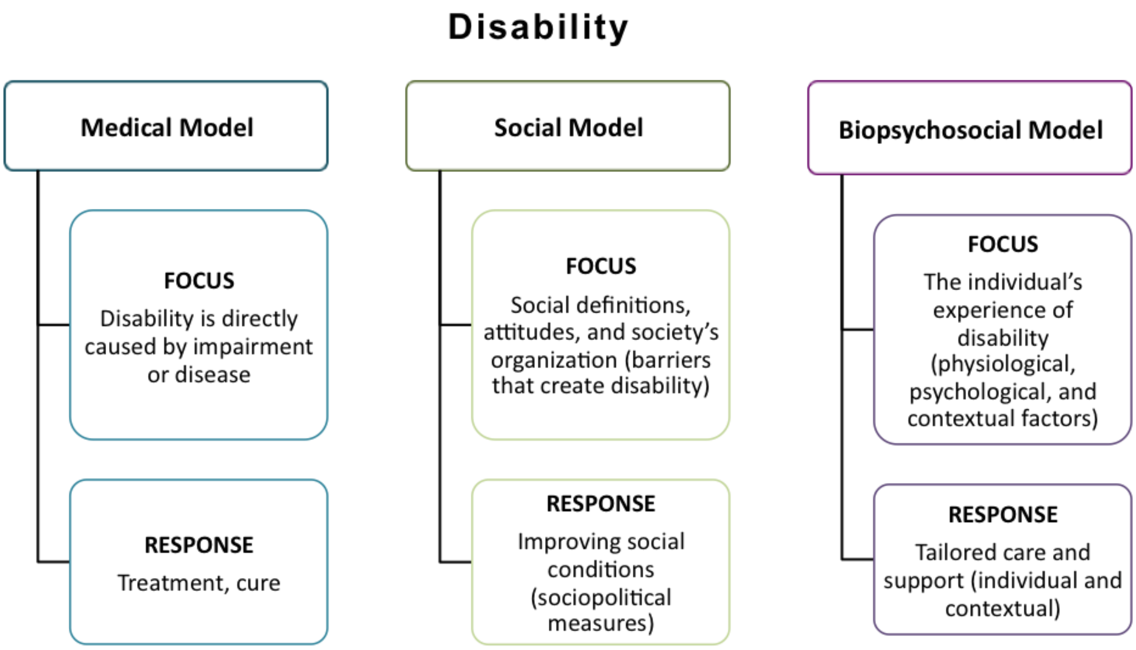


Figure 4 Models of disability

3) The *biopsychosocial model*, proposed by the International Classification of Functioning, Disability and Health (ICF), takes into account both biological and social factors that when interacting with each other affect the individual's functioning in society (WHO, 2002, p.9). Within this model (Figure 5), disability refers to impairments in body functions or structures, to activity limitations when performing a task or and action, and to participation restrictions in everyday life situations that a person can experience (WHO, 2011). In this model:

- *Body functions* are the physiological functions of body systems (including psychological functions).
- *Body Structures* are anatomical parts of the body, such as organs, limbs and their components
- *Participation* refers to the involvement in a life situation

Disability is thus defined and measured in this model on the basis of the interaction between an individual's health and contextual factors. A major contribution of the biopsychosocial model of disability is that it has encouraged the consideration of contextual factors on the individual's functioning (Dahl, 2002). These include personal factors (e.g., age, gender, social status, life experiences) and environmental factors (e.g., the physical world, relationships, roles, attitudes, values, social systems, services, policies, and laws). This work uses the biopsychosocial disability model as its underlying theory basis for examining dementia care and AT.

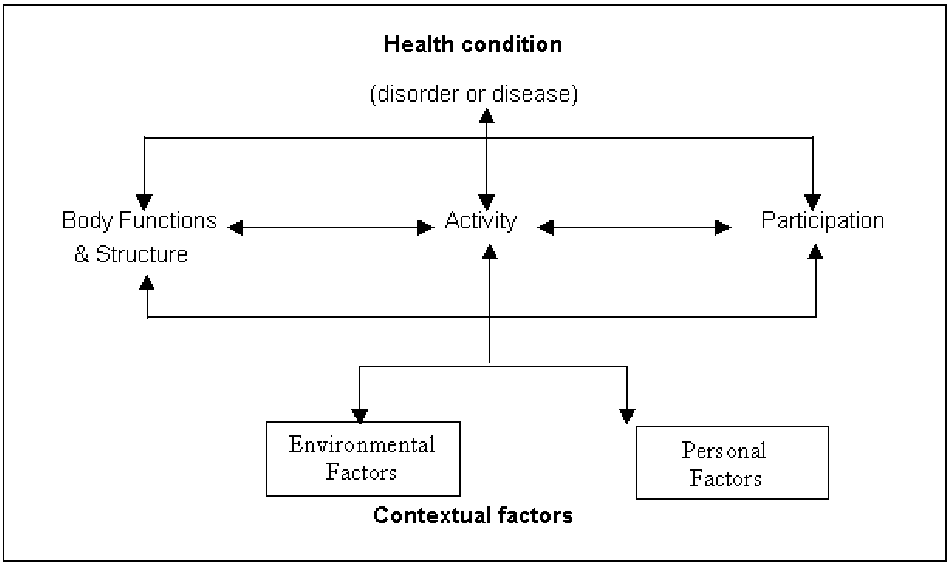


Figure 5 ICF Biopsychosocial model of disablility

There exists a wide range of disabilities that include physical, cognitive, sensory, psychiatric, and age-related or disease-related impairments. Light or moderate disability *(moderate dependency)* refers to the limitations a person can experience when executing Instrumental Activities of Daily Living (IADL), such as the management of personal finances, meal preparation or handling transportation. Severe disability *(severe dependency)* is associated to restrictions in Activities of Daily Living (ADL) which are essential to be able to live independently, such as eating, dressing or bathing (Marcotte, Scott, Kamat & Heaton, 2010).

Vulnerable populations are particularly affected by disabilities. For instance, people from lower income countries have a greater risk of being disabled than those from higher income countries (Braithwaite & Mont, 2008). With regard to gender, women have a higher prevalence of disabling conditions and of comorbidities (Newman & Brach, 2001). Moreover, in global population persons who have low income, low education or who are unemployed are more vulnerable to disabilities (WHO, 2011).

Difficulties in everyday functioning also appear to grow exponential with age, being highly concentrated in the "oldest-old" age groups (OECD, 2005). In part, this is due to age-related decline in cognitive abilities, which are an important predictor of functional status

(Ball, Ross & Viamonte, 2010). Mobility limitations are another cause of disability that concerns about 20% of persons age 65 of older (Guralnik, Fried & Salive, 1996). At a world level the three leading contributors to disability among older people are blindness (21.5%), cognitive decline (e.g., dementia) (11.9%) and deafness (10.6%) and the three main causes of death in this group of age are heart disease (32.9%), cancer (22.5%) and stroke (17.8%) (Alzheimer's Disease International [ADI], 2009).

Elderly persons with moderate limitations can benefit from informal caregiving and from other sources of support at home that can help them to continue to participate actively in the community as long as possible. On the contrary, older adults with severe limitations will require substantial help from a third party to fulfill ADL, a need that in most of the cases can only be addressed by institutional long-term care over an extended period of time (OCDE, 2007). Long-term care refers to a range of services such as personal care, health care, prevention, rehabilitation or palliative care, that are required by persons who are in situation of severe dependency (OCDE, 2005). Long-term services can be provided either at home or in an institution.

2.1.3.1 Estimates of Disability in France

In France, the Direction of Research, Studies, Evaluations and Statistics (DREES)[4] and the National Institut of Statistics and Economic Studies (INSEE)[5] conducted the survey Handicap-Health in Ordinary Households (HSM) in 2008 [6]. The aim of this survey was to study disability in the general population of young and older adults (Dos Santos & Makdessi, 2010). The survey covered the whole territory and concerned exclusively people living in ordinary households. Approximately 30,000 people responded to this survey. The study focused on the quality and the frequency of functional limitations encountered in daily life by adults divided into four groups of age (20-39 years, 40-59 years, 60-79 years, over 80). It also presented indicators of social participation (access to employment, education and vocational training, leisure) and provided data about the respondents' social and physical environment (family support and social networks, housing type, use of AT, housing facilities, accessibility).

Findings from the HSM survey showed that in France disability concerns about 2.7% of people aged 60 to79 years, and 11.2% of those aged over 80. Severe disability concerned about 0.6% of individuals in the 60-79 group and 2.5% of the respondents aged over 80. These

[4] DRESS : Direction de la Recherche, des Études, de l'Évaluation et des Statistiques
[5] INSEE : Institut National de la Statistique et des Études Économiques
[6] HSM : Handicap-Santé en Ménages Ordinaires

persons present major physical and cognitive limitations and their overall level of everyday functioning is substantially reduced. The totality of respondents that fell in this category reported relying on family, social and professional networks for assistance and support. However, while severe physical and cognitive limitations were observed in both age-groups, physical impairment concerned a greater number of respondents. Similarly, the number of persons that reported restrictions in IADL was significantly higher than the number who reported restrictions in ADL (Table 4). However, careful attention must be paid when interpreting these results since people living in long-care institutions were not included in the survey. Indeed, the prevalence of elderly persons with severe cognitive limitations (such as dementia) is higher in the population living in long-care institutions than among the elderly population living in households.

Table 4 Distribution of elderly respondents who reported at least one severe activity limitation or restriction

Age group	**Severe physical limitation (%)**	**Severe cognitive limitation (%)**	**Severe restriction ADL (%)**	**Severe restriction IADL (%)**	**Total (thousands)**
60-79	17,8	11,0	1,9	11,9	10 488
Over 80	51,6	26,2	11,9	44,1	2 698

Source: HSM survey (Dos Santos & Makdessi, 2010)

2.1.4 Predictors of the Institutionalization of the Older Adult

Increase in life expectancy and population aging can be expected to result in a rise of the number of disabled elderly people. Moreover, as noted before, severe disability is strongly linked to the demand of of long-term care and consequently to expenditure on it (Lafortune & Balestat, 2007). Therefore, general indicators of age-related disability illustrate how critical it is to find ways to manage risk factors (hypertension, obesity), and to prevent or postpone chronic diseases that lead to dependency in old age, such as arthritis, heart problems, dementia, and diabetes.

In this context, the identification of most significant predictors of the use of long-term care services by elderly people provides a useful information for the planning and the implementation of medical and social care strategies. Luppa et al., (2009) conducted a systematic review of predictors of institutionalization, or Nursing Home Placemet (NHP),in elderly people including main studies that showed evidence of each predictor. With this purpose, the authors used the *behavioral model* (Andersen, 1968) that explains the use of health services as a function of three variables: a) predisposition factors, such as sociodemographic characteristics and health beliefs, b) enabling factors, like personal and community resources, and c) perceived and evaluated needs that explain care-seeking strategies, adherence to treatment and the kind of treatment provided. The review included 36 different studies and a total of 754,071 individuals. The results of predictors analysed were synthetised by level of evidence (strong, moderate, weak or inconclusive) (Table 5).

Table 5 Predictors of NHP among elderly people

Predictors	Strong evidence	Moderate evidence	Weak evidence	Inconclusive evidence
Age	x			
Housing, not own house	x			
Ethnicity, white American	x			
Self-rated health status, low	x			
Functional impairment	x			
Cognitive impairment	x			
Dementia	x			
Prior NHP	x			
Number of prescriptions	x			
Employment status, employed		x		
Social network, low contacts		x		
Activity level, low		x		
Diabetes		x		
Marital status, married			x	
Gender, male				x
Living situation, living alone				x
Education, low				x
Income				x
Stroke				x
Hypertension				x
Arthritis				x
Respiratory diseases				x
Incontinence				x
Depression				x
Prior hospital use				x

Source: Luppa et al., (2009)

Luppa et al., (2009) analysis revealed that dementia diagnosis was the strongest predictor of NHP among older adults. The combination of progressive cognitive and functional decline observed in dementia could explain this finding. The likelihood of NHP of elderly with dementia was significantly higher (over 50%) compared to that of community-dwelling older adults (17%). Taken alone, functional impairment, evaluated by ADL and IADL, was another factor that predicted NHP. This predictor was reported in 96% of the studies. Finally, the probability of NHP in the elderly population with cognitive and/or functional impairment dramatically increased when there was a lack of support for everyday functioning either provided by family or professional caregivers.

All these factors confirm the necessity of conceiving and implementing prevention and care strategies that have the capacity to reduce disability in later life. The fact that age-related cognitive impairment is one of the major causes of disability and, consequently, of long-care demands, is one of the reasons for which we are focusing on these conditions in the following sections of this work. This interest is also explained by the possibilities that healthcare and assistive technologies offer to support everyday functioning in patients and caregivers.

2.2 Age-Related Conditions Having an Impact on Cognitive and Functional Status

This section provides a general overview of two common age-related conditions that particularly impact cognitive and functional status in older adults: mild cognitive impairment and Alzheimer’s disease. The description of these conditions focuses on their influence on functional capacity rather than on their neuropsychological characteristics because assistive technology usually targets everyday functioning. Nevertheless, main neuropsychological features are described for each condition in the corresponding diagnostic criteria.

2.2.1 Mild Cognitive Impairment

Mild Cognitive Impairment (MCI) is a condition that affects approximately 10% to 20% of people aged over 65 years (Alzheimer’s Association, 2012). It is usually characterized by memory loss but other cognitive deficits can prevail (Albert et al., 2011; Petersen & Morris, 2005; Winblad et al., 2004). Two aspects characterize MCI: a) cognitive decline must be confirmed by neuropsychological assessment (significantly lower performances in cognitive tasks than what is expected for age), and b) cognitive decline does not compromise the overall functional ability. Currently, MCI is diagnosed by using established neurological and neuropsychological tests, and a set of clinical criteria (Petersen et al., 1999) (Box 1). However, most recent recommendations consider that the best prediction models should involve a combination of neuroimaging and chemical biomarker measures (Albert et al., 2011).

Moreover, different patterns of clinical manifestations of MCI have been identified by Winblad al., (2004):

a) Amnestic MCI (aMCI) versus Non Amnestic MCI (na-MCI): depending on whether there is an impairment in episodic memory, deficits in learning and recalling recently learned information, or not. The category of na-MCI will be used when cognitive decline concerns other type of ability different from memory, such as attention, language, viusospatial skills, or executive function.

b) Single domain versus multiple cognitive domains: depending on whether the person has deficits in one single cognitive domain or in multiple, independently from the fact that memory is affected or not.

Box 1 Criteria for the clinical diagnostic of MCI (Petersen et al., 1999)

1. Subjective memory complaint: This information should be provided either by the patient, by a knowledgeable informant
2. Objective memory impairment: impaired delayed recall performance or difficulty benefiting from semantic cues during learning or recall
3. Normal general cognitive function on measures of general cognition and other nonmemory indexes
4. Intact functional ability: Skills and capacities required to perform independently everyday activities are preserved. However, the person can face some difficulties when performing complex IADL and may require minimal aids or assistance
5. Absence of dementia: Cognitive deficits do not affect significantly functional or social capacities

2.2.1.1 Progression to Dementia

It has been largely documented that individuals with MCI are at higher risk of developing AD, or any other form of dementia, than healthy individuals. The conversion rate in persons with MCI to AD has been estimated at 10–15% per year, while it is only of 1–2% for healthy controls (Petersen et al., 2003; 2010,DeCarli, 2003). Also, recent evidence suggests that prevalence of AD is higher for the multi-domain aMCI type than for other subtypes (Albert et al., 2011). This progression rate has been estimated at 60% over two years (Mitchell, Arnold, Dawson, Nestor, & Hodges, 2009). Another noteworthy fact is that in the general population the prevalence of aMCI, including both single and multi-domain presentations, is 2.3 times more common than na-MCI (Petersen et al., 2010). This estimation is coherent with the higher prevalence of AD compared to other forms of dementia (Azheimer’s Association, 2012).

From a clinical perspective the degree of severity in memory impairment, or in other cognitive functions affected by MCI, is associated to the risk of progressing to dementia. MCI prevalence also appears to increase with age, to be higher in men, in never-married subjects, and in subjects with *APOE* ε3ε4 or ε4ε4 genotype (Mitchell et al, 2009). Besides, other studies have found that patients with MCI who reported IADL impairment experienced a higher degree of cognitive decline (Purser, Fillenbaum, Pieper, & Wallace, 2005). These individuals were more likely to convert to dementia as well compared to those who do not report IADL difficulties (Peres et al., 2006).

Etiology of MCI

Once the clinical subtype of MCI has been determined, it is fundamental to identify the etiology of the deficits (Winblad et al., 2004). Given that aMCI often results from AD pathology recent recommendations have formulated the concept of “MCI due to AD” which can be considered as an early stage of AD (McKhann et al., 2011). This cognitive profile typically involves deficits in episodic memory, which concerns personal events and experiences. At a neurobiological level “MCI due to AD” is associated with specific brain changes that are commonly observed in AD (Albert et al., 2011). Etiology concerning na-MA includes cerebrovascular disease, Lewy body dementia, Parkinson disease, frontotemporal dementia, or no specific underlying pathology.

Even so, it is important to acknowledge that not all individuals with MCI will progress to AD or other kind of dementia (Petersen & Morris, 2005). Actually a great proportion of them will revert to normal (Mitchell et al., 2011). A number of epidemiological studies underline the fact that different factors, other than neurodegenerative disorders, affect cognition in elderly populations and may account for many cases of reversible MCI. These causes include vascular risks, psychiatric status, genetic background, or hormonal changes, (Ritchie, 2004; Ganguli, Dodge, Shen & DeKosky, 2004). In any case, a follow-up evaluation 6 months and a year later is recommended for individuals MCI who have recently been given a diagnosis of MCI.

2.2.1.2 MCI and Functional Status

The assessment of functional status is a key factor for the diagnosis of MCI. Indeed, current diagnostic criteria differentiate MCI from dementia based on the assessment of whether or not cognitive decline affects significantly functional abilities, such as the possibility to work or to perform everyday activities (Albert et al., 2011). Everyday functioning assessment is usually made with the patient and knowledgeable informant who can report the day-to-day activities of participant.

Although individuals with MCI maintain functional independence in daily life they can exhibit some difficulties when performing complex IADL tasks (Table 6). Furthermore, patients with MCI can be slower, experience planning difficulties or poor judgment, and be less efficient in everyday functioning than they were in the past (Aretouli & Brandt, 2010; Peres et al., 2006).

Table 6 Functional abilities affected in individuals with MCI

Study	**Functional abilities**	**Subjects *n,* age (SD), MMSE (SD)**	**Assessment of functional status**
Aretouli & Brandt, (2010)	Keeping appointments Finding things at home Remembering current events Using the telephone Following TV programs Difficulties driving and using transportation Managing finances Organizing and completing activities Taking medication	MCI: *n*= 124, 76.28 y/o (7.52), 28.20 (1.22) HC: *n*= 68, 72.41 y/o (7.25), 29.26 (0.87)	Informant report rating using the Activities of Daily Living-Prevention Instrument (ADL-PI), and the Informant Questionnaire on Cognitive Decline In the Elderly (IQCODE)
Ahn et al., (2009)	Telephone use Meals preparation Taking medication Managing belongings Keeping appointments Talking about recent events Performing leisure activities/hobbies	MCI: *n*=66, 70.76 y/o (7.33), 24.77 (3.10) HC: *n*= 61, 64.44 y/o (5.60), 27.64 (1.44)	Informant report rating using the -Instrumental Activities of Daily Living (S-IADL) and Seoul-Activities of Daily Living (S-ADL)
(Bangen et al., 2010)	In aMCI: abilities related to managing money, such as counting money, performing calculations, paying bills, and taking precautions with finances In na-MCI: abilities related to health and safety issues such as awareness of own's health status, assessing health problems, dealing with medical emergencies, and knowledge of healthy behaviors	aMCI: *n*=22, 74.86 y/o (7.05), n/a na-MCI: *n*=16, 77.13 y/o (8.53), n/a HC: *n*= 82, 74.26 y/o (9,38), n/a	Performance based measure using the Managing Money and Health and Safety sub-scales of the Independent Living Scales (ILS)
Jefferson et al., (2008)	Subtle problems performing functional tasks, such as: Misplacing objects Having trouble recalling familiar phone numbers Forgetting details of recent events Difficulties to concentrate on more than one thing Doing or saying the same thing over and over again Disorientation or confusion Avoiding certain social situations Being irritable and easily upset Having poor memory for events from	MCI: *n*=38 74.6 y/o (7.5), 28.0 (1.7) HC: *n*= 39 72.4 y/o (5.5), 29.3 (0.9)	Informant report rating using the Instrumental Activities of Daily Living and Physical Self-Maintenance Scale (IADL-PSMS)

Study	Functional abilities	Subjects *n,* age (SD), MMSE (SD)	Assessment of functional status
	the past Does not keep self busy doing useful things Getting tired for no apparent reason		
Peres et al., 2006	Using the telephone Using transportation Taking medication Managing finances	MCI: *n*=285 n/a HC: *n*=828 n/a	Self assessment or informant report rating, when required, using Lawton scale of IADL
Reppermud et al., (2011)	Observing important dates or events Concentrating on reading Describing what he/she has just seen or heard Taking part in conversation Taking a message for someone else Doing two things at the same time Coping with unfamiliar situations Doing things safely Performing a task when under pressure	MCI: *n*=293, 78.83 y/o (4.70), 28.01 (1.53) HC: *n*=828, 78.30 y/o (4.66), 28.75 (1.20)	Informant report rating using the Bayer-Activities of Daily Living Scale (B-ADL)

HC=Healthy controls, MCI= Mild Cognitive Impairment, aMCI=amnestic MCI; naMCI= non-amnestic MCI, y/o= years old; MMSE= Mini-Mental State Examination

Studies reported in Table 7 have identified a number of domains, skills or tasks in which patients with MCI have worse performances than age-matched individuals with normal cognition. These evaluations were conducted either by using self-reported questionnaires, performance-based IADL assessments or informant interviews. Findings conclude that although functional impairment in MCI is not as severe as in AD, individuals with MCI may require some assistance with daily activities, in particular for those that require a high cognitive demand (Reppermund et al., 2011). In most of the cases family members provide this support. However, in the scenario where cognitive deficits increase -conversion to AD or to other form of dementia- the need of assistance will also increase and caregiver burden may occur. In this context, support and assistive technologies that aim at compensating or enhancing functional abilities may prove useful. That is why a first step for designing adapted systems is the identification of problematic tasks for individuals with MCI, issue that will be discussed further below.

2.2.2 Alzheimer’s Disease

AD is a neurodegenerative disorder and the most common cause of dementia among elderly people, accounting for an estimated 60%–80% of cases (Alzheimer’s Association, 2012). Despite a wide range of symptoms, several cognitive functions are usually impaired in AD: memory, language, perceptual skills, attention, constructive abilities, orientation, problem solving and functional capacity. With regard to everyday functioning, in early stages of AD a decreased ability to perform instrumental activities of daily life is noticeable (e.g., driving, managing finances or medication). In moderate to severe stages of the disease the decline in skills implicated in the execution of basic daily activities can lead to disability (e.g., bathing, eating, using the toilet).

Over the last decades AD diagnosis has been made based on clinical judgment by using established international criteria from the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA) (Table 7).

Table 7 Core clinical criteria for Probable AD dementia (McKhann et al., 1984)

Critieria for the clinical diagnosis of Probable AD include:	- Dementia established by clinical examination and documented by the Mini-Mental Test, Blessed Dementia Scale, or some similar examination, and confirmed by neuropsychological tests - Deficits in two or more areas of cognition - Progressive worsening of memory and other cognitive functions - No disturbance of consciousness - Onset between ages 40 and 90, most often after age 65 - Absence of systemic disorders or other brain diseases that in and of themselves could account for the progressive deficits in memory and cognition.
Diagnosis of Probable AD is supported by:	- Progressive deterioration of specific cognitive functions such as language (aphasia), motor skills (apraxia), and perception (agnosia) - Impaired activities of daily living and altered patterns of behavior - Family history of similar disorders, particularly if confirmed neuropathologically - Laboratory results of: normal lumbar puncture as evaluated by standard techniques; normal pattern or nonspecific changes in EEG, such as increased slow-wave activity, and evidence of cerebral atrophy on Computerized Tomography with progression documented by serial observation.

A revised version of AD diagnosis criteria was recently published (Albert et al., 2011). One of the major modifications of the updated version is that AD is considered as a part of a continuum of clinical and biological phenomena. In fact, revised guidelines cover the earlier presymptomatic stages of the disease, MCI and then dementia due to AD (National Institute on Aging [NIA], 2011). According to this new perspective, McKhann et al., (1984) criteria described only what it is actually known about the later stages of AD, when the effects of cognitive and functional decline are evident. Two main characteristics differentiate original and new AD diagnostic criteria (Alzheimer's Association, 2012):

(a) Recent recommendations identify three stages of AD (preclinical AD, MCI due to AD, and dementia due to AD), the first of them occurring before cognitive and/or functional deficits are noticeable. In contrast, original criteria (Box 2) require cognitive decline severe enough to affect everyday functioning before establishing an AD diagnosis (McKhann et al., 1984).

According to the same criteria (McKhann et al., 2011) dementia is diagnosed when there are cognitive or behavioral symptoms that:

- Interfere with everyday functioning
- Represent a decline from previous levels of functioning and performing; and
- Are not explained by delirium or major psychiatric disorder;
- Cognitive impairment is detected and diagnosed through a combination of (1) history-taking from the patient and a knowledgeable informant, and (2) an objective cognitive assessment;
- The cognitive or behavioral impairment involves a minimum of two of the following domains: (1) memory, (2) judgment, (3) visuospatial abilities, (4) language, or (5) personality.

Box 2 Core clinical criteria for Probable AD dementia (McKhann et al., 2011)

The patient meets criteria for dementia, and in addition, has the following characteristics:

A. Insidious onset

B. Clear-cut history of worsening of cognition by report or observation

C. Initial and most prominent cognitive deficits are evident on history and examination in one of the following categories.

a. *Amnestic presentation:* Deficits include impairment in learning and recall of recently learned information. Evidence of cognitive dysfunction in at least one other cognitive domain.

b. *Nonamnestic presentations:*

- Language presentation: Prominent deficits in word-finding, and deficits in other cognitive domains.

- Visuospatial presentation: Prominent deficits in spatial cognition (object agnosia, impaired face recognition, simultanagnosia, and alexia). Deficits in other cognitive domains should be present.

- Executive dysfunction: Prominent deficits are impaired reasoning, judgment, and problem solving. Deficits in other cognitive domains should be present.

D. Diagnosis of probable AD dementia should not be applied when there is evidence of (a) substantial concomitant cerebrovascular disease; or (b) core features of Dementia with Lewy bodies other than dementia itself; or (c) prominent features of behavioral variant frontotemporal dementia; or (d) prominent features of semantic variant primary progressive aphasia or nonfluent/ agrammatic variant primary progressive aphasia; or (e) evidence for another concurrent, active neurological disease, or a non neurological medical comorbidity or use of medication that could have a substantial effect on cognition

(b) New criteria incorporate biomarker measures, such as ß-amyloid and tau levels in the cerebrospinal fluid and blood for diagnosis confirmation at the preclinical stage. At later stages histopathological markers provide a definite confirmation of the clinical diagnosis of AD, whereas clinical criteria only support a probabilistic one (Dubois et al., 2007). However, it is important to note that although biomarkers are increasingly used to support research in AD and as optional clinical tools they are not yet used for routine diagnostic purposes.

2.2.2.1 Etiology of AD

During the last decade there has been a great advance in the understanding of the biological basis of AD. Brain changes occurring in AD have been largely described and include a) the extracellular accumulation of the protein *ß*–amyloid, which affects synapses and contributes to neuronal death, and b) the intracellular accumulation of the protein tau, in the form of neurofibrillary tangles, that blocks the neuron's transport systems leading also to neuronal damage (Braak, Thal, Ghebremedhin, & Del Tredici, 2011; Delacourte et al., 1999). As a consequence of cell loss the brain of individuals with AD shows a significant shrinkage or brain atrophy (NIA, 2011). For diagnosis purposes, distinctive AD markers comprise structural changes early observed on the medial temporal lobe, molecular change -hypometabolism or hypoperfusion- in temporoparietal areas and changes in cerebrospinal fluid biomarkers (Dubois et al., 2007).

It is important to note that AD progression can show some variability from one individual to another. For example, while typical progression is rather slow, with a mean decline of less than 3 points in the Mini Mental Status Examination (MMSE) per year (Morris et al., 2003, Schmidt et al., 2010), some patients will have a slower progression and others will show a more rapid decline, with a loss of 6 or more points in the MMSE per year (Schmidt, Wolff, Shalash, & Zerr, 2011). The fact that the duration of the stage of "dementia due to AD" oscillates between 2 and 15 years illustrates well this variability (Ashford & Schmitt, 2001).

The most common form of AD is late-onset or sporadic AD, which accounts for about 90% of cases. This form usually occurs after age 65. The precise causes that underlie brain changes associated to sporadic AD remain largely elusive even if a number of genetic, environmental and life-style risk factors have been identified including advancing age, genetic predisposition, family history, cardiovascular risk factors, MCI, head, or traumatic brain injury (Alzheimer's Association, 2012). There are also rare familial forms of AD, usually developed in young individuals (in their late 30s-50s), for which genetic mutations have been identified. These "Early onset dominantly inherited" diseases are responsible for a small percentage of AD cases estimated at 1% (NIA, 2011). In these cases AD is caused by the mutation in the gene for the amyloid precursor protein or in the genes for the presenilin 1 and presenilin 2 proteins. Individuals who inherit any of these genetic mutations will certainly develop AD (Bertram, Lill, & Tanzi, 2010).

2.2.2.2 Prevalence of AD

When applying the age-specific, or age-and-gender specific prevalence estimates, to the population projections, the estimated number of people living with dementia worldwide in 2010 is 35.6 million (UN, 2009). This number is expected to double every 20 years, to 65.7 million in 2030 and 115.4 million in 2050 (ADI, 2009). At a world level dementia is one of the three main causes of disability among older adults (11.9%) and is the 8th in the order of conditions contributing to Years of Life Lost (ADI, 2009).

Prevalence studies on dementia generally show a higher risk in women than in men. In fact, the lifetime risk for 65-year-old woman to develop AD at the age of 95 years is estimated twice as high as for men (22% and 9% respectively) (Andersen et al., 1999). Other factors have been associated to a higher risk of AD such as a lower educational level (Ott et al., 1995) or having a poor social network, for example, when comparing married and single individuals without close social ties (Helmer, Joly, Letenneur, Commenges, & Dartigues, 2001).

2.2.2.3 AD and Functional Status

According to the recent diagnosis criteria (Albert et al., 2011) cognitive and behavioral symptoms that hinder the patient's everyday functioning are noticeable only in the stage of dementia due to AD. However, AD must be considered as a heterogeneous disorder in which clinical profiles, biomarker patterns or neuropathological characteristics can differ from one individual to another (Schmidt et al., 2011). Consequently, different patterns of functional impairment between AD patients can be found. With regard to this point, the ability of the brain to tolerate AD-related pathology, referred as cognitive reserve, is one of the factors that would explain the variability observed in functional impairment among individuals with AD (Fratiglioni & Wang, 2007). In fact, several studies have shown that some individuals with extensive neuropathological AD-related lesions do not manifest the clinical impairment expected for this kind of brain damage.

When referring to functional abilities affected by AD we can categorize them according to their link to a particular cognitive or neuropsychiatric symptom (Table 8). They can also be categorized according to the different stages of the disease (Table 9). Generally, the progression of clinical symptoms follows the pathological pathway of brain changes associated to AD (Dubois et al., 2007). Thus, at the first stages these changes will concern the entorhinal cortex and the hippocampus, parts of the brain involved in memory. Then, at later stages loss of neuronal connections and cell death will affect areas in the cerebral cortex responsible for language and reasoning. Eventually, AD neuropathology will affect many other areas of the brain impairing the patient’s abilities to execute basic bodily functions such as walking or swallowing, being ultimately fatal (Alzheimer’s Association, 2012).

Table 8 Cognitive/neuropsychiatric symptoms and examples in everyday functioning (McKhann et al., 2011)

Cognitive or neuropsychiatric symptoms	**Examples in everyday functioning**
Memory loss	Repetitive questions or conversations, misplacing personal belongings, forgetting events or appointments, getting lost on a familiar route
Poor judgment	Poor understanding of safety risks, poor decision-making ability
Executive dysfunction	Inability to manage finances, inability to plan complex or sequential activities
Impaired visuospatial abilities	Inability to recognize faces or common objects or to find objects in direct view despite good acuity, inability to operate simple implements, or orient clothing to the body
Impaired language functions (speaking, reading, writing)	Difficulty thinking of common words while speaking, hesitations; speech, spelling, and writing errors
Changes in personality, behavior, or comportment	Mood fluctuations such as agitation, impaired motivation, initiative, apathy, loss of drive, social withdrawal, decreased interest in previous activities, loss of empathy, compulsive or obsessive behaviors, socially unacceptable behaviors

Table 9 Functional difficulties and AD progression

Early stage (1-2 years)	**Middle stage (2-4 years)**	**Late stage (5 years or more)**
• Mild communication difficulties • Significant memory loss, particularly for things that have just happened • Not knowing the time of day or the day of the week • Become lost in familiar places	• Severe memory loss, especially of recent events and people’s names • Can no longer manage to live alone without problems • Unable to execute independently IADL and ADL • May become extremely	• Difficulties for eating • Being incapable of communicating • Not recognizing relatives, friends and familiar objects • Difficulties to understand what is going on around them • Difficulties for walking

Early stage (1-2 years)	Middle stage (2-4 years)	Late stage (5 years or more)
• Difficulty in making decisions • Being inactive and unmotivated • Show mood changes, depression or anxiety •Unusual reactions of anger or aggressive behavior • Loss of interest in hobbies and activities	dependent on their family and caregivers • Increased difficulty with speech • Wandering and other behavior problems such as repeated questioning and calling out, clinging and disturbed sleeping • Spatial disorientation at home as well as outside • Possible hallucinations	• Bladder and bowel incontinence • Displaying inappropriate behavior in public •Confinement to a wheel chair or a bed

Source (ADI, 2009)

With regard to the impact of AD on functional abilities other factors that merit careful consideration are *fluctuating symptoms* (NIA, 2011). Fluctuating symptoms are ususally observed in cognitive functioning and refer to spontaneous alterations in cognition, attention, and arousal. Thus, the patient seems to experience "brief interruptions of consciousness, periods of increased confusion and cognitive impairment, episodes of diminished arousal" (Escandon, Al-Hammadi, & Galvin, 2010, p. 215). Behavioral fluctuations can also occur in individuals with AD primarily involving mood variations and sleep/wake patterns. These day-to-day variations are often reported by family members, or other caregivers, as the patient having "good" and "bad" days. Fluctuating symptoms have a negative effect on functional abilities and on the rating of dementia severity (Ballard, Walker, O'Brien, Rowan, & McKeith, 2001; Bradshaw, 2004; Escandon et al., 2010).

In one of the few studies conducted on this subject, Bradshaw (2004) assessed cognitive fluctuations in patients with probable dementia with Lewy bodys and with AD. The aim of the study was to document and illustrate distinctive features of fluctuating symptoms in both conditions. Experimental data was gathered by using caregivers reports and the "One day fluctuation assessment scale". Findings showed that fluctuations in AD were associated to a diminished capacity to cope with the cognitive demands of the immediate environment. Furthermore, fluctuations in AD patients involved generally the memory domain: repetitiveness in conversation or forgetfulness in relation to a recent task or event (Table 10). Still, despite the frequency with which caregivers usually report fluctuating symptoms (10%-20% of them) (Escandon et al., 2010) many questions regarding this issue are still unresolved. Certainly, fluctuating symptoms should receive further examinations since they contribute to disability in this population and could be targeted by clinical interventions.

Table 10 Cognitive fluctuations on a day in AD patients reported by caregivers

Has the patient had a period (or periods) today when he or she seemed to be confused and muddled and then a period (or periods) when he or she seemed to be improved and functioning better? Give examples of the worst and best period of function

Worst day moment	Best day moment
- She repeated the same question over and over 5–8 times in an hour	- She didn't repeat herself so much
- He forgot the time and date and asked me 10 times in an hour	- He remembered the day
- She repeated the same question numerous times over a few hours	- She recognized people by name
- She was unsure of where she was going and why	- She was fleetingly objective and less repetitive
- When he had to sort things out himself and remember what to do	- When there was someone to guide and remind him
- He got snappy, agitated and couldn't think of what he wanted to say	- He was talkative and productive, making his own bread
- After an argument she got agitated and couldn't think	- Normal conversation and presented well to others who don't live with her

Source (Bradshaw, 2004)

2.2.2.4 AD and Preserved Capacities

Most of the litterature on AD has focused on the progressive decline of cognitive and functional abilities that result from this condition. However, various studies have shown that individuals with AD maintain some cognitive abilities and personal psychological resources throughout the course of the disease. Such findings have inspired care strategies that take into consideration daily difficulties experienced by individuals with AD and exploit at the same time the patient's preserved capacities and skills at every phase of the disease (Van der Linden & Juillerat, 1998).

Memory deficits in AD are generally characterized by the inability to consciously retrieve information from the past. Nevertheless, individuals with AD may be able not only to access these previous experiences but also to acquire new skills through the use of implicit or non-conscious memory processes (De Vreese, Neri, Fioravanti, Belloi, & Zanetti, 2001). Among the most studied process known to be relatievely well preserved in AD are *procedural memory* and *repetition priming*. Procedural memory allows gradual acquisition and maintenance of perceptual, motor and cognitive skills through repeated practice (Halteren-van Tilborg, Scherder, & Hulstijn, 2007). Repetition priming refers to the "facilitation in cognitive processing that occurs as a consequence of repeated exposure to a stimulus event" (Fleischman, 2007, p. 889). Empirical evidence confirms that patients with AD are capable of learning new skills through the use of procedural memory strategies and to access to previously learned information, under certain conditions, by the mecahnisms of repetition priming, and this so even at relatively advanced stages of the disease.

With regard to preserved abilities in AD, another area that has received special attention is *emotion processing*. The interest given to this factor is explained by its fundamental role in communication and social behavior and, at a more general level, by the influence emotion processing has on the quality of life of patients and caregivers. For instance, Bucks & Radford (2004) investigated the changes in recognition and identification of non-verbal communicative signals of emotion (face and prosody) in individuals with AD. No significant differences were observed between AD patients and healthy controls with regard to the recognition of non-verbal cues relative to different emotions (happiness, sadness, anger, fear or neutral). Therefore, results allowed concluding that non-verbal emotional processing skills are relatively preserved in AD. Other studies have confirmed that patients with severe dementia can recognize and react to facial emotions (Burnham & Hogervorst, 2004; Guaita et al., 2009). Coste & Butler (2004) argued that people at advanced stages of AD pay more attention to non-verbal than to verbal communication (gestures, voice and pitch, facial expressions and body movements), and become quite adept to understand these features of social communication. Thus, the ability to read and decode non-verbal messages would allow individuals with AD compensate for their cognitive and sensory losses.

An issue that has been subject of debate is the effect of dementia on personhood (Caddell & Clare, 2010; Edvardsson, Winblad, & Sandman, 2008). Some authors have suggested that dementia desintegrates personhood at the later stages of the disease, and that recognizing this fact would be a fundamental step to grant families the opportunity to mourn the loss of the past they had with the person (Davis, 2004). On the contrary, other studies have described periods when patients with severe AD talk or act in a way that shows the awarness they have of their situation and functioning (Clare, Rowlands, Bruce, Surr, & Downs, 2008; Normann, Henriksen, Norberg, & Asplund, 2005). Accordingly, these findings provide an argument in favor of the persistence of personhood in severe dementia: “the insight of the mental tragedy in dementia is an evidence of an active interior life, even in the advanced stages of the disease” (Baloyannis, 2010, p. 109).

In summary, recognizing that despite existing difficulties, people with AD not only retain some abilities, stenghts and resources, but also their values, preferences, life-long habits, and life experiences, has relevant implications for the design of interventions that (a) rely on preserved cognitive capacities and a supportive context, (b) involve effective forms of communication, such as the use of supportive listening, positive feedback, non-verbal and emotional communication, that are less dependent on cognitive strategies, and (c) integrate person-centered care strategies.

2.2.2.5 Role of Informal Caregivers in AD

As the disease progresses people with AD increasingly rely on the support of others. Informal caregivers (e.g., family or friends) frequently provide this care. If informal care is not available, or no longer sufficient, formal care is usually required (e.g., professional or paid nursing or personal care). In spite of this, it has been estimated that one in seven persons with AD live alone, and half of them do not have an identifiable caregiver. These persons are exposed to several risks such as inadequate self-care, malnutrition, untreated medical conditions, falls, wandering, and accidental deaths (Alzheimer's Association, 2012).

Informal caregiving concerns assistance and care and it usually comprises: (a) personal care (e.g. dressing, bathing, eating, getting in or out of bed), (b) practical household help (e.g. transportation, shopping, and household chores), (c) help with paperwork (e.g., filling out forms, and settling financial or legal matters), (d) managing safety issues and behavioral symptoms of the disease, and (e) finding and using supportive services (e.g., making arrangements for medical care and paid inhome, assisted living, or nursing home care) (Alzheimer's Association, 2012; Bolin, Lindgren, & Lundborg, 2007).

There is broad consensus in the literature about the relevance of informal caregivers' role in AD care (Clyburn, Stones, Hadjistavropoulos, & Tuokko, 2000; Lyons, Zarit, Sayer, & Whitlatch, 2002; Ory, Hoffman, Yee, Tennstedt, & Schulz, 1999; Schulz & Martire, 2004). For instance, it is estimated that 80% of the home care is provided directly by family and friends, and the remaining 20% by formal care services (Alzheimer's Association, 2012). Most older adults with dementia receive assistance from their spouse or children, and although caregiving tasks are sometimes divided among several family members or friends, the more typical scenario is that most care is provided by one individual (Schulz & Martire, 2004). In addition, half of these caregivers live in the same household as the person for whom they provide care (Alzheimer's Association, 2012). Another specificity of caregiving in dementia is the duration of the caregiving role due to the slow and insidious nature of the progression of AD. Studies indicate that people aged > 65 years survive an average of 4 to 8 years after a diagnosis of AD; yet, some live as long as 20 years with AD (Alzheimer's Association, 2012). Consequently, for some individuals, the caregiving role lasts many years, even decades (Schulz & Martire, 2004).

Although informal caregivers may report positive feelings about their role (e.g., family togetherness, satisfaction of helping others), dementia caregiving caring is burdensome and stressful and has a negative impact on the caregiver's physical and mental health (Alzheimer's Association, 2012; Cartwright, Archbold, Stewart, & Limandri, 1994). Furthermore, individual and contextual factors have an influence on caregiver's burder, for example, it has been found that high frequency of disturbing behavior in the individual with AD and low informal support (i.e., help from other family members or friends) are related to a more important caregiver's burden and a high prevalence and incidence of depressive and anxiety disorders in this population (Clyburn et al., 2000). However, it is worthy to note that a feature of caregiving in the context of AD is the uniqueness of each case because of the specific combination of variables that arises from particular situations. Thus, caregiving should be considered as a dynamic process in which the characteristics of the caregiver, the care recipient and contextual factors are interacting continuously.

Some of the recommendations to improve the quality of life in caregivers of persons with AD are to provide them with disease related information and effective strategies for the management of disturbing behaviors in AD, the use of formal care services, the provision of social support, and the improvement of coping skills in burdened caregivers through psycho-educational programs (Clyburn et al., 2000). Technology-based interventions involving telephone calls, the Internet, video or audiotapes, and computers have also proven effective in improving outcomes such as increasing caregiver knowledge, skills, and well-being, and decreasing caregiver burden and depressive symptoms (Schulz, Lustig, Handler, & Martire, 2002; Topo, 2008).

2.2.3 Theoretical Models of Dementia

It has been pointed out that the way AD is defined results in different care paradigms (Dröes et al., 2010; Zeisel & Raia, 2000). For example, in the traditional *medical model* of dementia, cognitive deficits and behavioral disturbances are directly related to the progressive neurodegenerative processes and, usually to pharmacological treatment. However, a critical limitation of this model is that focusing solely on the disease and its symptoms can come at the expense of his/her psychosocial needs (e.g., having a sense of belonging, feeling safe and respected) (Edvardsson et al., 2008; Spector & Orrell, 2010). Another frequently mentioned negative consequence of the medical model is that it perpetuates the notion that the "problem" resides within the individual without taking in consideration that the organization of society may contribute to excessive disability (Azheimer Europe, 2010).

On the contrary, *social models* of dementia focus on how people with dementia are disadvantaged by their physical and social environment (Brittain, Corner, Robinson, & Bond, 2010). The National Collaborating Centre for Mental Health [NCCMH] has provided the following definition: "From a social perspective dementia can viewed as one of the ways in which an individual's personal and social capacities may change for a variety of reasons, and changes in such capacities are only experienced as disabilities when environmental supports are not adaptable to suit them" (p. 66).

Psychosocial models of dementia recognize the role of social and environmental factors in the experiences lived by people with dementia. In addition, they contribute to the understanding of the psychological aspects involved in this condition (e.g., communication, emotional responses, or compensation mechanisms). In psychosocial models the emphasis of care strategies is placed on the emotional experiences and retained capacities and skills of the person with dementia (Dröes et al., 2010). In the same line of thought, *person-centered care* approaches have been developped to promote high quality care and quality of life in individuals with AD (Brooker, 2005; Edvardsson et al., 2008; Spector & Orrell, 2010).

Tom Kitwood, considered as the founder of the concept of person-centred dementia care, introduced in the nineties a groundbreaking equation/model that contributed to the understanding of dementia within the individual's social-psychological milieu. In this equation (Figure 6) there is an emphasis both on personhood as well as on individual characteristics involved in the dementing process (Kitwood, 1993, p. 541).

$$SD = P + B + H + NI + SP$$

SD= clinical manifestation of dementia; P= personality (in the sense of resources for action); B= biography; H= health; NI= neurological impairment; SP= social psychology

Figure 6 Kitwood's equation for dementia (1993)

Focus on personhood implies that the patient is considered above all as a person, despite decline in cognitive and functional abilities. Focus on individual characteristics, as modulating factors, allows the understanding of the great variability observed in cognitive and non-cognitive symptoms among individuals with dementia. In summary, Kitwood's model gives directions for addressing both the biomedical and the psycho-social needs of persons with AD.

Based upon existing models of dementia, Spector & Orrell (2010) proposed a comprehensive and pragmatic biopsychosocial model of dementia that differentiates between biological (i.e., physiological) and psychosocial processes involved in the disease. Moreover, this model allows the study of the interrelationship between the two processes and distinguishes between fixed (i.e., unchangeable) and tractable (i.e., susceptible of change) factors (Figure 7).

Within this perspective, dementia is seen as a dynamic process in which the interaction between factors determines the disease progression and the effectiveness of interventions. The authors also suggested that the use of non-pharmacological approaches in complement to medical care, endorsed by this model, would help to improve quality of life and reduce excess disability in those with AD. This objective could be accomplished by focusing on the individual's preserved capacities, what the person can do, rather than on the diminished abilities.

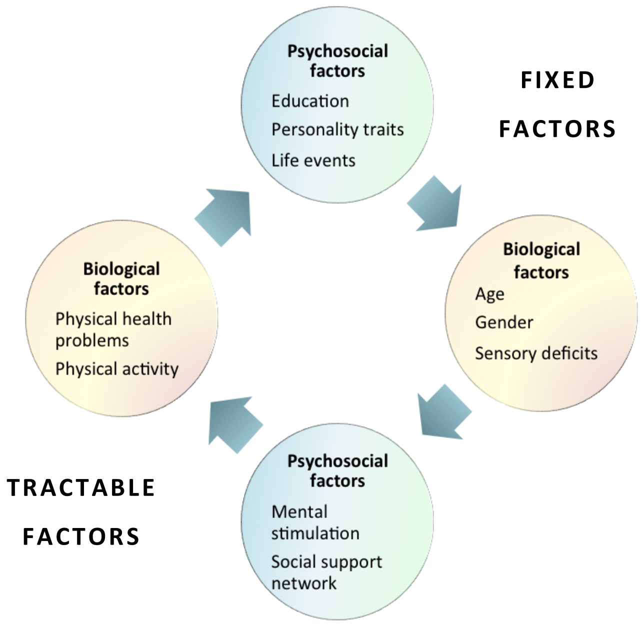


Figure 7 Biopsychosocial model of dementia adapted from Spector & Orrell (2010)

Finally, since one of the objectives of this work is to examine the theoretical framework that supports the development and use of AT for elderly with cognitive impairment, the relation between disability and dementia care models could be summarized as follows (Figure 8):

(a) Medical models of disability and dementia focus on the impairment (disability) resulting from a health condition (e.g., neurodegenerative brain disorder in the case of dementia). These models call for a treatment of the symptoms, and coexisting conditions, usually involving pharmacological therapy (i.e., treatments for cognitive impairment or anti-dementia drugs and for behavioral and psychological symptoms).

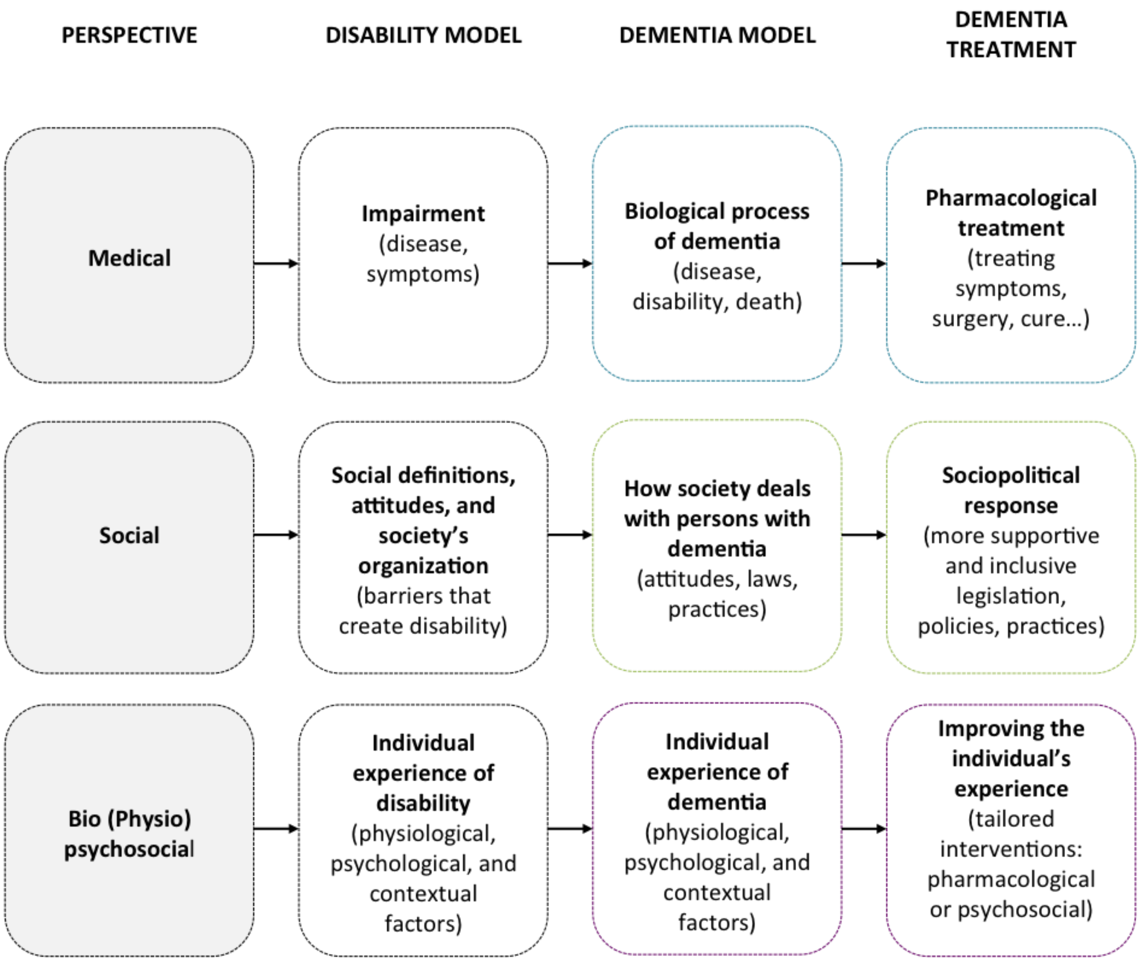


Figure 8 Relation between disability and dementia care models

(b) Social models of disability and dementia focus on societal factors that create disability. In this approach disability is not considered as an intrinsic characteristic of the individual; it is rather the society that fails fail to integrate individuals with dementia. Thus, disability is viewed as an outcome produced by social factors (e.g., attitudes, organization). Within these models, sociopolitical solutions are required to promote the inclusion of elders with dementia (e.g., inclusive legislation, design, and practices).

(c) Biopsychosocial models propose an approach that encompasses both, physiological and psychosocial factors. In this perspective, biomedical and social models are not mutually exclusive. Therefore, good practice for dementia care might involve pharmacological and non-pharmacological interventions, which are seen as complementary strategies, as long as they serve the needs of people with dementia and their caregivers (e.g., person-centered care).

2.2.4 Looking for a Broad and Balanced Perspective

The preceding sections have presented how functional capacity is affected in later life by cognitive impairment and the role of psychosocial and physiological factors in this process. Also, it has been discussed how theoretical models of disability and dementia have an influence on the implementation of care and supporting services for older adults with AD. According to this frame of reference, three ideas appear to be of critical importance when designing interventions that meet effectively the needs of individuals with MCI or AD and their caregivers:

1) **Individuals with AD experience increasing disability while some of their capacities remain unimpaired**

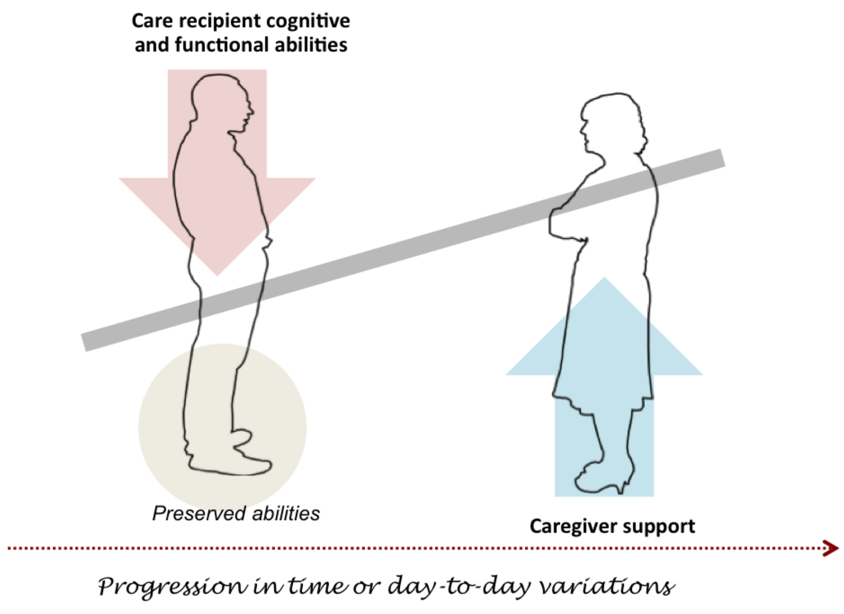
Cognitive and functional deficits in AD tend to worsen with time. Progressive decline alongside with neuropsychiatric symptoms contribute to disability. For this reason AD is one of the main causes of institutionalization of elderly people, affecting both quality of life and life expectancy (see section 2.1.4). However, it would be reductive to consider AD exclusively under the perspective of “loss and decline” by ignoring preserved capacities such as some cognitive skills, emotion processing, non-verbal communication, personality characteristics, and life history variables (Figure 9). Also, it is fundamental to keep in mind that AD patients can expect to live actively many years after the diagnosis. To the extent that patient’s preserved capacities and strenghts can be used to implement appropriate and effective care strategies these factors should be taking into consideration when conducting a clinically relevant assessment of his/her needs. Such approach “opens the possibility to take measures to reduce the extent of possible resulting disability and one way to this is through the use of appropriate assistive technology” (Alzheimer’s Europe, 2010, p. 16) (Figure 10).

2) **Individuals with AD need increasing assistance for everyday functioning from informal caregivers, which in turn need increasing external support**

As disability increases the need of assistance and support to manage everyday activities will also become more important (Figure 9). Nearly all persons with AD will need, at some point of their lives, support in everyday activities. It has been estimated that family members and other informal caregivers provide in average 80% of care at home (Alzheimer's Association, 2012). The demands put on caregivers can range from providing verbal prompts, supervision and minimal assistance in early phases of the disease, to complete physical guidance for daily tasks and continuous care in most advanced stages. As a result, family caregivers have high burden levels, associated to depressive and anxiety disorders. The caregiver burden increases significantly as functional and cognitive impairment limit the ability of the patient to care for him/herself. Consequently, caregivers could benefit in turn from external sources support, such as AT applications, which have proven effective in reducing caregiver burden (Schulz et al., 2002; Topo, 2008) (Figure 10).

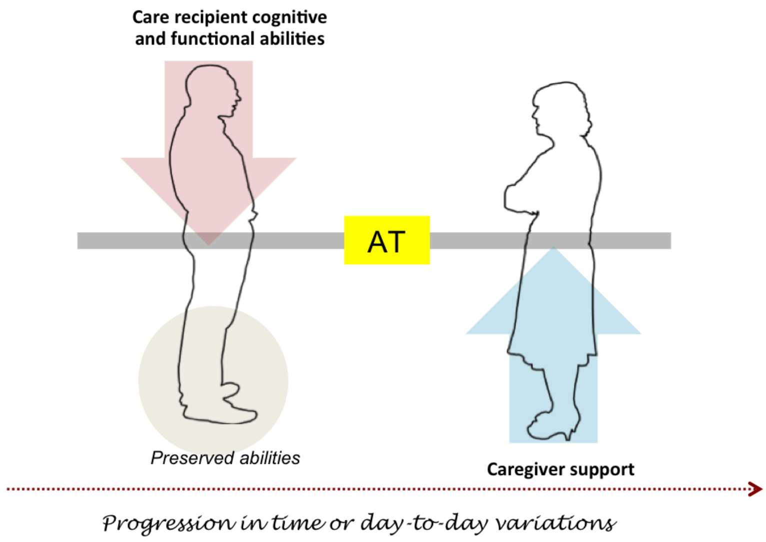
3) Inter-individual heterogeneity of AD and possible fluctuations

Functional limitations generally become more evident and more restricting with the progression of dementia. Still, people with AD differ in the patterns of deficits they experience and in the rate with which their abilities change. In addition, AD patients can show day-to-day cognitive and behavioral fluctuations that affect functional abilities and influence the need of assistance for everyday functioning. This is a challenging issue when designing assistive devices for persons living with AD that requires adopting a dynamic approach that is sensitive to the disease progression and/or symptoms fluctuations (Figure 9, 10).



In persons with AD cognitive and functional capacities decline as the disease progresses whereas other abilities remain stable. The grey bar represents an inverse correlation between the decrease in capacities observed in AD and the increase in the amount of help required from a caregiver. This relationship is not static and will fluctuate over time, being influenced, for example, by day-to-day variations and the progression of the disease.

Figure 9 Care recipient -caregiver interaction over time/day.



AT might contribute to a redistribution of caregiving duties and help persons with dementia remain autonomous for a longer period of time. AT solutions should build on the person's strengths and have the potential to adapt to day-to-day variations observed in persons with AD and to the progression of the disease over time.

Figure 10 Care recipient -caregiver interaction over time/day and support role of AT

2.3 Non-Pharmacological Approaches for Older Adults with Cognitive Impairment

As mention above, MCI has multiple contributing causes and there is a large variability of symptoms among individuals. Currently, there are no widely accepted treatment guidelines for MCI (Palmer, Musicco, & Caltagirone, 2010). However, there is a range of potential interventions for individuals with MCI, both pharmacological and non-pharmacological, which has been the focus of recent research (Chertkow et al., 2008).

In the field of dementia, biological models have dominated over the past decades having a considerable influence on diagnosis and care strategies (Dröes et al., 2010). Within this approach medication has been widely used as a first-line treatment for the cognitive and psycho-behavioral symptoms of AD (Rozzini et al., 2007; Shah et al., 2008). Indeed, although there is no cure for AD, a number of symptomatic pharmaceutical treatments are recommended by professional guidelines (Alzheimer's Association, 2012; Neugroschl & Sano, 2009; Waldemar et al., 2007). However, in recent years, non-pharmacological interventions for persons with dementia and their caregivers have gained an increasing popularity, particularly, when it concerns the management of agitation and aggression associated to AD (Ballard et al., 2009; Douglas, 2004).

Non-pharmacological treatment is a general term that refers to the various therapies that do not involve medication. The term has often been used in parallel to, and sometimes interchangeably with, the term *psychosocial intervention* defined as “the aid or care that is offered to reduce or prevent the mental or behavioral problems that occur in the process of adaptation to the consequences of dementia” (Dröes et al., 2010, p. 147). The current interest in these interventions is supported, on one hand, by the adoption of a more holistic approach to AD in which psychosocial and person-centered care strategies are promoted (Edvardsson et al., 2008; Hoe & Thompson, 2010; Spector & Orrell, 2010). On the other hand, a growing body of evidence-based research has proven the efficacity of non-pharmacological therapies in this field (Ballard et al., 2009; Moniz Cook, Swift, James, Malouf, De Vugt, Verhey, 2012; Woods, Spector, Jones, Orrell, & Davies, 2005; Woods, Aguirre, Spector & Orrell, 2012). As a result, current clinical guidelines endorse the use of an integrated approach for the management of dementia that involves both pharmacological and psychosocial interventions[7] (Alzheimer's Association, 2012; Grand, Caspar & MacDonald, 2011; NIA, 2011; WHO, 2012).

Persons with MCI can benefit from different non-pharmacological treatments including cognitive interventions and the management of risk factors for AD and of somatic disorders (e.g., diet, physical activity, life-style changes). These interventions may be beneficial to the overall health of persons with MCI, however, at present time, there is not enough evidence to assess their potential benefits in preventing or hindering the conversion to AD (Palmer et al., 2010). Non-pharmacological interventions for AD include a variety of therapies focused on the person with cognitive impairment (patient), on the caregiver, and on both of them.

When focused on the patient (Figure 11), these treatments are designed to support and enhance cognitive function, help the person maximize his/her preserved abilities, reduce psycho-behavioral symptoms, and promote overall safety, autonomy, social participation and quality of life in persons with AD (ADI, 201; De Rotrou, 2012; Douglas, 2004; Zeisel & Raia, 2000).

The scope of non-pharmacological interventions focused on the patient with AD is quite broad. They could be grouped into four main application domains as follows[8]:

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[7] In France, public health recommendations for the treatment of AD from the High Authority for Health (HAS) include from a biomedical perspective: specific pharmacological treatment, the management of coexisting conditions and of nutritional status, and from a psychosocial perspective: the use of non-pharmacological interventions focused on cognition, psycho-behavioral symptoms, communication, physical activity, quality of life, support for caregivers, and referral to social services regarding financial and legal information (HAS 2011).

[8] In the practice an overlap might exist between these interventions.

- **Cognition:** Cognitive Interventions refer to structured programs that are intended to maintaining cognitive functioning and optimize preserved capacities. They can focus on specific cognitive processes (e.g., episodic or procedural memory, selective or divided attention), cognitive strategies (e.g., mnemonic methods), residual cognitive capacities that can still be used when others are impaired, or global activities involving cognitive and other kinds of components, such as physical activity, social or occupational activities (Park, Gutchess, Meade & Stine-Morrow, 2007; Willis and Schaie, 2009). Several approaches can be used in this context: cognitive stimulation, cognitive training or cognitive rehabilitation (Clare, Woods, 2004). The content of these programs comprise test-like tasks, modeled after those used in neuropsychological assessment, or tasks related to daily activities (e.g., grocery shopping, taking care of finances). Outcomes measures for these interventions include neuropsychological assessment of cognitive abilities (e.g., MMSE, ADAS cog), psychological measures of self-esteem and quality of life.

- **Functional abilities:** The objective of these methods is to support elderly people with cognitive impairment so that they can live safely and independently in their own homes and communities for as long as possible. Interventions in this area include customized training programs for specific daily tasks, AT, and physical design to support independent functioning (Zeisel, 2011). Outcomes measures for these interventions include functional assessment (e.g., ADL, IADL), psychological measures of self-esteem and quality of life.

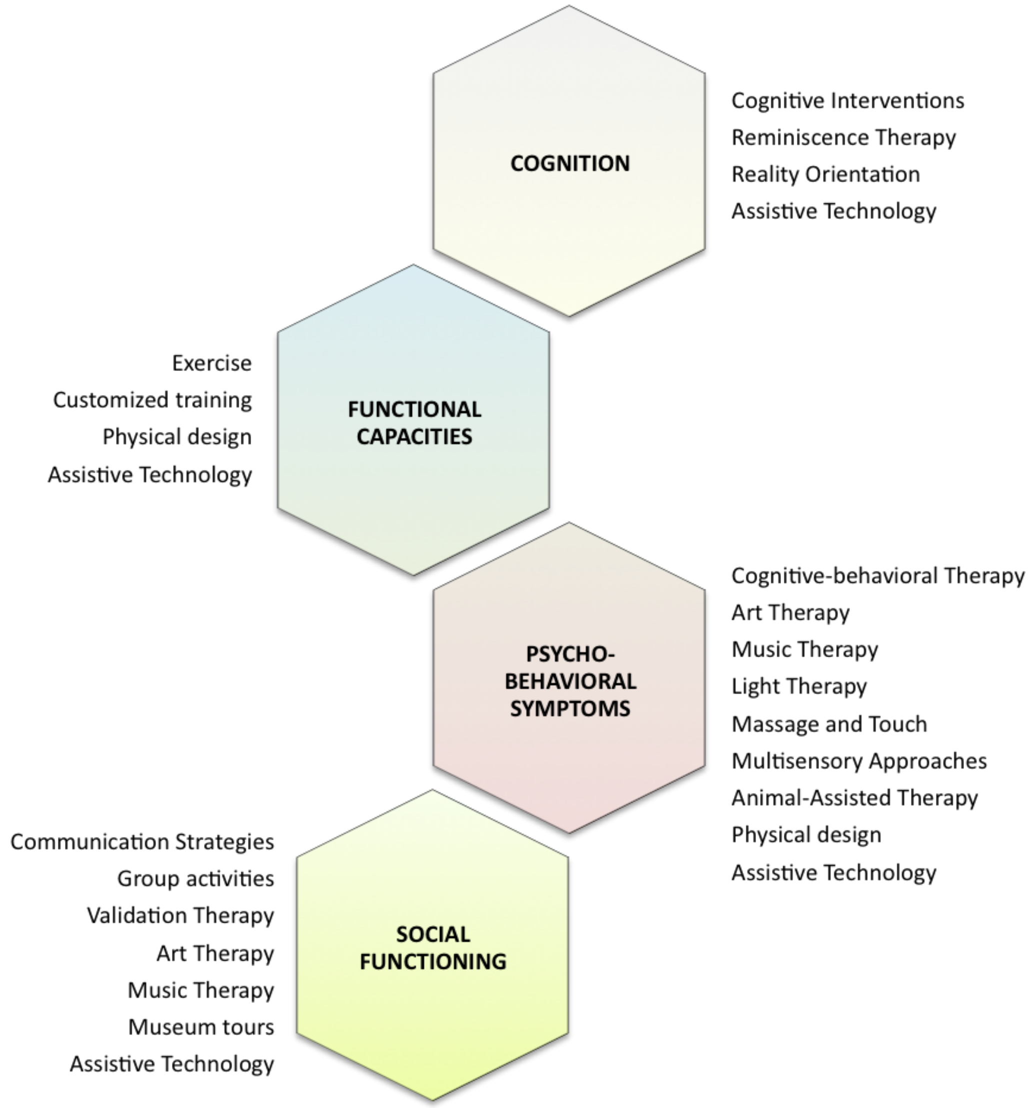


Figure 11 Non-pharmacological interventions for AD focused on the patient

- **Psycho-behavioral symptoms:** Symptoms such as apathy, agitation, mood disorders, disinhibition and manifestations of psychotic (hallucinations, delusions) have a negative impact on the quality of life of persons with AD and cause considerable stress in caregiver. Indeed, the severity of symptoms is correlated with caregiver burden (Mohamed, Rosenheck, Lyketsos, & Schneider, 2010). Psycho-behavioral symptoms are also a major cause of institutionalization of patients (Allegri et al., 2006). Interventions in this area are aimed at reducing these symptoms through the use of therapies involving music, multisensory stimulation, animals, light, massage and touch, physical design or occupational activities (Zeisel, 2011). Outcomes measures for these interventions include neurobehavioral assessment (e.g., Cohen-Mansfield Agitation Inventory), psychological measures of self-esteem and quality of life.

- **Social functioning:** The ability to engage in spontaneous verbal interactions and conversation responsiveness can be affected by AD. In addition, specific language disorders, usually observed throughout the disease, have a negative impact on social participation (Dickens, Richards, Greaves, & Campbell, 2011; Douglas, 2004). Interventions focused on social functioning are designed to promote community integration for the persons with cognitive impairment and to provide them with opportunities of social interaction (e.g., art therapy, music therapy, activity therapy, museum tours) (Zeisel, 2011). This category can also classify therapies that focus on identity and self. For example, reminiscence therapy and reality orientation are approaches that use personal material, positive and significant to the person, with the purpose of reminding him/her of facts about him/herself. Outcomes measures for these interventions include the assessment of social participation, social interaction, self - esteem and quality of life.

When focused on informal caregivers, psychosocial interventions are intended to improve psychological symptoms resulting from the caregiving situation, such as stress, anxiety and depression. They include educational programs, which target different issues related to the management of the disease such as communication strategies (Haberstroh, Neumeyer, Krause, Franzmann & Pantel, 2011), cognitive reframing techniques (Vernooij-Dassen, Draskovic, McCleery & Downs, 2011), and other solutions to improve caregiver burden (e.g., Cognitive Behavioral Therapy, counseling, care support, respite care). Finally, interventions focused on formal caregivers object to facilitate the management of patients and to prevent burnout and stress in care staff (Hoe & Thompson, 2010). A variety of combined approaches that focus both, on the informal caregiver and the person with dementia, also exist (For a review see Smits et al., 2007).

2.3.1 Assistive Technology and Gerontechnology

It is increasingly recognized that technology, when used appropriately and ethically, has the potential to support elderly people with cognitive impairment and their caregivers (Buettner, Yu, & Burgener, 2010; Carrillo, Dishman, & Plowman, 2009; Cahill, Macijauskiene, Nygård, & Faulkner, 2007; Dishman & Carrillo, 2007; Hagen, 2007; et al., 2007; LoPresti, Bodine, & Lewis, 2008; Nugent, 2007). Various terms have been used to refer to ICT-based products and services that are used to support people for supporting and assistive purposes: cognitive prosthetics, telehealth, pervasive computing, technology-based reminding support (Van der Roest, Wenborn, Dröes, & Orrell, 2012). However, the most widely used term to define these systems is Assistive Technology (AT).

There are a number of definitions of AT each of them describing in a different way the products, purposes and outcomes they refer to, for instance:

- *"AT is any product or service designed to enable independence for disabled and older people".* (UK, The King's Fund, 2001)
- *"Any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities"* (US, Assistive Technology Act, 2004).
- *"An umbrella term for any device or system that allows individuals to perform tasks they would otherwise be unable to do or increases the ease and safety with which tasks can be performed"* (WHO, 2004).

A recent and more comprehensive definition of AT was provided by Hersh & Johnson (2008a, p. 196):

> *"Assistive technology is a generic or umbrella term that covers technologies, equipment, devices, apparatus, services, systems, processes and environmental modifications used by disabled and/or elderly people to overcome the social, infrastructural and other barriers to independence, full participation in society and carrying out activities safely and easily".*

As it was highlighted before, concerning the terms of disability and dementia, the way AT is defined can also be interpreted according to a wider conceptual framework. In this regard, Hersh & Johnson (2008a) pointed out that the terminology used to define AT reflects the influence of a particular model of disability (i.e., biomedical, social, biopsychosocial). By analyzing AT concepts, it is possible to suggest a correspondence between disability, dementia and AT definitions as described in Figure 12. Two factors require careful consideration; first, from a social perspective the term "Accessible Technology" is preferred over Assistive Technology, because the former emphasizes the role of technology in making human activities accessible, rather than the need of assistance (Ladner, 2010); and second, it is important to acknowledge that although the relationship between models is presented as linear, an overlap may exist among them.

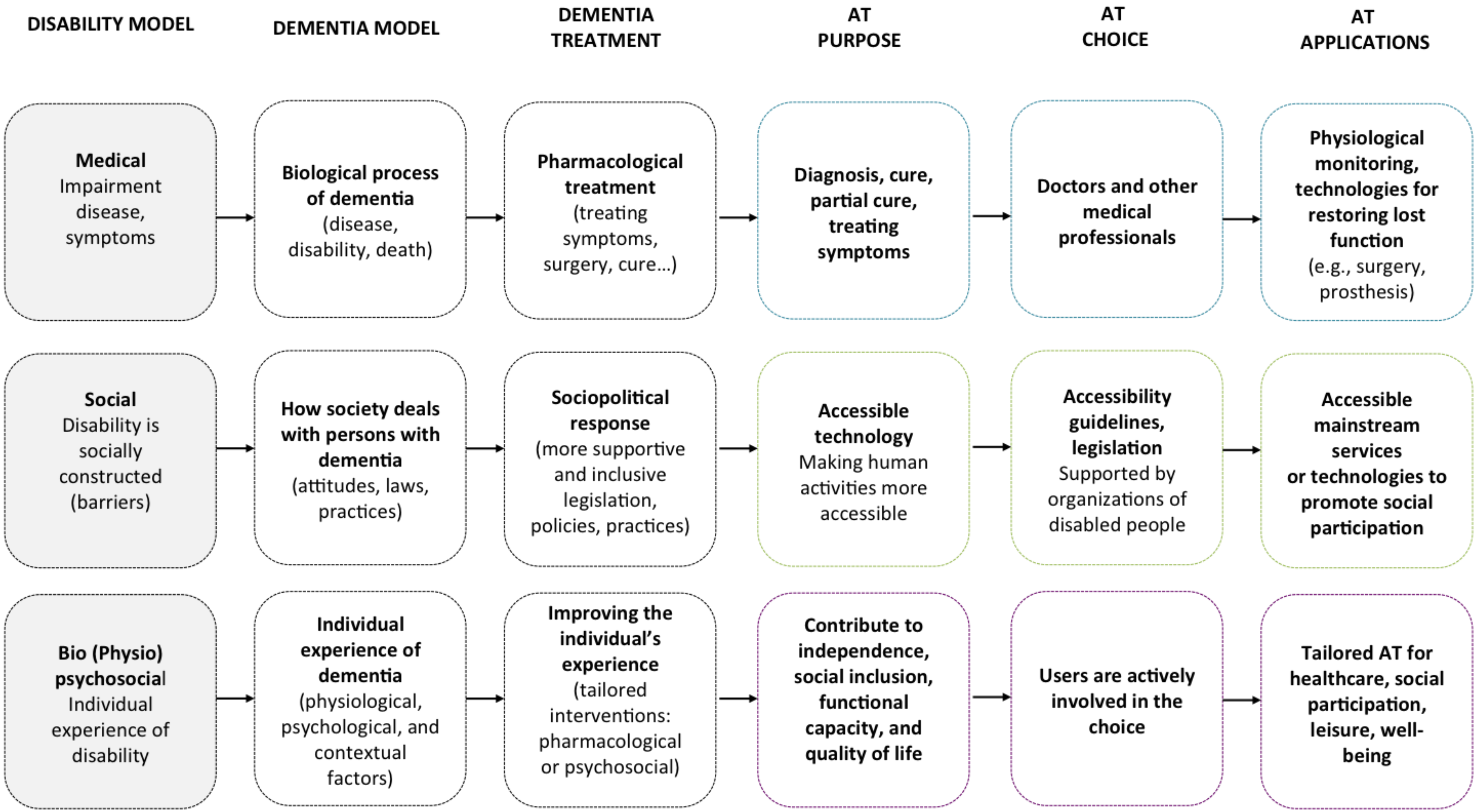
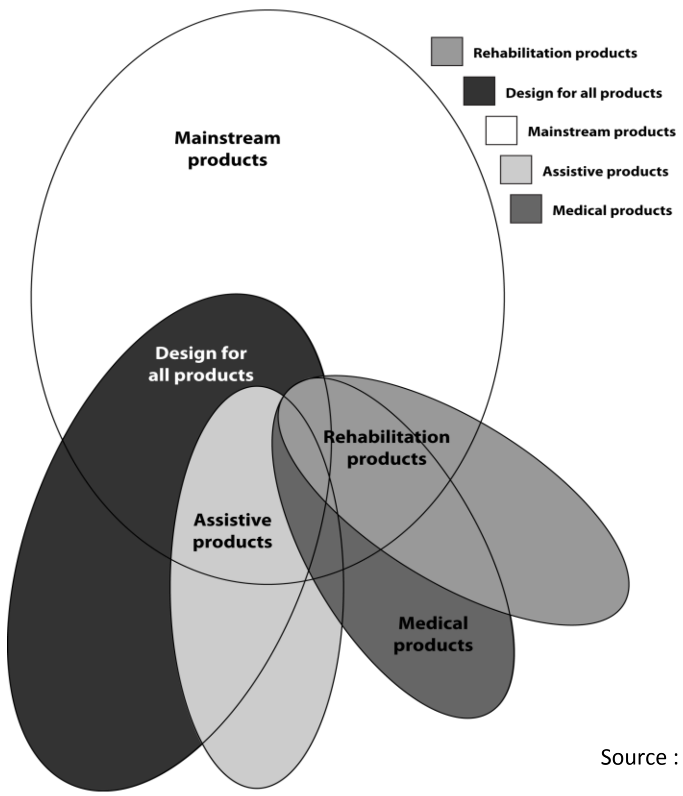


Figure 12 Relation between disability, dementia, and objectives and applications of AT

In Hersh & Johnson's (2008) definition of AT it is particularly noteworthy that the specifications of "use by disabled and/or elderly people" and "use to overcome different types of barriers" help to distinguish between AT and the use of mainstream technologies by disabled people. However, they recognized that these categories comprise the two ends of the same continuum, and that over time, what is currently considered AT may become a component of a mainstream product for which design for all[9] principles are applied, i.e., "Accessible Technologies" (Ladner, 2010). Figure 13 illustrates the relationships between mainstream, design for all, assistive, medical and rehabilitation products (Hersh, 2010). The intersection of the ovals indicates the overlap between the different concepts.



Source : Hersh (2010)

Figure 13 Relationship between mainstream, assistive, rehabilitation, medical products and design for all products

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[9] Design approach which aims to make products accessible and usable by as wide as possible a range of users, regardless of different factors (e.g., disability, age, size, culture, ethnic background or class)

2.3.1.1 The Field of Gerontechnology

Bouma, Fozard, & Bronswijk (2009) pointed out that GT is an application-oriented endeavor in which scientific research focuses on understanding the needs of elderly people and matching them with suitable innovative and existing technology. Consequently, the field of GT draws upon a wide range of disciplines. With regard to this aspect, Bouma et al. (2009, p.73) proposed a conceptual matrix of the main discipline groups of aging and technology that are associated to GT (Figure 14). The interceptions in the matrix refer to different concepts, applications and methods that are relevant to GT.

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		Technology discipline					
		Chemistry Biochemistry	*Architecture Building*	*Information Communication*	*Mechatronics Robotics*	*Ergonomics Design*	*Business management*
Ageing discipline	*Physiology Nutrition*	- Preventive nutrition	- Experimental housing - Healthy indoor environment	- Telecare	- Biorobotics - Resource sharing (man-vehicle)	- Individual differences - User participation - Inclusive design - Standardization	- Care management innovation
	Psychology Social psychology		- Experimental housing - Domotics	- Situated learning - Temporal discount & benefits - Technology acceptance - Persuasive technology - Domotics - Navigation tools		- Individual differences - User participation - Inclusive design - Standardization	- Technology acceptance - Persuasive technology - Targeted marketing
	Sociology Demography			- Technology generation (protocols)	- Technology generation (protocols)	- Technology generation (user interface)	- Targeted marketing
	Medicine Rehabilitation	- Preventive drugs - Perceptual implants (materials)	- Healthy indoor environment	- Perceptual implants (signal processing) - Modelling restrictions - Telecare	- Biorobotics - Resource sharing (man-vehicle)	- Self medication - Telecare	- Care management innovation

Figure 14 Interdiscipline matrix of gerontechnology (Bouma et al., 2009)

It is easier to understand how AT is placed within the framework of GT when one considers how technology can serve the goals of elderly people with cognitive impairment. Bouma et al. (2009, p.74) provided another conceptual matrix to represent the potential of

GT to help elderly people achieve their goals in different life domains (Figure 15). The interceptions in this matrix present some examples of products and services corresponding at the same time to a daily life domain and to a particular human goal.

It is interesting to note that if the definition of AT provided by Hersh & Johnson (2008) is used, AT could be linked not only to the GT goals of compensation/assistance and care support/care organization but to all of them. Three reasons that can explain this relationship between AT and GT are: 1) Hersch & Johnson (2008) definition of AT emphazises social participation as a goal, this feature is also found in in the GT matrix for the goal of enrichment and satisfaction (Bouma et al., 2009); 2) Both conceptual frameworks consider the role of contextual factors (personal and environmental), and 3) Both perspectives take into consideration the overlap that may exist between assistive and mainstream products. Nevertheless, while both GT and AT focus on the elderly population, AT also targets people living with a disability regardless of their age.

	Life domain				
Goal	*Health* *Self-esteem*	*Housing* *Daily living*	*Mobility* *Transport*	*Communica-tion* *Governance*	*Work* *Leisure*
Enrichment *Satisfaction*	- Self care - Self assessment	- Remote con-trol	- Timetables	- House phone - Surface mail - Ticket ma-chines - Fax machines - Alpha-numeric key-boards	- Mechanical miniature camera - TV-remote control - CD - Menu style UI
Prevention *Engagement*	- Home trainer - Accelerometer - anti-oxydative stress supple-ments - Strength train-ing programme	- Sheltered housing - Natural venti-lation - Safety illumi-nation - Thermostat	- Handrails - Sturdy grip	- Noise abate-ment	
Compensation *Assistance*	- Active alarms	- Jar openers - Barrier-free design	- Rollator-walker - Wheelchair - Elevator	- Hearing aids - Antiglare spectacles - Telephone with number memory - Cordless phone - Speech output	- Power tools - Focused lighting - Virtual dolls - Easy opening cans
Care support *Care organiza-tion*			- Powered lifting devices	- Active alarms	

Figure 15 Impact matrix of gerontechnology (Bouma et al., 2009)

2.3.2 The Use of AT as a Non-Pharmacological Intervention in MCI and AD

Several AT products and services have been designed over the last years to meet the needs of persons with cognitive impairment and their caregivers. Indeed, different literature reviews have provided a comprehensive analysis of the use of AT among older adults with MCI or AD (Bharucha et al., 2009; De Joode, Van Heugten, Verhey, & Van Boxtel, 2010; Gillespie, Best, & O'Neill, 2012; LoPresti et al., 2004; Nugent, 2007; Pollack, 2005).

In this context, AT serves many purposes: to contribute to the autonomy and quality of life of the person with cognitive impairment, to prevent or delay nursing-home placement, to support caregivers on their task, and to reduce the costs associated to home-care (e.g., personal nursing services). This is the case of video surveillance systems, wearable or environmental sensors (e.g., fall detectors, smart carpets, smoke detectors, actimetry sensors, mobile tracking devices), technologies for memory support (e.g., pill boxes, electronic calendars), cognitive stimulation software, and social assistive robotics, among others. Furthermore, some authors have distinguished between general assistive devices and AT focused on cognition, also called Assistive Technology for Cognition (ATC) (Gillespie et al., 2012; LoPresti et al., 2004, 2008; Pollack, 2005). ATC is intended to support people with cognitive impairment on daily activities and to help them compensate for their deficits (e.g., attention, executive function, prospective memory, task monitoring, and sequential processing). These interventions have also addressed information processing deficits that may affect language, sensory abilities, or the understanding of social cues (LoPresti et al., 2008).

Lauriks et al., (2007) have provided an insight into the state of the art in ICT solutions that could contribute to meet the most frequent needs of patients with dementia and their caregivers. Needs were inventoried and classified into four areas:

- *Generalized and personal information* about the disease, healthcare service offerings, legal and financial issues, support services, and care planning.

- *Support with regard to everyday problems* that arise from symptoms of dementia. AT which aimed at compensating for disabilities such as memory problems and daily activities in the form of reminders (to take medication or keep appointments) have proven efficacious in stimulating cognitive functions as well as enhancing feeling of independence and autonomy in the person with AD. Studies showed that a person with AD is able to handle AT, and also benefits in terms of confidence and enhanced positive affect, thereby indirectly reducing the caregiver's perceived burden.

- *Social contact and company* could be effectively realized through simplified mobile phones or videophones that have been reported to facilitate communication between persons with cognitive impairment and their family or friends. Increased activity and communication levels were observed with computer software providing music or video memories or robotics such as a toy dog or an entertainment robot.

- *Health monitoring and perceived safety.* The authors observed that implementing monitoring technologies and detection devices or alarm systems inside and outside the home of the elderly person contributed to enhanced perceived safety and security of the person suffering from dementia as well as the caregivers. AT can also be used to continuously assess the elder's cognitive and health status which can be useful health professions, i.e. monitoring patient status.

With the purpose of responding to aforementioned needs, there is a wide range of AT products and services, intended to be used by older adults with cognitive impairment, that vary according to their scope and complexity (Table 11).

Table 11 AT for older adults with cognitive impairment (MCI, AD)

Domain	**Objectives**	**Examples**
Prevention and security	Reducing the risks of accidents at home (falls, fires, floods, etc.)	Devices that automatically detect environmental hazards (fall sensors, monitoring systems to detect fire, gas leakage, or water overflow, room thermostats, etc.)
	Supporting orientation and spatial navigation in outdoor/indoor environments	GPS, tracking and navigation systems
	Notifying relatives and health care professionals in case of emergency	Home wireless safety alarms, passive infrared devices, automated data collection and transmission
Health monitoring	Recording and measuring the activity of the patient to define behavioral patterns allowing the detection of anomalous situations and assistance in case of emergency	Internet of things, sensors and devices embedded into everyday objects (under carpet motion sensors, signal night time activity, RFDI reader chips, micro and nano technologies,)
	Monitoring certain physiological parameters to prevent or detect situations that require medical intervention	Biomedical sensors, automated data collection and transmission (blood pressure, glucose levels, weight, pedometer)

Domain	Objectives	Examples
	Facilitating follow-up of chronic medical conditions	Telehealth, assistive robots
Cognition	Compensating cognitive deficits that can affect daily task completion by providing cues, reminders, and sequential guidance	Task monitoring systems, automated prompting systems embedded in everyday objects for supporting daily activities (hands washing, meal preparation, medication intake, location of items)
Stimulation and socialization	Reinforcing the residual cognitive capacities of the patient	Cognitive training software and cognitive games (TV, radio, box internet, game consoles)
	Helping to maintain social contact and reduce isolation	Social network, sensorial stimulation tools, physical activity monitoring systems, companion robots, algorithms that detect emotions
		Telecommunication devices using familiar and adapted interfaces (TV, radio, cell phone, tablet, picture phone)
	Encouraging the engagement of the person in leisure activities that have a positive effect on self-esteem	Applications that provide updated and location-based information about cultural and entertainment activities, applications that provide creative activities; technology for relaxation
Support caregivers	Providing personalized information about caregiving activities	Online psycho-educational programs, support networks, telephone-mediated services, video or audiotapes, and interactive television

2.3.3 Issues that Merit Further Consideration

- The majority of AT applications that might be used in dementia care have been developed originally for younger persons with typically nonprogressive traumatic or anoxic brain injuries, which raises concerns about their generalizability to dementias (Bharucha et al., 2008).
- Although many AT products and services have been developed over the past decades to assist older adults with cognitive impairment, usability issues have not always received the attention they deserve (Demiris et al., 2004; Van der Roest, 2012). This is important since psychological barriers related to the use of technology are common among older adults and they appear to be more significant in those with dementia (Hawkey, Inkpen, Rockwood, McAllister, & Slonim, 2005).
- Different studies have confirmed that AT acceptance and the willingness of elderly people to use AT depends on several factors: the user's "felt" need for help, perceived usefulness

of AT, and individual preferences (McCreadi & Tinker, 2005). The match between AT and user needs has also been found to be one of the most important predictors of long-term use of AT (Scherer, Sax, Vanbiervliet, Cushman, & Scherer, 2005). However, the research to date has tended to focus separately on technological innovation issues, and users' needs and acceptance issues. Consequently, a priority in this field should be the study of these factors within the process of design and development of AT solutions, and not outside from it.

- Subjective and identity-related factors associated to the use of AT have been overlooked by the literature and should be properly addressed. These aspects include: elderly people's views on prospective AT users (Demiris et al., 2004; Neven, 2010), whether the person feels that use of AT either supports or weakens his/her sense of personal identity (McCreadi & Tinker, 2005), and the feelings about becoming a user of AT for the first time, which has been found to be a very difficult step to take (Valkila, Litja, Aalto, & Saari, 2010).
- Some studies have found that despite the potential of AT and the growing number of AT products and services that are affordable, accessible, and available on the market, clinicians may not implement them, in part because they may be uncomfortable or inexperienced with technology (Sohlberg, 2011).
- The limited systematic training that persons with cognitive impairment and their families receive to learn to use AT devices may constitute another barrier to their effective use (Sohlberg, 2011).
- Privacy regulations and other ethical issues have a strong influence on people's attitudes toward AT (Demiris et al., 2004) (Perry, Beyer, & Holm, 2009)
- Outcomes regarding the efficacy of AT have primarily addressed functional improvement within limited specific domains of daily life. Nevertheless, other clinical and care-related outcomes have been overlooked, such as the global impact of AT on the user's quality-of-life and well-being, and the effects of AT on formal and informal caregivers (Van der Roest et al., 2012).

2.4 Conclusions

MCI and AD are among the most common causes of cognitive decline in elderly individuals. Also, progressive cognitive decline has a negative impact on functional abilities, quality of life, autonomy, and life expectancy. Cognitive impairment in elderly individuals impacts as well family members and other informal caregivers, since they provide most of the care.

As the number of older adults with cognitive disabilities increases there is a social and economical demand to find cost-efficient solutions to support them on their daily life activities and help them live safely at home for as long as possible. Furthermore, in order to provide them with optimal care and support it is fundamental to conceive adaptive solutions that can evolve with their needs.

Health professionals, families, patients, and policy makers are turning to AT to find alternative methods to deal with the increasing need for healthcare due to aging demographics. However, the use of AT for these purposes still poses many challenges in terms of acceptability, usability, accessibility, and ethical issues that need to be addressed to ensure their successful implementation. It has also been highlighted that the terminology used to describe disability, dementia, and AT may be carefully analyzed since it underpins different conceptual frameworks, which have important implications for the design and implementation of AT solutions.

3 HUMAN FACTORS IN THE DESIGN OF ASSISTIVE TECHNOLOGY

This chapter provides an overview of the field of Human Factors/Ergonomics (HF/E) and covers the definition of basic concepts related to the design and development lifecycle of AT. Two conceptual frameworks for the definition of AT systems are here described: the Human Activity Assistive Technology model (HAAT), and the Comprehensive Assistive Technology model (CAT). Some design approaches are also reviewed: Product-Centered Design, Universal Design, User-Centered Design, and User-Sensitive Inclusive Design. Then, some of the main HF/E techniques are described and matched to the phase(s) of the product development lifecycle in which they are usually employed.

3.1 Scope of Human-Factors/Ergonomics

Human Factors/Ergonomics (HF/E) is a multidisciplinary field that studies human-system interactions and, more specifically, aims to ensure that systems are adapted to the sensory, perceptual, cognitive and motor capabilities of potential users, as well as to their needs and preferences. The primary goal of this discipline is to guarantee that users of a system are able to accomplish the tasks they desire to undertake efficiently and in a safe, error-free, comfortable, and satisfying manner (Rogers, Mayer & Fausset, 2010). The International Ergonomics Association (IEA) provides the following definition of HF/E:

> "*Scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well being and overall system".* (IEA, 2000)

Cognitive ergonomics, also called "cognitive engineering", is a branch of HF/E that specifically studies the cognitive functions (e.g., perception, learning, memory, problem solving) involved in human-system interaction for the execution of a task, taking into account the context of the interaction (Gersh, McKneely & Remington, 2005). Cognitive ergonomics aims at improving task effectiveness by reducing the execution time, number of errors, and learning time to use a system, and globally improve user satisfaction (Cañas, 2008). Relevant topics of HF/E are mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress, and training the user to work more efficiently with tools and environments (IEA, 2000).

3.1.1 HF/E and AT Design

HF/E techniques are used to assess human performance and understand the demands (cognitive, perceptual, motor) placed upon individuals, by systems and the environment, to perform everyday tasks. They have the advantage of being applicable to a wide variety of products and populations (Rogers et al., 2010). Thus, HF/E tools are a valuable aid to: (a) identify the needs of people with cognitive disabilities, (b) guide the design of AT products and services aimed to support them in everyday activities, and (c) understand the technological, psychological, or social barriers that may prevent AT use (LoPresti, Bodine & Lewis, 2008).

Charness & Holley (2001) have pointed out that adopting a HF/E approach when designing products and services for people with AD and their caregivers can help to better understand the capabilities of these individuals and to make more effective design decisions, such as providing them with environmental support (e.g., prompting devices can be used to remind individuals with memory impairment to perform a task at the appropriate time, or to provide them with step-by-step task guidance).

When designing AT systems for people with cognitive, physical, or sensory impairments, two HF/E techniques are particularly useful: task analysis and mental workload analysis. Task analysis consists in decomposing tasks into identifiable steps (e.g., goals, operations, plans) in order to anticipate errors or problems that users may encounter when interacting with a system and to make recommendations for mitigating or eliminating these problems (Fisk, Rogers, Charness, Czaja, & Sharit, 2009). Mental workload refers to the relation between the mental resources demanded by a task and the resources or skills to be supplied by the user (Parasuraman, Sheridan, & Wickens, 2008). Sometimes indeed, human capacities may restrict the use of certain systems, consequently the achievement of certain tasks. If the mental workload inherent to a task exceeds the capabilities of the user, the interaction with the system may result in unproductive, dangerous or frustrating outcomes. Thus, mental workload analysis helps to ensure that AT design does not exceed user capabilities.

To sum up, the study of user, system, and context characteristics undertaken by HF/E practitioners can help to develop AT solutions best suited to users. For this purpose, a fundamental step in the design of AT is to define these characteristics and establish an appropriate *function allocation* between users and technology (Cañas, 2008). This means determining which functions will be carried out by AT and which by users, anticipating the possible contexts of use.

3.1.2 Knowing the User

Defining the target user group of an AT product or service requires the description of some general characteristics of users, including health status, capabilities and limitations in terms of sensory, perceptual, cognitive and motor functions. User profiles must also include sociodemographic factors and the living situation of the person (e.g., place of residence, housing characteristics, professional occupation, technology experience, areas of interests, social networks). Rogers et al. (2010) have proposed a list of commonly asked questions relating to the user group that can be useful to identify user-system problems, their source, and potential solutions (Table 12). General guidelines, direct observations, surveys, questionnaires, and interviews can serve to answer these questions.

Table 12 General questions related to the user-group profile definition

General characteristics	Who are the users? Is the design for a single user or for multiple users? What are the cultural differences between users? What is the average age of the intended user population?
Physical characteristics	What is the average body size of the user population? Do users have mobility problems that restrict normal body movements? What are the strength characteristics of the users?
Perceptual characteristics	What are the visual capabilities of the users? What are the auditory capabilities of the users? Do important perceptual differences exist between users?
Cognitive characteristics	What are the users' memory capabilities and limitations? What are the users' attentional capabilities and limitations? What decisions does the user have to make? What learning is required of the user?

Source: Rogers et al., (2010, p. 42)

Data from the experimental literature on cognitive aging can be useful to characterize user groups of older adults and to define some design specifications. Table 13 provides general characteristics of three subgroups of older adults: healthy elderly individuals, persons with MCI, or AD. Fisk et al. (2009) and Pak & MacLaughlin (2011) provide an interesting work on age-related changes to consider when designing technological products, environments, systems and training programs for elderly users. We refer to their work for a more detailed analysis on these issues.

Table 13 General characteristics of three subgroups of older adults

<table>
<tr><th></th><th>Healthy individuals</th><th>Individuals with MCI</th><th>Individuals with AD</th></tr>
<tr><td>Cognitive functioning</td><td>- Decline in working memory
- Semantic memory is usually preserved, but the retrieval is slower
- Prospective memory can be weakened, but some strategies can help to compensate for this deficit (contextual association, cognitive aids)
- Procedural memory is preserved for well learned behaviors, but performance is usually lower, and learning new procedures is less efficient
- Attentional processes and information processing are usually affected, particularly for complex tasks.
- Language comprehension is preserved</td><td>Add to the problems encountered in normal aging:
- A cognitive impairment reported by the patient and/or a knowledgeable informant that can be objectively assessed by neuropsychological tests and/or an increase in execution time objectified by cognitive tasks;
- Memory deficits mainly impact the tasks of information retrieval
- Difficulty to encode information effectively during the learning phase
- Regarding semantic memory, there may be some deficits in the identification of familiar faces
- Difficulties to plan or monitor behavior when carrying out complex activities
- Diminished ability to maintain information in working memory
- Difficulties to focus attention on some tasks</td><td>- Presence of multiple cognitive deficits including (APA, 1996):
1. A memory deficit (inability to save new information or return previously acquired information);
2. One (or more) of the following difficulties:
a. aphasia (language impairment);
b. apraxia (inability to perform fine motor acts despite intact motor function);
c. agnosia (failure to identify or recognize objects or persons despite intact sensory function);
d. disturbance in executive functioning (planning, organizing, sequencing, abstracting).
- The procedural memory remains intact for a long time for well learned behaviors, but execution time is slower than in normal aging
- Learning new procedures is possible, but requires repeated and systematic training of the task</td></tr>
<tr><td>Motor skills</td><td colspan="2">- Older adults have slower reaction times than younger adults
- Fine motor skills are slightly affected in normal aging: problems with coordination, reduced accuracy, slowness
- An increased loss of balance, posture and gait may develop with age, affecting autonomy
- There is a general decrease in muscle strength, but it does not appear to significantly affect the small muscles of the hand</td><td>- In addition to problems encountered in normal aging, gross motor skills can become impaired (walking and sitting) as well as fine motor skills (buttoning a shirt, holding a spoon)
- Cognitive impairment and dementia are risk factors for falls among elderly people (Vassallo al., 2009)</td></tr>
<tr><td>Sensory capabilities</td><td colspan="2">- Hearing decline is common, especially for high frequency sounds
- Visual acuity diminishes after the age 40 years
- Hypersensitivity to light
- Decreased depth, color and contrast perception
- Tactile sensitivity and the quality of proprioception decreases</td><td>- In addition to visual problems encountered in normal aging, deficits in the perception of contrast, movement, and a reduced visual field can be observed
- Disturbances in complex visual functions such as reading, visual-spatial exploration and the identification and naming of objects can also appear (Richard, 2009)</td></tr>
</table>

	Healthy individuals	Individuals with MCI	Individuals with AD
Technology experience	- In general, older adults use less technological applications than young adults, especially women - The use of technology is influenced by socio-educational level, needs and attitudes towards technology - In Europe, 36% of people aged 55-64 use a computer daily, and 16% in the age group of 65-74 (Eurostat, 2010)		- In addition to the facts observed in normal aging, the presence of cognitive impairment restricts the possibility of learning to use new technologies - Up to a certain stage of the disease, technologies that were used before the onset of cognitive impairment may still be usable
Social environment	- People aged 55 and over are mostly retired (71.3%), living in couple (74.6%), and without their children (84.0%) (Dickens et al., 2011) - The prevalence of social isolation among elderly people is estimated between 7 and 17% across studies. 40% of people aged over 60 years report feeling lonely (Institut National de Prévention et d'Education pour la Santé [INPES], 2005)		- Patients can live at home or in institutions according to disease severity - The presence of cognitive impairment is an aggravating risk factor for isolation, in part because it progressively inhibits the abilities to communicate - At home, most patients receive help from a family member or a professional
Psycho-behavioral disorders	- The prevalence of Major Depressive Episodes during the past 12 months is 4.6% in the 65-75 years age group (Dickens et al., 2011) - Loneliness and widowhood are risk factors for depression - Other mood disorders can be observed including anxiety		- Apathy (decrease in social activities, lack of interest, social withdrawal) - Emotional upset (anxiety, aggression, agitation) - Depression increases dramatically in hospitalized patients and long-term care residents (Gebretsadik et al., 2006) - Psychotic symptoms (delusions, hallucinations)
Everyday functioning	Activities of daily living are usually preserved	Basic activities of daily living are preserved but some difficulties can be observed in complex instrumental activities (budget management, medication intake, use of public transportation)	Progressive impairment, first in complex instrumental activities of daily living including housework, cooking, telephone use and then in the most basic daily activities such as bathing, walking, eating

Finally, because general guidelines cannot cover all the details required to design personalized AT products and services (LoPresti et al., 2008), the definition of a complete user profile will require the use of interviews, questionnaires, neuropsychological or cognitive testing or other data-collection methods (e.g., techniques from medicine or cognitive neuroscience).

3.1.3 Defining the System and User-System Interaction

In addition to the definition of user profiles, it is important to describe the properties of the system and the interaction between the user, the system and the context. Concern regarding the interrelationship of these three factors is one of the reasons why the use of *human performance models* is very common in HF/E. The main purpose of human performance models is to capture some aspects of human behavior in an activity-related context. One of the most renowned models is the one proposed by Bailey (1989), specifically conceived to conceptualize the process of design and application of technology. Bailey's Human Performance Model basically describes that for any human performance there are three major components that should be considered: the human, the activity, and the context (Figure 16). By analyzing the role of each component and studying the relation between them, for a particular case, it would theoretically be possible to predict human performance.

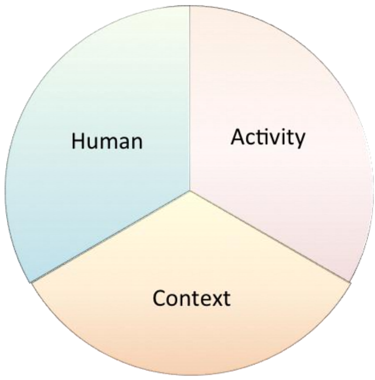


Figure 16 Human Performance Model (Bailey, 1989)

In general, system analysis can be conducted by using different techniques such as task analysis, previously described, and process diagrams, which are a way to graphically represent the main components of the task (Rogers et al., 2010). The primary goal of these procedures is to identify and anticipate the indicators for success and failure for each step of the task (Annett & Stanton, 1998). Table 14 provides a set of general questions that can be helpful to make a general description of the system and of user-system-context interaction.

Table 14 General questions related to the definition of system characteristics and user-system interaction

System characteristics	What is the purpose of the system? What tasks are involved? Is the system automated? What are the system inputs and outputs?

	What sort of feedback is provided by the system? What instructions have been provided? What is the context of use?
Environmental characteristics	What are the lighting conditions of the environment? How much clutter is in the environment? How much noise is in the environment and what are its sources? Is the system operating outdoors or indoors?
User-system interaction	What are the cognitive (memory, attention, information processing) demands on the user? What are the perceptual (visual and auditory) demands on the user? What are the user's experiences in relation to the system? What are the task demands? Are multiple users interacting? How much workload is placed on the user?

Source: Rogers et al., (2010, p. 42)

Heuristics, or rules for system design, are also useful to define the characteristics of a system. Heuristic reviews consist in comparing a set of established principles commonly accepted to the system in question (Lazar, Feng, & Hochheiser, 2009). Fisk et al. (2009) have proposed some general guidelines for effective interface design for older adults. These recommendations cover different categories: physical characteristics of the system, navigational issues, information organization, and general conceptual issues such as conveying current system status, providing feedback on task completion, enabling error recovery and ensuring design adaptability and flexibility for different user levels.

Finally, it is worth pointing out that the evaluation of some general aspects of the system can be conducted without the involvement of users. On the contrary, the study of user-system interaction requires user involvement. These techniques will be described later in this chapter.

3.2 Human-Performance and AT Models

AT models are largely inspired by human performance models used in HF/E, thus, they incorporate the same basic scheme: user, activity, and context; their specificity is that they include AT within the system. In the field of AT, theoretical models serve several purposes, such as the design, development and evaluation of AT products and services, and the improvement of professional practice, research, and policy development (Hersh 2010, 2011; Lenker & Parker, 2003). Besides, some AT models can be used to evaluate the outcomes of AT products, either at a particular moment or through repeated assessments over time (Cook & Hussey, 2002; Hersh & Johnson, 2008b; Fuhrer, Jutai, Scherer, & DeRuyter, 2003).

Although several models and theoretical frameworks for the classification or the assessment of AT outcomes exist (For a review see Bernd, Van Der Pijl, & De Witte, 2009), to date only two models have focused on the definition of AT systems: the Human Activity Assistive Technology model (HAAT) proposed by Cook & Hussey (2002) and the Comprehensive Assistive Technology model (CAT) proposed by Hersh & Johnson (2008a). Indeed, some of the authors that have investigated this topic agree that this is a poorly developed field in which further research is needed (Bernd et al., 2009; Hersh & Johnson, 2008; Lenker & Parker, 2003). In addition, neither the HAAT nor the CAT model has ever been used in the field of dementia.

3.2.1 HAAT Model

The Human Activity Assistive Technology model (HAAT) was proposed by Cook & Hussey (2002) to improve the understanding of how AT can enhance human performance (Figure 17). The model was directly adapted from the Human Performance Model of Bailey (1989) to which the AT component is added.

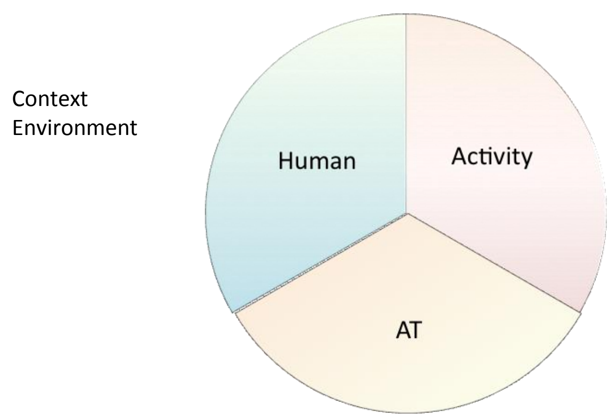


Figure 17 Human Activity Assistive Technology (HAAT) model

Key components of the HAAT model include:

- Human: a person with disabilities who controls a number of intrinsic enablers (e.g., sensory input, central processing, and effectors or motor output). The combination of physical and psychological capabilities and limitations is taken into account.

- Activity: tasks or operations that the individual intends to achieve in areas such as self-care, work/school, and leisure/play.
- AT: extrinsic enablers such as human/technology interface, processor, environmental interface, that contribute to enhance the individual's performance.
- Context and environment: factors related to the social, cultural, and physical context in which the person and the AT have to operate, and the setting or location in which the activity takes place.

This model contributes to the understanding of dynamic and sometimes complex interactions between the various components of the model that should be considered when implementing AT solutions. For instance, Cook and Hussey discussed the role of personal assistants (e.g., caregivers) often combined with the use of AT (Bernd et al., 2009). The authors also insisted on the importance of measuring the effectiveness of the AT system. To this end, the authors proposed a framework for AT delivery that includes three key stages: device procurement, introductory use, and longer-term use (Figure 18).

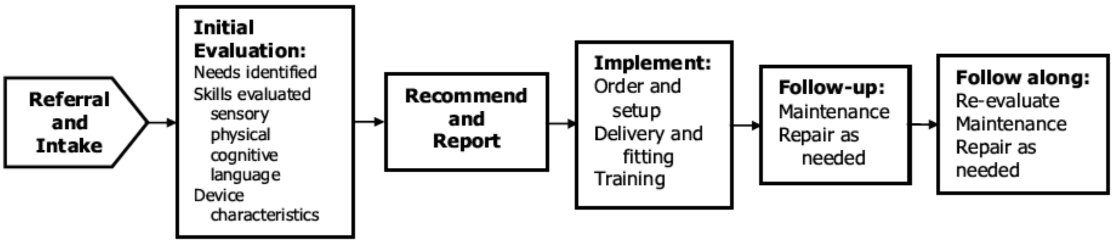


Figure 18 Framework for AT system delivery after the HAAT model (Cook & Hussey, 2002)

Some limitations of the HAAT model have been pointed out including: (a) the lack of specificity to describe in detail the 'human' and 'activity' components; (b) its emphasis on the rehabilitation aspects which reflects the influence of the medical model of disability (e.g., disability is seen as residing in the person and the main goal of AT is performance enhancement and compensation), which would make it unsuitable to cover a wider range of human and AT domains, and (c) having a tendency towards Product-Centered rather than User-Centered design approaches (Hersh & Johnson, 2008a).

3.2.2 CAT Model

Hersh & Johnson (2008a, 2008b) proposed the Comprehensive Assistive Technology (CAT) model, that was developed out of the HAAT model in response to the need of widening the flexibility and applicability of a modeling framework for AT. In contrast with the HAAT model, influenced by the medical model of disability and Product-Centered Design approaches, a social model of disability and User-Centered Design approaches are prevalent in the CAT model.

One of the main contributions of the CAT model is that it offers a detailed analysis of each one of its components: person, context, activities, and AT. Factors that are relevant to these components are organized in a tree structure (Figure 19).

Person- P

P.1 Characteristics
- P.1.1 Personal information
- P.1.2 Impairment (e.g., sensory, cognitive, physical, mental health or others)
- P.1.3 Skills
- P.1.4 Preferences (e.g., type of interface, device appearance)

P.2 Social aspects
- P.2.1 Community support (e.g., family, friends)
- P.2.2 Education and employment

P.3 Attitudes
- P.3.1 Attitudes to assistive technology
- P.3.2 General attitudes (e.g., self-esteem, self-identity, motivation, perseverance)

Context- C

C.1 Cultural and social context
- C.1.1 Wider social and cultural issues
- C.1.2 User's social and cultural context

C.2 National context
- C.2.1 Infrastructure
- C.2.2 Legislation
- C.2.3 Assistive technology context

C.3 Local settings
- C.3.1 Location and environment
- C.3.2 Physical variables

Activities- A

A.1 Communication and Access to information
- A.1.1 Inter-personal communications
- A.1.2 Access to print media
- A.1.3 Telecommunications
- A.1.4 Computer and Internet access
- A.1.5 Communication using other technology

A.2 Mobility
- A.2.1 Reaching and lifting
- A.2.2 Sitting and standing
- A.2.3 Short distance locomotion inside and outside
- A.2.4 Long and medium distance locomotion
- A.2.5 Movement on ramps, slopes and stairs

A.2.6 Obstacle avoidance
A.2.7 Navigation and orientation
A.2.8 Access to environment

A.3 Cognitive activities

A.3.1 Analysing information
A.3.2 Logical, creative and imaginative thinking
A.3.3 Planning and organising
A.3.4 Decision making
A.3.5 Categorising
A.3.6 Calculating
A.3.7 Experiencing and expressing emotions

A.4 Daily living

A.4.1 Personal care
A.4.2 Timekeeping, alarms and alerting
A.4.3 Food preparation and consumption
A.4.4 Environmental control and using appliances
A.4.5 Money, finance and shopping
A.4.6 Sexual and reproductive activities

A.5 Education and employment

A.5.1 Learning and teaching
A.5.2 Professional and person-centred
A.5.3 Scientific and technical
A.5.4 Administrative and secretarial
A.5 5 Skilled and non-skilled
A.5.6 Outdoor working

A.6 Recreational activities

A.6.1 Access to visual, audio and performing arts
A.6.2 Games, puzzles, toys and collecting
A.6.3 Holidays and visits: museums, galleries, heritage sites
A.6.4 Sports and outdoor activities
A.6.5 DIY and craft activities
A.6.6 Friendships and relationships

Assistive Technology - AT

AT.1 Activity specification

AT.1.1 Task specification
AT.1.2 User requirements

AT.2 Design issues

AT.2.1 Design approach
AT.2.2 Technology selection

AT.3 System technology issues

AT.3.1 System interface
AT.3.2 Technical performance

AT.4 End-user issues

AT.4.1 Ease and attractiveness of use
AT.4.2 Mode of use
AT.4.3 Training requirements
AT.4.4 Documentation

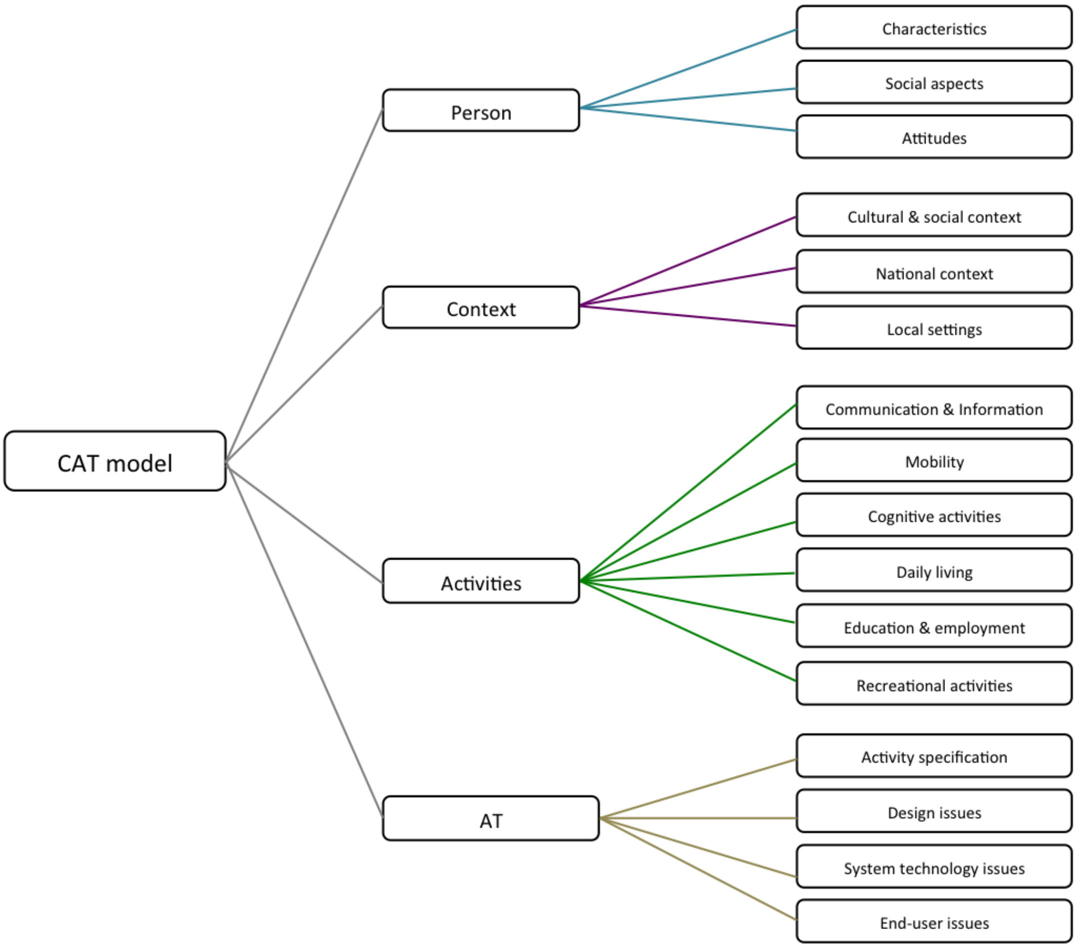
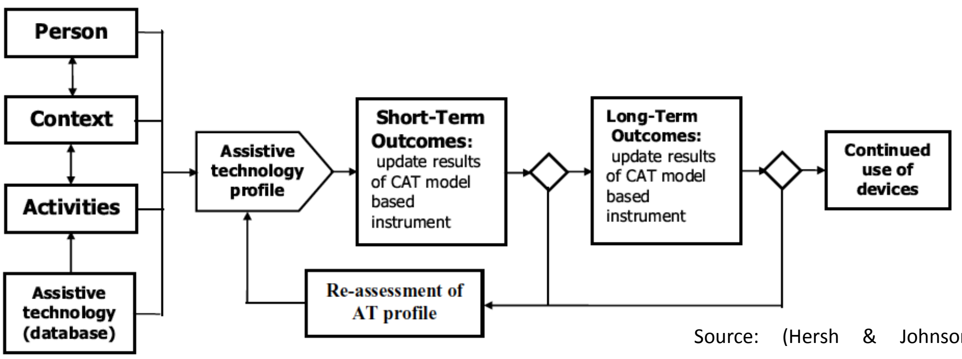


Figure 19 Comprehensive Assistive Technology (CAT) Model

Among the possible applications of the CAT model are: the identification of new areas of human functioning for which AT could provide a solution, the analysis of existing AT solutions, the formulation of guidelines to inform the design of new AT devices, either for a particular individual or user group, and the assessment of AT outcomes and AT profile over time to evolving needs of individuals with disabilities (Figure 20).



Source: (Hersh & Johnson,

Figure 20 CAT model in end-user assessment and device provision process

3.3 Design Approaches

3.3.1 Product-Centered Design

Product-Centered Design (PCD) is a conventional design approach that refers to the methods used to conceive and manufacture a product whose features, functionalities, and uses reflects the perspective of designers or manufacturers. Within this approach the manufacturer or another stakeholder different from the end-users (e.g., company, health professionals) decides which kind of product or service should be implemented. Consequently, design is understood as a formal process in which the product is derived from a set of specifications previously defined (Denning & Dargan, 1996) (Figure 21). When a designer uses a PCD the focus is on the product and innovation, the object of design is product efficiency (Norman, 1993), and the value of design is associated with the product quality factors defined by the manufacturer (Prahalad & Ramaswamy, 2004).

One of the criticisms of PCD is that in this approach users have to adapt their behavior to accommodate new products and not inversely (Norman, 1993). Consequently, there is little connection between the designer's actions and users' concerns. Actually, in PCD user involvement is limited to the documentation of requirements and specifications and the final sign-off (Denning & Dargan, 1996). A long established practice in this approach is *user modeling* that consists in developing a model of "typical users" to predict real users' behavior (Van Rijn, Johnson, & Taatgen, 2011). This implies assuming a degree of homogeneity within the group of prospective end-users. However, sometimes the use of guidelines and user models is not enough to cover all the possible interactions between a user and a system in a specific situation; indeed, guidelines are based on generalizations. This situation is more critical when end-users include persons with special needs or disabilities, because of the heterogeneity observed in these populations (LoPresti et al., 2008). The divergence between what the user values, needs, and is able to do and the manufacturer's own view of the product or services, which often results in high product dropout rates, is one of the reasons that have contributed to a change of paradigm, from PCD approaches to User-Centered Design approaches (Prahalad, 2004).

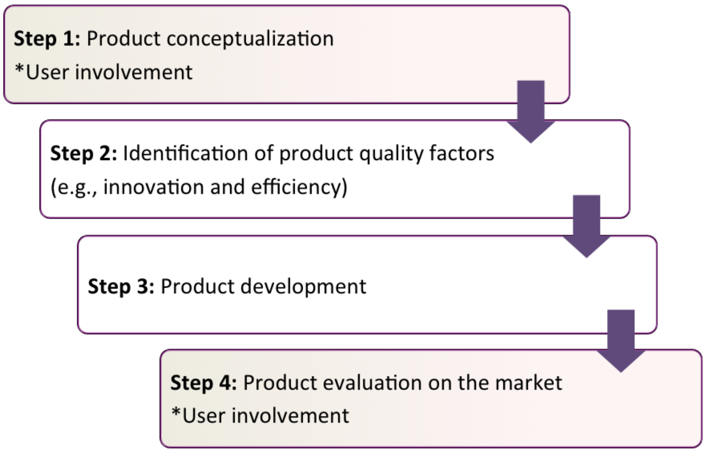


Figure 21 Product-Centered Design cycle

3.3.2 Universal Design

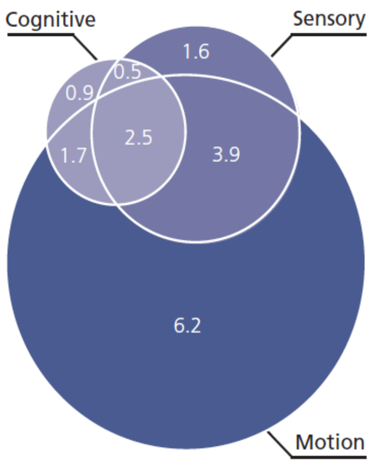
Universal Design (UD) and related approaches such as Design for All (Design for All Foundation, n.d.), or Inclusive Design (Keates & Clarkson, 2003), refer to a set of practices aimed at conceiving and developing *"products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design"* (Center for Universal Design [CUD] of North Carolina University, 1997; Mace, 1985). The concept emerged in the field of architecture but was later transferred to the design of all kind of environments and products, particularly in the area of human-machine interaction (e.g., hardware, software, media, and communication) (Bühler, 2001).

Central to the approach of UD is the idea of giving equal treatment to people with disabilities or not and providing them with equal opportunities for participating in society. The focus is on *inclusivity* at a social level through the conception of products and services that can accommodate, to the greatest extent possible, all kinds of users without stigma (Clarkson & Keates, 2002). The CUD (1997), institution in which the term of UD was coined, provided a set of guidelines for its practice:

(1) Equitable Use: The design is useful and marketable to people with diverse abilities.
(2) Flexibility in Use: The design accommodates a wide range of individual preferences and abilities.
(3) Simple and Intuitive Use: Use of the product is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

(4) Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
(5) Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions.
(6) Low Physical Effort: The design can be used efficiently and comfortably with minimal fatigue.
(7) Size and Space for Approach and Use: Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

One of the most common methods of UD is to examine and quantify *design exclusion*, or the total number of users that will be excluded from the use of a product (Clarkson, Dong, Keates, 2003). This technique allows designers to identify the shortcomings of a product and to improve its design. Design exclusion is measured first by evaluating product features against user capabilities, and then by calculating the proportion of prospective users who do not have the required level of capabilities to use the product. For this purpose three categories of user capabilities are taken into account: motion, cognition, and sensory.



Source: Clarkson et al. (2003)

Figure 22 Prevalence (%) of multiple capability losses in older adults + 65 (Great Britain)

Although UD has the potential of contributing to improve product usability in conventional design, UD practices might not always be useful when users with multiple or severe impairments are concerned. Clarkson et al. (2003) have pointed out that usually in elderly users multiple capability losses account for product exclusion (Figure 22). Also, because elderly people and persons with disabilities are very heterogeneous groups in terms of capabilities and limitations, UD is "a very difficult, if not often impossible task" (Newell, Gregor, Morgan, Pullin, & Macaulay, 2011, p. 236). For instance, in many cases improving some aspects of the design to make it accessible to a group of users may reduce usability for other groups of users (Pak & MacLaughlin, 2011).

A solution that has been suggested is to take into consideration the needs of the broadest user group possible and to make some design improvements to adapt the final design to the needs of the users who were initially excluded (Bühler, 2001). However, Newell et al. (2011) argued that this solution is not optimal, first, because it implies the application of UD principles at the end of the design cycle, which can lead to greater costs and compromise the design for both the traditional and marginalized groups of users. Also, because considering the customization of the product for marginalized groups of users as an “add-on” can be patronizing and demeaning.

In response to these critics, Pak & McLaughlin (2011) suggested to think of UD as a philosophy that often proves useful to make products and services usable by people with the widest possible range of abilities. Still, they have suggested keeping in mind that sometimes it is more convenient to design customizable interfaces that can be tailored to different users rather than a single design. Similarly, Newell et al. (2011) concluded that UD is not entirely appropriate when designing for older people and individuals with disabilities and proposed the use of ‘‘User-Sensitive Inclusive Design”, a new methodology better adapted to these particular users (see 3.3.3.1).

3.3.3 User-Centered Design

User-Centered Design (UCD) comprises the techniques, processes, and procedures that emphasize placing the user at the center of the design process with the purpose of designing usable products and systems (Rubin & Chisnell, 2008). Within this approach, users’ needs shape the product and not inversely. Consequently, users are not expected to adapt their behavior to the product, as in PCD (Norman, 1993). The standard 9241-210 of the International Standardization (ISO) describes as characteristics of UCD (ISO 9241-210, 2010): (a) The design is based upon an explicit understanding of users, tasks and environments; (b) Users are involved throughout design and development; (c) The design is driven and refined by user-centered evaluation; (d) The process is iterative; (e) The design addresses the whole user experience, and (f) The design team includes multidisciplinary skills and perspectives.

Rubin & Chisnell (2008) have summarized the principles of UCD as follows:

a) Early focus on users and tasks: This includes involving users throughout the entire design and development lifecycle and considering users' needs and requirements as the primary objective of the design. In this context, *needs* refer to the area of difficulty for the person on which no or inappropriate support is provided (van der Roest, 2009) and *requirements* to the necessary attributes that a system must have in order for it to have value and utility to the user (Young, 2001). Technical and social/environmental requirements are normally deduced to satisfy user requirements.

There is a large volume of published studies describing the benefits of involving end-users in the development and evaluation of technological products. For instance, Shah & Robinson (2007) conducted a literature review in which they examined several studies that involved users in the development of medical devices and technologies. Among the most commonly found benefits associated with user involvement were: the generation of ideas by users, having access to users' perspectives, and improvement in the design, user interfaces, functionality, usability, and quality of medical devices. However, the authors pointed out some barriers in user involvement, such as the difficulty of finding a representative group of end-users, and time and cost factors. They concluded, however, that both users and manufacturers benefit from this collaboration. On one hand, users will have access to technological products that really fulfill their needs and expectations. On the other hand, manufacturers will increase the likelihood that their products find acceptability on the market.

b) *Empirical measurement and testing of product usage:* This point refers to behavioral measurements of different factors while testing prototypes with actual users. Usability metrics are used for this purpose. There are several methods for evaluating usability and different standards and conceptual models. Seffah, Donyaee, Kline, & Padda (2006) conducted a literature review on this topic highlighting the limitations and complementarities of different usability standards. In addition, they proposed a model called "Quality in Use Integrated Measurement" that included 10 factors, each one of them corresponding to a specific usability feature that was previously identified in an existing standard or model (i.e., efficiency, effectiveness, productivity, satisfaction, learnability, safety, trustfulness, accessibility, universality, usefulness).

c) *Iterative Design:* Process in which the product is designed, modified according to the observed successes, shortcomings, and impressions, and tested repeatedly from the earliest phases of product development (e.g., conceptual models and design ideas) until a satisfactory level of usability has been achieved.

In general UCD practices are increasingly popular in conventional design and have proved to increase product usefulness and usability and the speed and costs of the design process (Garrett, 2010; Vredenburg, Mao, Smith, & Carey, 2002). Nevertheless, when designing for particular populations, like elderly people or individuals with disabilities, traditional methods of UCD appear to remain unsatisfactory for different reasons. First, the great variety that exists among users makes it difficult to constitute a group of representative users (Gregor, Newell, & Zajicek, 2002). Furtherore, UCD methods rely to a great extent on users' capacity to communicate their views on a product, which can be challenging for some user groups. Finally, UCD techniques are strongly focused on usability issues failing to consider the person as a whole (Newell et al., 2011).

3.3.3.1 User-Sensitive Inclusive Design

In response to the need of finding a suitable methodology to involve elderly people or persons with disabilities in user research, Newell & Gregor (2000) proposed the concept of User-Sensitive Inclusive Design (USID). USID is closely related to UCD and UD approaches, although this new paradigm introduced some conceptual and methodological changes with the purpose of covering the particular design requirements of older adults and persons with disabilities. Specifically, USID replaces "Centered" by "Sensitive" to reflect the great range of functionality and characteristics observed in these user groups, and "Universal" by "Inclusive" because USID considers inclusion as a more achievable goal with these populations than the conception of a single design that is usable and pleasing for any eventual user.

One of the interests of this approach when working with elderly people living with dementia is that it takes into account the changing needs of prospective users as their abilities change, due to the progression of the disease or to different states of arousal (Newell et al., 2011). In this sense USID paradigm considers the variability that exists between individuals with disabilities (i.e., inter-variability) and also the intra-variability observed in a particular person from a period of time to another (i.e., fluctuating symptoms). Finally, since the user is not considered as a static entity, the products conceived within a USID approach attach great importance to the personalization aspects and to the potential of interfaces to accommodate changes in the user's behavior (e.g., cognitive, motor, and sensory capabilities) from day to day or even moment to moment.

3.4 Product Design Lifecycle

The design lifecycle comprises a set of steps or phases for idea generation, prototyping, usability testing, and implementation of a product; these cycles can be structured in a formal (e.g., step-by-step) or informal way (e.g., ad hoc) or anywhere in between. Most of the projects that focus on developing technology-based applications have product design lifecycles that usually involve different HF/E methods (Rubin & Chisnell, 2008). Although there are a number of different examples of product design lifecycles (Pagliari, 2007), these can be categorized into two basic types: waterfall and iterative processes.

A *waterfall design process* refers to the successive development of design phases in which the output of each phase constitutes the input for the following phase (Figure 23). The specificity of this method is that as the design advances the change process is scoped down to manageable limits (Royce, 1970). Although this procedure can be practical for small and well-defined projects conceived within a PCD approach, its rigidity is a major shortcoming. In fact, in waterfall models, system requirements (i.e. attributes in a system) are fixed, which results in a static final design that restricts users and designers as it resists the implementation of desirable and necessary changes in requirements (Nuseibeh, 2001). This goes against the principle defined by Boehm (2000) as *"I'll Know It When I See It" (IKIWISI)*, which refers to the fact that requirements often emerge only after users have had an opportunity to view, interact, and provide feedback on prototypes.

With regard to the design for minority groups, such as elderly people and persons with disabilities, the limitations of using a waterfall design process are associated to the rigid methodologies of requirements gathering and design implementation that it involves. In fact, designing for these populations would necessitate a more open and flexible framework, which takes into account the wide variety of user characteristics (e.g., adaptation to the given attributes of individual users) and the evolving needs of users over short and long term periods (Gregor et al., 2002).

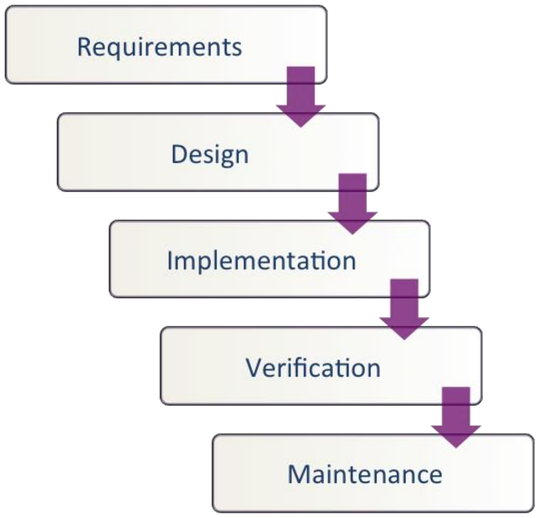


Figure 23 Waterfall design lifecycle

Iterative design methods involve a multi-stage process with frequent backtracking. This means that rework is not only allowed but also desired because one of the assumptions in this method is that requirements and solutions can only be identified and understood over time. In this sense iterative design lifecycles use a completely different methodology from the one used in waterfall lifecycles. The former are dynamic and fluid, this means that problems and solutions can be redefined at different moments of the design process, in the latter clear requirements are established and validated in the earliest phases of the design, thus assumed as fixed entities.

The use of iterative design processes is characteristic of UCD approaches; consequently, they tend to be more convenient for designing for heterogenous groups (e.g., users with disabilities, older adults) than waterfall processes. Iterative product design lifecycles (Figure 24) usually involve the following stages that may overlap or repeat (Hersh, 2010, p.7):

(a) Learning about the users and identifying their needs
(b) Using the current knowledge of the users to inform the design
(c) Presenting the users repeatedly with early prototypes for evaluation
(d) Iterative (re)-design is conducted to fix the shortcomings of the design that were identified in end-user testing, thus, evaluation and redesign are repeated as often as required

Involving the idea of iteration in design, Zeisel (1984) provided a representation of the design cycle as a spiral process (Figure 25), characterized by three aspects (a) backtracking or the return at certains points of the process to definition of the problem, which can be revised and readjusted by shifting focus (i.e., moving away rather than towards the final solution), (b) iteration, and (c) as the design process evolves, the range of potential solution narrows in the movement towards and acceptable solution (see the right part of the figure 'decision to build').

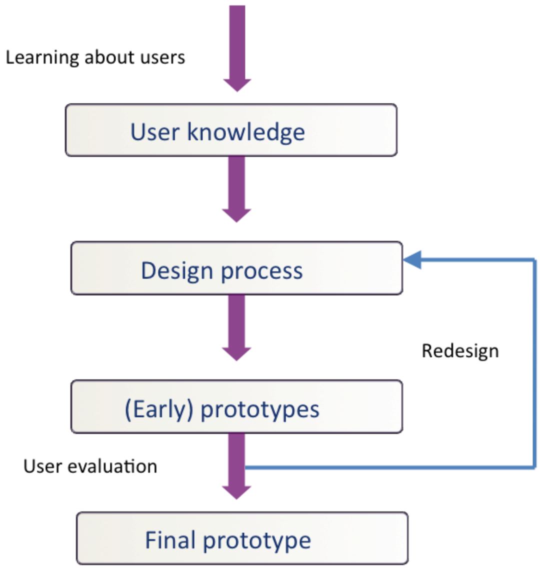


Figure 24 Iterative product design lifecycle

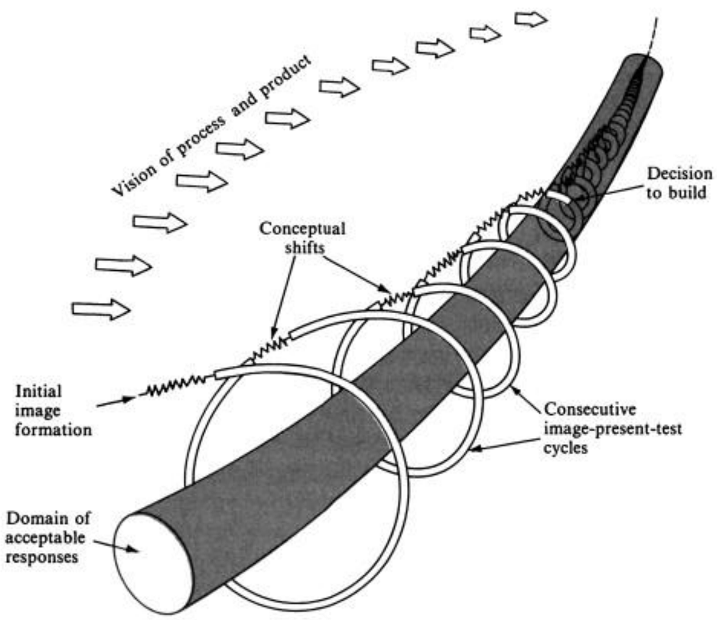


Figure 25 Design development spiral (Zeisel, 1984)

3.4.1 HF/E Methods in the Process of Product Design

HF/E provides a number of methods and techniques that can be used throughout the product development lifecycle. Some of them are focused on the user, particularly the methods that allow the definition of user profiles and requirements. Others are focused on the system and its interaction with the user. Moreover, a number of these techniques can be used for the assessment of additional factors that are not directly related to the field of HF/E, but that are equally important in product design, particularly for the development of AT solutions (e.g., ethical analysis, marketing and valorization strategies). Most of these techniques require the involvement of the user, although some of them are managed by experts and without the involvement of users (i.e., heuristic evaluations, consistency inspection, value analysis methods). In accordance, these methodologies are typically employed in UCD approaches.

Table 15 presents an overview of the principal methods employed in the product design and development lifecycle. In the following sections requirement gathering practices and usability inspection methods will be detailed. For a description of the other techniques we refer to the works of Courage & Baxter (2005), Lazar, Feng & Hochheiser (2009), and Rubin & Chisnell (2008) who have provided an in-depth analysis.

Table 15 Principal HF/E methods in user research and stages of product design

Phase	Goal	Methods
User knowledge	Definition of user profile	Interviews Neuropsychological assessment Questionnaires Socio-demographic surveys
	Needs and requirements gathering	Card sorting Collaborative workshops Ethnographic research Focus groups Interviews Prototyping Questionnaires Use case scenarios
(Early) prototypes	Prototype design and validation	Cognitive walk-through* Consistency inspection* Guidelines and checklists* Heuristic evaluations* Prototyping Storyboards Task analysis Think-aloud verbal protocols User tests Use case scenarios

Phase	Goal	Methods
Final prototype	Final product assessment	Ethnographic research Follow-up studies Interviews
Transversal analysis	Ethical analysis	Focus groups Guideline reviews Interviews
	Market analysis and valorization strategies	Focus groups Value analysis methods*

* Methods that do not require user involvement

3.4.1.1 Requirement Gathering Practices

The first step in the product development cycle is to know the user and identify the problematic situation to which the product or service designed should supply a solution. For this purpose two tasks are required: the definition of user profiles (see 3.1.2), and the identification of users' needs and requirements, which are the base upon which system specifications will be established.

User needs basically refer to problem domains on which no, or inappropriate, support is provided (van der Roest, 2009). Once a potential solution is outlined, defining requirements is the next stage. Requirements refer to the features or attributes that the product should have or how it should perform to respond to the user's needs; for instance, the tasks that the user will be able to accomplish with the new product, the kind of technology that will be used, or the functionalities that the product will provide (Courage & Baxter, 2005). Requirements can come from different sources: end-users, designers, manufacturers, or decision-makers. However, in UCD practices priority is given to user requirements (Rubin & Chisnell, 2008). It is important to note that normally, requirements cannot be gathered all at once. Hence, it will be necessary to assess them repeatedly throughout the different phases of the product design lifecycle (e.g., after direct interaction with prototypes).

Many techniques for eliciting and identifying users' needs and requirements exist (Courage & Baxter, 2005; Hickey & Davis, 2004; Lazar et al., 2009; Young et al., 2001). Among the most frequently used requirement gathering practices are:

- *Surveys:* Defined set of questions to which an individual is asked to respond. This technique has the advantage of allowing the collection of data from a larger number of people. It is also a cost/efficient method that provides an overview of a user population.

- *Interviews and focus groups:* Methods used to study users' opinions, attitudes, and feelings regarding different issues related to the design of a potential product. Their advantage is that they provide in-depth data from an individual or multiple users at one time.

- *Ethnographic research:* This method involves extended periods of observation and interaction with potential end-users in their own environments (e.g., home, workplace). The aim is to gain a better understanding of users and the context in which they would use the product. This method is useful to enrich user profiles and develop scenarios and task descriptions that have the potential to inform the design.

- *Collaborative workshops:* Collaborative, dynamic and interactive work between an expert and a group of potential end users with the aim of discovering requirements and encouraging consensus about the product specifications. Collaborative workshops are a powerful and useful method to prioritize needs and resolve contentious issues.

- *Prototyping:* This method is concerned with the development of quick and basic prototypes of a product, or some of its components, that are shown to users in order to get their feedback on product features and functionalities.

3.4.1.2 Usability Inspection Methods

Usability refers to a set of quality attributes to assess the ease of use of a product. In a general way, the usability of a system is determined by a set of criteria (Ferré, Juristo, Windl, & Constantine, 2001; Harada, Mori, & Taniue, 2010; Thyvalikakath, Monaco, Thambuganipalle, & Schleyer, 2009) including:

(a) Learnability: How easy it is to learn the functionalities of the system.
(b) Efficiency: Number of tasks that users can perform in an amount of time.
(c) Retention over time: How easy it is to remember how to use the system after a period of non-use.
(d) Error rate: Number of commission or omission errors that users make while performing a task.
(e) Satisfaction: How pleasing the experience with the system is.

Usability inspection is the generic name for a variety of methods that are all based on having evaluators inspect a product. Typically, they are all aimed at finding usability problems in a design, evaluating the severity of usability flaws, and identifying ways to improve the design. Different usability techniques exist for evaluating products, interfaces and interactive systems; these methods can be employed alone or in conjunction at different moments of the design cycle (Rubin & Chisnell, 2008). The main usability methods involving experts are:

- *Heuristic evaluations*: This technique consists in having usability specialists who are not part of the project team judge each element of the design following established usability principles (i.e., heuristics) and based on their previous experience (Fisk et al., 2009). In heuristic reviews experts put themselves in the place of the target-users for conducting the product analysis.

- *Consistency evaluations*: This technique is mostly employed for the assessment of interfaces. The experts assess the overall consistency of the system (e.g., layout, color, terminology) and compare the design with an existing set of guidelines (Lazar et al., 2009).

- *Guidelines and checklists*: Method used to evaluate fundamental issues of the design and to ensure that a number of elements have been addressed (Fisk et al., 2009).

- *Cognitive walk-throughs*: Technique used to explore how a user might interact with a product by envisioning the user's route through an early concept or prototype of the product. The evaluation requires a paper mockup or an early prototype, a task scenario, knowing the end-user population and the context of use of the planned product (Wharton, 1994).

Although expert evaluations allow the discovery of several usability problems, empirical methods are the main way of evaluating user interfaces; with *user testing* probably being the most commonly used method (Nielsen, 1994). The basic methodology for conducting a user test consists in observing how end-users interact with prototypes or final technological products to perform realistic tasks (e.g., using an electronic pill organizer, playing a videogame) (Rubin & Chisnell, 2008). During the evaluation performance and preference measures are collected (e.g., task completion time, number of tasks completed with and without assistance, ease of use, ease of learning, satisfaction). User testing helps to reveal usability problems that may hinder user experience and provides information to solve them. Furthermore, through this method, it is possible to analyze the impact of different variables on task performance (e.g. when comparing two or more groups of users with different cognitive profiles) (Lazar et al., 2009). Test sessions can be conducted in a specialized usability laboratory or in the normal context of use.

Other methods for usability inspection include:

- *Task analysis:* This method consists in dividing a task into the sequence of steps required to achieve a goal by taking into account the physical and cognitive demands placed upon the users (Pak & MacLaughlin, 2011).

- *Think-aloud verbal protocols:* Users are asked to think aloud while interacting with the product and to focus on what they are doing and why they are doing it. The purpose of this method is to discover the problems that users encounter when using a product, information that can be used to improve the design (Fisk et al., 2009).

- *Card sorting:* This technique is used to examine content organization, vocabulary, and labeling systems used, for example, in a user interface. Participants are either given a set of cards showing the content of the application without titles and asked to do the naming, or they are requested to organize the content into some preexisting categories which are written on the cards (Rubin & Chisnell, 2008).

3.5 Conclusions

This chapter provided an overview of the scope of the discipline of HF/E and the relevance of its methods for the design and development of AT. Indeed, the general purpose of AT cannot be conceived outside the *person-activity-context* system that is at the foundation of human performance models traditionally used in HF/E; it is normal, thus, that AT models (*person-activity-context-AT*) are derived from them. However, although classical HF/E methods and existing AT models provide a good basis for structuring the design process of AT for older adults with AD, some changes and adjustments are required to effectively use these tools in this context.

4 EMPIRICAL STUDIES: USER RESEARCH WITH OLDER ADULTS WITH NORMAL COGNITION, SUFFERING FROM MCI AND AD

This section presents three empirical studies and a literature reiew on the subject of AT for older adults with cognitive impairment. Each study corresponds to a specific phase of product design. Table 16 describes main charcteristics of the four studies.

Table 16 Description of the four studies included in this thesis

Study	Description	Method	Technology targeted	Population (*N*)	Ethical approval
I	User needs and requirements gathering	Focus groups, questionnaires	Social assistive robot	MCI patients (*N* = 10), AD caregivers (*N* = 7), Cognitively healthy older adults (*N* = 8)	Yes
II	Usability study	User test	GUI assistive robot	MCI patients (*N* = 11), Cognitively healthy older adults (*N* = 11)	Yes
III	Usability study incremental design	User test	Cognitive training software	AD patients (*N* = 10), MCI patients (*N* = 8), Cognitively healthy older adults (*N* = 8)	Yes
IV	Literature review on computer-based cognitive interventions	Systematic review	Software for cognitive training	AD patients (*N* = 8), MCI patients (*N* = 200), Cognitively healthy older adults (*N* = 3878)	NA
V	Ethical analysis on the design and use of AT	Analysis	AT products and services	Older adults with cognitive impairment and caregivers	N/A

4.1 Are We Ready for Robots that Care for Us? Opinions and Attitudes Among Older Adults Towards Social Assistive Robots[10,11]

Purpose: This study investigated how older people understand the concept of social assistive robotics and explored their attitudes and opinions on how such systems can support elderly individuals with cognitive impairment in everyday functioning and their caregivers in their duties. To this end, questions related to the technical and physical characteristics of the system, services and functionalities, user characteristics, societal and ethical issues, and subjective representations of the use of social assistive robots, were addressed in a mixed-method study. Specific attention was paid to the role of individual factors in technology acceptance.

Design and Methods: Twenty-five older adults ranging in age from 58 to 86 years old took part in this study. Participants were distributed in three groups: caregivers of persons with Alzheimer's disease, persons with Mild Cognitive Impairment, and healthy older adults. All participants completed a questionnaire covering socio-demographic factors, self-rated health status, attitudes towards technologies, and preferences regarding social assistive robots. Seven focus groups were conducted to elicit the opinions of participants about the use of robots at home. Material support for the discussions comprised a robot prototype and use case scenarios. In addition, graphic material from different robotics projects was used to illustrate different applications of these systems and explore the relationship between a robot's appearance and its functions. Content analysis was carried out based on recorded material from focus groups discussions.

Results: Older adults can gain an insight into the possibilities offered by social assistive robotics when clear information and concrete examples are provided. Overall results showed that older adults recognize the potential benefits of social assistive robotics for supporting everyday functioning and social participation of frail older adults, however significant differences were observed between current and future acceptance of these systems. A key theme that emerged in this study was the importance of customization of the robot's services, appearance, and social capabilities. AD caregivers and people with MCI had a higher perceived usefulness and acceptance of the system than healthy elderly individuals, confirming that subjective needs are strongly related to technology acceptance and will therefore influence system requirements. Cognitive support, opportunities for social interaction, and safety monitoring at home were reported as the most useful services that a social robot could provide. Mismatch between needs and solutions offered by the robot, usability factors and lack of experience with technology were seen as the most important barriers for the adoption of these systems.

Key words: Social assistive robotics, technology acceptance, older adults, Mild Cognitive Impairment, Alzheimer's disease

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[10] The present study was conducted within the framework of project PRAMAD, whose main goal is to design a technological solution integrating social robotics and ambient intelligence applications to support elderly individuals with cognitive impairment in everyday functioning and caregivers in their duties.

[11] This work was conducted together with Mélodie Boulay under the supervision of Pr. Anne-Sophie Rigaud. Romain Lardin and Laila Kamali contributed to data transcription.

4.1.1 Introduction

Many older adults prefer staying at home rather than moving into a long–term care facility as they age (Vasunilashorn, Steinman, Liebig, & Pynoos, 2012). Besides, as the number of elderly persons with a reduced degree of functional capacity increases, there is growing social and economic pressure to help these individuals to live at home for as long as possible (Fujisawa & Colombo, 2009). However, cognitive impairment, which is common among older adults, can seriously compromise independent living, in particular when it stems from progressive pathological conditions, such as some forms of Mild Cognitive Impairment (MCI), or Alzheimer's disease (AD). These individuals often need some help with everyday activities and require basic medical services, for example, medication, health monitoring, rehabilitation, and preventive services. In this context, the burden of care for informal caregivers and the risk of social exclusion for frail older adults represent a new challenge for society that has been increasingly addressed by Assistive Technology (AT).

AT refers to technological products, services or systems used to improve functional capacity and social behavior of individuals with disabilities, including age-related cognitive or physical deficits (Hersh & Johnson, 2008). AT for elderly persons with cognitive impairment can serve different purposes: assistance with daily tasks, communication and social interaction, management of behavioral symptoms, health monitoring, stimulation, and entertainment (Lauriks et al., 2007; Molin, Pettersson, Jonsson, & Keijer, 2007). Socially assistive robotics (SAR) is one of the forms of AT that has focused on designing concrete solutions to contribute to healthy living, safety, autonomy, and social inclusion of frail older adults (Broekens, Heerink, & Rosendal, 2009; Feil-Seifer & Mataric, 2005; Flandorfer, 2012). Throughout this paper the abbreviation SAR will be used to refer to social assistive robotics or social assistive robots.

SAR encompasses all robotic systems capable of providing assistance to the user by means of social interaction. In general, SAR systems have the potential to contribute to the life of users at different levels (Rich & Sidner, 2009): (a) by supporting and/or compensating functional abilities through different technology-based services (e.g., task reminder, task monitoring, schedule-management systems, navigation aids); (b) by offering opportunities to enhance social participation and psychological well-being (e.g., communication and social networking services, companionship aspects, recognition and expression of emotional states, collaboration and engagement capacities); (c) by providing monitoring that contributes to healthcare and safety, for which SAR can be associated with other devices capable of collecting data on the physiological activity of the person (e.g. fall detector); and (d) by making a continual assessment of the user's cognitive functioning through the analysis of daily behavior. This aspect pertains to applications that collect performance measures during task execution and facilitate the follow-up of cognitive deficits.

As noted before, robotics and ambient technology applications are open to many different uses for domestic and care purposes. However, while it is undeniable that there is a great innovation potential in these technologies they might not meet the needs of a varied target audience. Most commonly, this happens when SAR design is based on rocèszed representations of older users rather than on the analysis of individual backgrounds and needs (Michaud et al., 2007; Peine & Neven, 2011).

As for any other form of AT, the successful implementation of SAR depends on the understanding of user needs and the barriers to technology use that may exist (LoPresti, Bodine, & Lewis, 2008). In order to conceive acceptable solutions that succeed in meeting end-user needs, developers must gather subjective needs (i.e., those expressed by target end-users themselves), distinguish objective needs (i.e., those that can be measured by instruments, perceived or expressed by others, such as the caregivers) (van der Roest, 2009), and identify the tasks users intend to achieve as well as the cognitive/physical environmental barriers that reduce their abilities to perform them. Users must recognize the need for assistance, be able to make use of the assistive devices provided, and be willing to use and incorporate them in their lives (Broadbent, Stafford, & MacDonald, 2009).

For this reason, a fundamental step in the design process of AT is to gather the needs of potential users in the early stages of the project to ensure that the system meets the specified requirements. Thus, need gathering practices help: (a) to identify situations that are problematic for users in a given context; (b) to explore the solutions implemented by the persons using the resources at their disposal; (c) to determine what needs are not currently being met by the strategies available (e.g., area of difficulty for the person on which no, or an inappropriate support is provided) (van der Roest, 2009); and (d) to create solutions to address these unmet needs through the definition of new system requirements (Lazar, Feng & Hochheiser, 2009). In this sense, gathering information from the users is a necessary step to define and implement the system requirements (Hersh & Johnson, 2008).

A number of studies has been conducted on the needs of elderly people that could be met through healthcare and domestic robots and on the acceptance of these systems (Boissy, Corriveau, Michaud, Labonté, & Royer, 2007; Broadbent et al., 2009, 2010; Dautenhahn et al., 2005; Harmo, Taipalus, Knuuttila, Vallet, & Halme, 2005; Heerink, Krose, Evers, & Wielinga, 2009; Heerink, Kröse, Wielinga, & Evers, 2006; Heerink, Kröse, Evers, & Wielinga, 2010; Neven, 2010; Scopelliti, Giuliani, & Fornara, 2005; Wu, Fassert, & Rigaud, 2012; Young, Hawkins, Sharlin, & Igarashi, 2009). In a general manner, these works have shown that several factors appear to have a positive influence on the attitudes of elderly people towards SAR such as: user's perceived utility of such systems (e.g., facilitating the provision of care at home, enhancing their safety, and giving caregivers some respite and support) (Arras & Cerqui, 2005; Boissy et al., 2007; Scopelliti et al., 2005); the hedonic (e.g., perceived enjoyment, entertainment, pleasure) and social gains derived from the use of SAR (e.g., status gain) (Heerink et al., 2010; Scopelliti et al., 2005; Young et al., 2009); the possibilities of companionship that SAR offer (e.g., social presence, possibilities of human-like communication) (Dautenhahn et al., 2005; Harmo et al., 2005; Heerink et al., 2010); robot appearance (e.g., small size, familiar aspect combining human, machine and animal features) and personality (e.g., being caring, empathic, intelligent) (Broadbent et al., 2010; Wu et al., 2012); SAR being controllable and having a predictable behavior (Dautenhahn et al., 2005; Scopelliti et al., 2005).

Conversely, various factors have been identified as having a negative impact on the acceptance of SAR by older adults: their lack of confidence about the potential of robots to perform cognitive tasks (Scopelliti et al., 2005); having a representation of prospective users of SAR as being lonely, dependent, and frail people in need of care and company (Neven, 2010); the space requirements within the home derived from some physical characteristics of the robots (e.g., important size or mass of the system) (Scopelliti et al., 2005; Young et al., 2009); physical appearance of the robot (e.g., reluctance towards humanoid robots) (Arras & Cerqui, 2005; Dautenhahn et al., 2005; Wu et al., 2012); accessibility and usability issues (e.g., lack of technological experience, price and financing issues) (Young et al., 2009); and fear of technology (e.g., safety concerns about the use of SAR; reduction of social contact, robots replacing human capabilities) (Arras & Cerqui, 2005; Dautenhahn et al., 2005; Harmo et al., 2005; Scopelliti et al., 2005; Sparrow & Sparrow, 2006; Wu et al., 2012).

4.1.1.1 The Role of Individual Factors

Scopelliti et al. (2005) pointed out that different personal factors induce a vision of SAR either as tools that contribute to the autonomy and independence of elderly individuals or as threats to their self-identity and social participation. Moreover, these authors concluded that exploring people's representations of SAR in depth would be a valuable method for bridging the gap between SAR possibilities and user needs. They added that this task could be achieved by examining the role of socio-demographic factors (e.g., age, gender, education) on the acceptance of cognitive and affective components of SAR. Flandofer (2012) explicitly addressed socio-demographic issues in a recent literature review on SAR for elderly people confirming that these factors, including technological experience and cultural background, play a major role in the acceptance of SAR. The author has argued as well that several studies in this field have failed to investigate the influence of socio-demographic factors properly because of methodological limitations (e.g., small sample sizes) or because they have focused mostly on prototype testing rather than on the analysis of user profiles. In another review about human responses to healthcare robots, Broadbent et al. (2009) found that age, gender, cognitive abilities, education, experience with technology/robots, culture, roles, and attitudes towards robots are variables that have a considerable influence on the acceptance of healthcare robots.

In a wider perspective, Rice & Carmichael (2011) have outlined that one of the problems of user research in AT design is the tendency to homogenize older people as a target population affected by disability. This supposition may result in overlooking the group of relatively healthy elderly individuals who do not consider themselves as target-users of AT applications, since they do not feel the current need for being assisted in everyday life, but could benefit from the empowering aspects of AT, such as increased social participation, entertainment, and fun. Following this line of reasoning, the study of SAR acceptance should include a wider view of the diversity of characteristics, lifestyles, experiences, aspirations, values and needs among elderly people in order to establish more effective partnerships between designers, researchers, and users. This methodology corresponds to a "User-Sensitive Inclusive Design" approach, in which not only the wide variability that exists among users is taken into consideration but also the changing nature of individual characteristics over time (Gregor, Newell, & Zajicek, 2002; Newell & Gregor, 2000; Newell, Gregor, Morgan, Pullin, & Macaulay, 2011).

Finally, considering that in the context of chronic and progressive illness (e.g., dementia), assitive technologies such as SAR can be used for different purposes by the caregiver and the care-recipient it seems important to evaluate the perspectives on these solutions of both of them. Unfortunatley, most studies in this field have only rocès on one group or the other. Thus, little is known about how the views of caregivers and care-recipients on SAR converge or diverge.

4.1.1.2 Methodological Issues in the Study of SAR Acceptance

A number of questions have been raised about the methods used to gather needs and requirements of elderly people, in particular those with cognitive impairment, for instance: (1) whether to conduct large-scale studies that allow statistical analysis of the data or small scale studies that use qualitative analysis methods; (2) deciding which are the most suitable methods to present product-related information to potential users, for example to help them imagine potential applications for not-yet-existing technologies; and (3) creating solutions to compensate for communication and cognitive deficits that can hinder user involvement in the design process (Alm & Newell, 2008; Dautenhahn, 2007; Flandorfer, 2012). Among the techniques most commonly used for gathering needs and requirements in traditional user research are surveys, interviews, focus groups, use cases, requirement workshops, storyboards, modeling and prototyping (Young, 2002). Nevertheless, it is widely acknowledged that traditional methodologies must be adapted to suit the needs and capacities of elderly people with cognitive impairment and that more appropriate methods should be conceived to create an effective partnership between designers and potential users (Alm & Newell, 2008; Blackman et al., 2003; Dickinson, Arnott, & Prior, 2007; Eisma et al., 2004; Savitch et al., 2006).

When studying the acceptance of SAR, methodological issues merit further investigation since they impact the attitudes of elderly people towards these systems. One critical aspect is the way robotic systems are presented to future elderly users (Flandorfer, 2012; Heerink, Krose, Wielinga, & Evers, 2008). In this regard, Broadbent et al. (2009) concluded that direct experience of SAR positively influences the way they are perceived and valued by older adults. Thus, if it is true that the use of scenarios, videos, and static pictures can be practical to illustrate some applications of SAR to potential users, live demonstrations seem to be a more effective way to elicit opinions and study technology acceptance patterns.

4.1.2 Objectives

This study aims to examine the opinions and attitudes of elderly individuals towards SAR used to support older adults with cognitive impairment (MCI, AD) at home, and caregivers in their duties. A compartive approach that considers the views of elderly people with cognitive impairment, caregivers of persons with AD, and healthy older adults, will be used for this purpose. The role of other individual factors on SAR acceptance will be examined as well (e.g., age, gender, education, health and activity status, and current use of and attitudes towards to technology).

The assessment of ASR acceptance will cover the technical and physical characteristics of robots, services and functionalities provided, user's characteristics, participants' everyday problems, societal and ethical issues related to the use of SAR, and subjective representations of SAR. Results from this research will help define user requirements with respect to the possible contexts of use, to better articulate use cases and scenarios, and to create design solutions that satisfy users while simultaneously addressing social, technical, and business goals.

4.1.3 Methods

4.1.3.1 Participants

A total of 25 elderly individuals aged 58 to 86 (*M* = 72,6; *SD* = 7,73) enrolled in this study. Among the participants were ten individuals with MCI (40%), seven caregivers of patients with AD (28%), and eight healthy older adults (HOA) (32%). MCI was diagnosed according to the revised Petersen criteria (Winblad et al., 2004). Participants in the MCI group and AD caregivers were recruited through the APHP Broca Memory Clinic (Paris), HOA were recruited through local senior associations.

Table 17 Summary of the characteristics of the sample

Participants	MCI	AD caregivers	HOA	Total
n **(f, h)**	10 f (6), h (4)	7 f (5), h (2)	8 f (6), h (2)	25 f (17), h (8)
Age (SD), range	71.5 (6.13), 65-83	68.28, (7.99) 58-81	77.75 (7.16) 69-86	72.6 (7.73) 58-86
Education (*n*)	Elementary (0) High School (6) University (4)	Elementary (0) High School (1) University (6)	Elementary (1) High School (3) University (4)	Elementary (1) High School (10) University (14)
Activity status (*n*)	Active (4) Retired (6)	Active (4) Retired (3)	Active (8)	Active (16) Retired (9)
Self-rated health	5.3 (4)	5.28 (1.79)	3.25 (2.37)	4.64(3.06)

Participants	MCI	AD caregivers	HOA	Total
status* 0-12, (SD)				
Use of current technologies 0-15, (SD)	10.5 (3.59)	11.28 (3.45)	11.12(3.04)	10.92(3.26)
Interest in ICT 0-6, (SD)	3.3 (1.88)	4.14 (1.67)	4.25(1.28)	3.84 (1.65)

* Care recipient' health status rated by the caregiver in the AD caregivers group
n = number of participants; f = female; m = male; self-rated health status = frequency of health problems encountered (i.e., cognitive, mobility, psychological, or physical health problems); use of current technologies = number of current technologies used; ICT = Information & communication technologies

All participants volunteered for the study. The study was reviewed and approved by the University Paris Descartes ethical committee, the CCTIRS (Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé), and the CNIL (Commission Nationale Informatique et Liberté).

Socio-demographic factors were assessed in terms of age, gender, education, activity and self-rated health status. Caregivers rated the patient's health-status. Technology use factors were assessed in terms of use of current technologies and interest in new technologies. Table 17 provides a summary of the characteristics of the sample.

4.1.3.2 Study Design and Data Collection

A mixed-method approach combining a questionnaire and a series of small focus groups was used for data collection and analysis. The questionnaire (see Appendix A) comprised 11 questions covering: socio-demographic information, technology use, and appreciation of SAR (appearance and acceptance). The variables explored in this study are presented in Appendix B.

It was decided to conduct small focus groups, comprising between three and four participants, for two principal reasons: first, because they facilitate user involvement and provide more in-depth insights than large focus groups, and the aim of the study was to gain understanding of the participants' situation and their views on the use of SAR (Krueger & Casey, 2009); second, because when working with people with disabilities (e.g., dementia), or elderly people, the use of focus groups involving a small number of participants has proven to be a suitable research methodology for studying specific issues (Bamford & Bruce, 2002; Robinson, Brittain, Lindsay, Jackson, & Olivier, 2009; Savitch & Zaphiris, 2006). Thus, participants were distributed in seven focus groups that were purposefully heterogeneous (i.e., MCI, AD caregivers, and HOA) (Table 18).

Table 18 Focus groups composition

Focus group	*N*	Age (SD), range	Group c	Gender	Activity status
1	3	72.6 (9.29), 65-83	MCI (100%)	f (100%)	Retired (100%)
2	3	73 (11.3), 65-81	AD Caregivers (100%)	f (100%)	Active (33%), Retired (66%)
3	3	72.66(8.02), 65-81	MCI (100%),	f (33%), m (66%)	Active (66%), Retired (33%)
4	4	79.25(7.27), 69-86	HOA (100%)	f (75%), m (25%)	Active (100%)
5	4	64.75 (6.8), 58-72	AD Caregivers (100%)	f (50%), m (50%)	Active (75%), Retired (25%)
6	4	76.25 (7.80), 69-86	HOA (100%)	f (75%) m (25%)	Active (100%),
7	4	69.75 (2.36), 68-73	MCI (100%)	f (50%), m (50%)	Active (50%), Retired (50%)

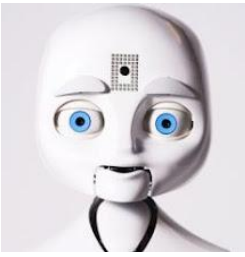
4.1.3.3 Material

The Robulab (Table 19, 1) was used for a live demonstration of the robot. Support material for the focus group comprised a PowerPoint presentation with pictures and videos clips from different robotics projects that were projected throughout the discussion (Table 19). The presentation covered a range of design solutions: *machine-like robots*, which have no human-like features; *human-like robots*, whose form resembles a human and have designed facial features (e.g., eyes, nose, mouth, eyelids, etc.); *androids* or very humanlike robots; *animal-like robots* that simulate animal behavior and morphology; *mechanical-looking humanoid robots* which combine human-like and machine features; and *mechanical-looking animal robots* which combine animal-like and machine features. These categories were defined from the works of DiSalvo, Gemperle, Forlizzi, & Kiesler (2002), MacDorman & Ishiguro, (2006), and Walters, Koay, Syrdal, Dautenhahn, & Te Boekhorst (2009).

Other material included a questionnaire (Appendix A), a participant's booklet containing the pictures and descriptions of the robots presented, a video projector, a computer, and a video camera. Data analysis was conducted using Dedoose version 4.3.87 (2012), a mixed methods and qualitative analysis research tool. Statistical analysis was performed using R version 2.13.2 (R development core team, 2011).

Table 19 Robots presented to participants in the focus groups

N	Picture	Robot, Producer, Country	Type of robot	Description
1		Robulab Robosoft (France)	Machine	- Mobile platform - The robot embarks a group of sensors and cameras that ensure autonomous navigation, target-user localization, and obstacle detection - Input devices include speech control and a touch-screen - The system was specifically programmed to provide cognitive and social support through a suite of applications (e.g., task reminder, cognitive training, navigation support, communication tools) (Soury et al., 2011)
2		Kompaï Robosoft (France)	Human machine	- Same configuration as Robulab but with a different appearance (human-like head) (Tapus & Chetouani, 2010)
3	 	Pearl Carnegie Mellon University (USA)	Human machine	- Mobile robot - It has a user-friendly interface with a face - Designed to help the elderly to navigate through a nursing facility - Provides advice, cognitive support, and functional assistance (Montemerlo, Pineau, Roy, Thrun, & Verma, 2002)

N	Picture	Robot, Producer, Country	Type of robot	Description
4		Telenoïd Osaka University, ATR (Japan)	Human-like	- Humanoid with minimal human appearance and an anonymous identity - The covering skin is made of high quality silicon to mimic human skin - Designed to be used as a communication device, with applications in remote work, remote education, and elderly care - Allows the transmission of "human presence" at distance (e.g., voice, face and head movements) from the operator who uses a computer, a webcam and a teleoperation software, to the person that has the Telenoïd - The operator can also activate other behaviors with a button (e.g., bye-bye, happy) (Yamazaki et al., 2012)
5		Mamoru University of Tokyo Toyota and Fujitsu (Japan)	Human machine	- Small desktop elder-care robot - Designed to provide prompts and reminders (e.g., Item location, medication intake) - It uses a wide-angle camera to keep track of the room, and detect objects regardless of rotation, scale, or lighting conditions (Toto, 2008)
6		EVE PIXAR, DISNEY studios (USA)	Human machine	- Animated female robot from the film Wall-E (Stanton, 2008) - Mix between human and machine features - Emotions are represented through facial expressions and voice (Howey, 2010)
7		Nexi MIT Media Lab (USA)	Human-like	- Mobile manipulator robot capable of social expression - Aimed at a range of applications for personal robots and human-robot teamwork - It has hands to manipulate objects, eyes (video cameras), ears (an array of microphones), and a 3-D infrared camera and laser rangefinder to support real-time tracking of objects, people, voices, and indoor navigation (Chandler, 2010)

N	Picture	Robot, Producer, Country	Type of robot	Description
8		Geminoid F Osaka University, ATR (Japan)	Android	- Android that will work as a duplicate of an existing person - It consists in three elements: a robot, a central controlling server, and a teleoperation interface - Designed to be used as a substitute for clerks, when typical responses are required (Nishio, Ishiguro, & Hagita, 2007)
9		iCat Philips Electronics (The Netherlands)	Animal machine	- Cat-like appearance - It has a face that is able to express emotions - Not particularly aimed at being a companion but more at functional assistance -Strongly relates to social interaction (Heerink, Kröse, Wielinga, & Evers, 2006)
10		Paro Intelligent Systems Research Institute (ISRI) of the National Institute of Advanced Industrial Science and Technology (AIST) (Japan)	Animal-like	- Soft seal robot developed to study the effects of robot therapy in elderly people with cognitive impairment, and other populations with disabilities - The robot has programmable behavior as well as a set of sensors (touch sensor, infrared sensor, stereoscopic vision and hearing). - Actuators include eyelids, upper body motors, front paw and hind limb motors. - Not mobile (Wada, Shibata, Saito, Sakamoto, & Tanie, 2005; Kazuyoshi Wada & Shibata, 2008)

Note: Paro, Icat and Pearl descriptions adapted from (Broekens, et al., 2009)

4.1.3.4 Procedure

A group of possible participants were contacted by telephone and given information about the purpose and nature of the study using easily understandable concepts. If interested, they were scheduled to participate in a focus group. On the day of the meeting, all participants read and signed an informed consent form before beginning the session. A semi-structured questionnaire was used to collect socio-demographic and technology use information. Also, each participant received a copy of the booklet allowing him or her to follow the sequence of the discussion.

Discussions were lead by two trained moderators. One of them presented the scenarios and demonstrated the capabilities of the robot, and the other asked questions and kept the conversation on the subject ensuring that each participant was able to express his or her views. A semi-structured format, beginning with broad questioning and then moving into more specific and structured questioning, was used for the discussion.

Each session began with the introduction of the robot. One of the moderators guided the robot through the room with the purpose of showing the system in action. The general characteristics of the robot were presented: size, autonomy, weight, and interaction modalities (i.e., direct input through the touchscreen and voice command). Since people with cognitive impairments are prone to misunderstandings, they were encouraged to ask questions about the system and to rephrase the explanations using their own words to ensure that they had understood them. Then, the main functionalities of the robot were illustrated through different use case scenarios: (1) *Fall detection:* The robot is able to detect falls, if the user cannot stand up after falling down, or if he/she remains immobile in an abnormal position; (2) *Communication:* using the e-mail or the video call applications the user can communicate with health professionals, distant caregivers and family not living in the same house; (3) *Drug intake and appointments reminder:* the robot can look for the person and remind him/her of specific events; (4) *Affective computing applications:* By using sensors and algorithms the robot can gather information about the user's emotions (e.g., facial expressions, emotional speech), also, the system can exhibit emotional capabilities to enrich the interaction with users (e.g., simulate human emotions); (5) *Detection of emergency situations:* through the use of sensors located in the environment the system is able to detect emergency situations and alert caregivers and/or health professionals; (6) *Telemonitoring:* the system can monitor and analyze the user's physiological signs or behavioral patterns (e.g., sleep patterns, physical activity); (7) *Engagement in cognitively stimulating activities and leisure/cultural activities;* and (8) *Offering support for everyday activities* (e.g., weather forecast application, online grocery shopping application).

Participants were invited to give their views on these functionalities and on what they would expect the robot to do. Furthermore, they were encouraged to give examples of the problematic situations they or their relatives, in the case of caregivers, encountered in daily life and to imagine the possible solutions that SAR could supply.

In the second part of the discussion, the facilitator gave a brief introduction about different design solutions concerning the appearance of SAR. Participants were asked to give their thoughts on robot appearance while the pictures and videos of robots were shown. Other topics brought up in the discussion included the match between robot's appearance and functions and affective computing applications. In the last part of the meeting, societal and ethical issues were treated. Before leaving, participants were asked to complete the last section of the questionnaire concerning robot appearance preferences and system acceptance. Focus groups were digitally recorded, fully transcribed and subjected to content analysis using an open coding approach (Strauss & Corbin, 1990). Responses to the questionnaires were analyzed using descriptive and non-parametric statistical techniques.

4.1.4 Results

4.1.4.1 Questionnaires

Perceived usefulness and acceptance of the robot

Participants with MCI and AD caregivers had a more positive perception of the usefulness of SAR than HOA. Regarding the current acceptance of the system results suggested that participants in the MCI and AD Caregivers groups were more likely to accept to use the robot system at the present time than HOA, although these scores were rather low in all groups, since they did not reach the average score of 1.5 of 3.0 (Table 20). Future acceptance of the system was positively rated in all the three groups. However AD caregivers expressed less interest in using the system in the future compared to participants in the two other groups. A series of Fisher's exact tests were performed to determine if user groups differed with regard to these aspects but no statistically significant difference was observed. Regarding the difference between current and future acceptance of the robot in each group, a series of Wilcoxon signed-rank tests were carried out. This difference was significant for the MCI group ($W = -36$, $p < .02$, two-tailed test) and for the HOA group ($W = -36$, $p < .02$, two-tailed test) but not for the AD caregivers group ($W = -4$, $p > .05$, two-tailed test).

Table 20 Perceived usefulness, current and future acceptance of the robotic system

Attitudes towards SAR	**MCI** (0-3) *(SD)*	**AD Caregivers** (0-3) *(SD)*	**HOA** (0-3) *(SD)*	**F-test *p* value**
Perceived usefulness	1.9 (1.1)	1.86 (0.9)	1.13 (1.13)	.41
Current acceptance	1.1 (0.99)	1.29 (1.11)	.13 (0.33)	.20
Future acceptance	2.2 (0.63)	1.67 (1.21)	2.13 (0.64)	.29

A series of Spearman's Rank Order correlations was run to determine the relationship between individual variables and perceived usefulness, current and future acceptance of SAR (Table 21). There was a moderate, positive relationship between activity status and current acceptance of the system, suggesting that retired individuals were more likely to accept to use the system at the present time than participants that still had a professional activity. Moreover, individuals with a high interest in technology were also open to accept to use the robot at the present time since there was a moderate, positive correlation between these two variables. Statistical analysis also revealed that there was a moderate, negative relationship between education and perceived usefulness of the robot, and between education and future acceptance of the system, both correlations being significant. This finding means that individuals with a low education level had a more positive perception of the usefulness of the robot and expressed their intention to use it in the future.

Table 21 Relationship between individual factors and SAR acceptance

Attitudes towards SAR	**Age** r_s (***p***)	**Gender** r_s (***p***)	**Education** r_s (***p***)	**Activity** r_s (***p***)	**Health** r_s (***p***)	**Technology use** r_s (***p***)	**Technology interest** r_s (***p***)
Perceived usefulness	0.05 (.80)	0.05 (.80)	-0.42 (.03)*	0.22 (0.26)	0.06 (0.75)	-0.17 (0.39)	0.17 (.40)
Current acceptance	-0.36 (0.07)	-0.36 (0.07)	0.14 (0.48)	0.43 (0.02)*	0.28 (0.16)	0.29 (0.14)	0.42 (.03)*
Future acceptance	0.16 (0.41)	0.16 (0.41)	-0.43 (0.03)*	-0.05 (0.80)	-0.24 (0.23)	-0.27 (0.18)	0.12 (.54)

* Correlation is significant at the 0.05 level

Concerning the intention to use the robot at the present and in the future, results revealed that participants were more likely to accept to use a robot in the future (*M*= 1.96, *SD*= .88), than at the present time (*M*= .84, *SD*= .98). Furthermore, the difference between current and future acceptance scores was observed in all user subgroups regardless of the variable used as a distribution factor (Figure 26). A Wilcoxon Signed-ranks test indicated that this difference was significant (z = -3.08, p < .002, two-tailed test).

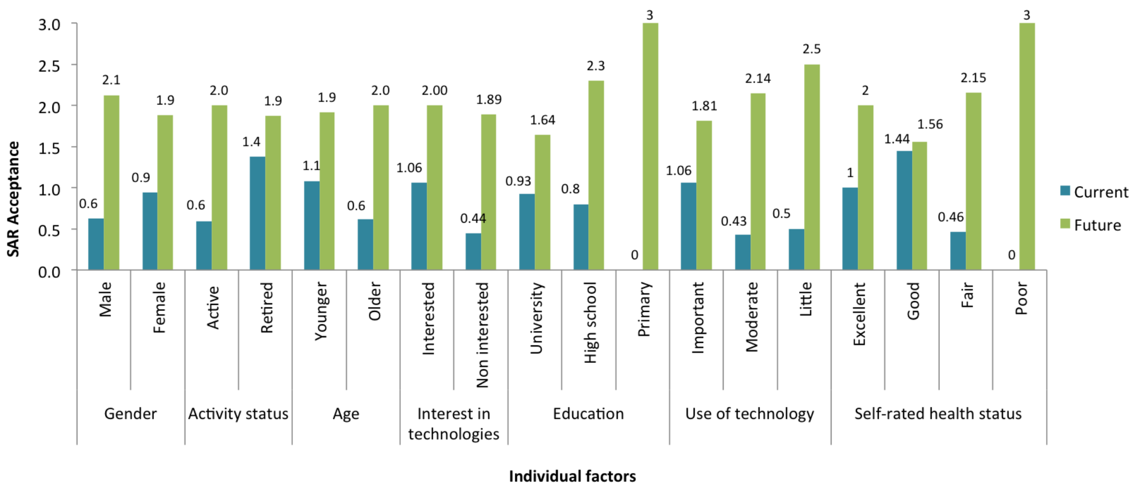


Figure 26 Current and future acceptance of SAR systems by individual factors

Different reasons were provided by participants to justify the perceived usefulness they had of SAR and their degree of acceptance towards them (Table 22). Participants' responses showed a wide variety of factors that were positively associated to SAR: companionship, the possibilities of compensating for cognitive and functional decline, and their contribution to socialization and to safety at home. On the contrary, to explain their lack of interest in SAR, participants claimed that robots could threaten their autonomy, that they were too young or self-sufficient to need any assistance of this kind, that they did not see the additional benefits that these systems could bring with respect to already existing technologies, and generational technology gap issues.

Table 22 Perspectives on perceived usefulness and acceptance of the robot

Factor	Positive	Negative
Perceived usefulness	**Provides companionship** "I will not feel lonely" "It will be an amusing companion" "It will be a positive distraction" **Compensation for cognitive or functional decline** "It will be of service to those with difficulties" "It will be like an assistant" "It will take care of my needs" "I would have loved my mother, who had AD, to have benefited from such a robot" **Support for caregivers** "It helps the patient and his/her entourage" **Helps to improve safety** "It will ensure my domestic security"	**Useless for people who perceive themselves as autonomous** "This robot is not useful to me because I am too young" "I believe the use of the robot will restrict my autonomy" "This robot is not useful to me because I am still active" "This robot is not good for me but it could be useful for disabled people" **Redundancy with other technologies** "I already have a computer which gives me access to the same services" **Size of the robot** "It could interest me after improving its size (too big)" **It might violate privacy** "The idea of surveillance does not

Factor	Positive	Negative
	Provides cognitive stimulation "The robot will allow me to exercise my brain" **Helps to improve social life** "It will help me to have social contact outside of my home"	appeal to me"
Current acceptance	**Provides companionship** "It will add dynamism to my life and make it more happy" **Helps to improve the patient's safety** "It will ensure the security of frail people" **The robot allows compensating for cognitive or functional decline** "It will help those who have memory loss" **Helps to improve social life** "It could allow one to have a social life" "It will reinvigorate one's social life" **Novelty effect** "I am very interested to discover new technologies"	**Useless for autonomous people** "I am still autonomous" "Maybe later in life" "I don't need it for the moment" "I am too young" **Generational technology gap** "This robot addresses a generation which is familiar with new technology" **State of progression of the disease** "This robot is difficult to envision because my relative is gravely affected by AD" " At the current state of my wife's illness, we are not yet concerned" **Rejection of new technologies** "My relative is hostile to this type of technology" **Redundancy with other technologies** "I already have all of the equivalent technological devices at my home"
Future acceptance	**Curiosity effect** "I can't wait to try it" **Provides companionship** "I will feel less lonely" "I will not feel alone" "It will bring me companionship because I am alone" **Helps to maintain autonomy** "It will delay my entry into a retirement home" "It will allow me to maintain my autonomy for as long as possible" "It will replace my future shortcomings" **Compensation for cognitive or functional decline** "It may provide me with useful services" "Perhaps, I will be needing some help" "It will allow me to continue to do my errands if I can not leave my home" **Helps to improve safety** "The robot will ensure me tranquility, security and will reassure my family as well" "It will have a role of security which will reassure those closest to the patient" **Helps to improve social life** "It will allow me to keep my contacts"	**Generational technology gap** "This type of robot will be a total stranger" **State of progression of the disease** "The aggravation of my relative's state will be another obstacle, (to adopt the robot)" "This robot will be difficult to adopt because my relative does not have the capacity to adapt" **Difficulty to project oneself into the future** "I prefer to avoid the question, I am afraid of what is coming next" "It is difficult to know which state I will be in, in the future, to estimate its usefulness"

Factor	Positive	Negative
	Provides opportunities for leisure/recreation "It is a good support for leisure activities like playing"	

Services and functionalities

As regards the services that should be taken into account when developing the robot, those that were found as the most interesting to be implemented were: (a) applications allowing for compensation of memory or other cognitive deficits, including cognitively stimulating activities (e.g., locating lost items, reminding events); (b) services to enhance social interactions and information sharing between users, caregivers, family, health professionals (e.g., video calls, email); (c) applications that contribute to safety and comfort at home (e.g., detection of falls, help the user to prevent/manage critical situations) and (d) aids to support everyday functioning (e.g., online grocery shopping, journey planning, simplified Internet access) (Figure 27).

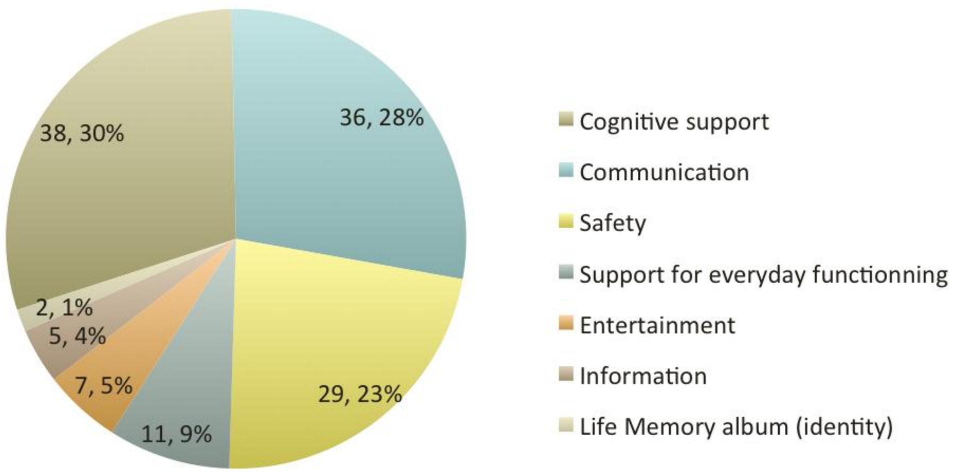


Figure 27 Priority services to be delivered by a social assistive robot

Other functions mentioned were entertainment applications (e.g., music, poetry, and reading) and information and news applications for keeping the user up to date with current events (e.g., broadcast news sources). An interesting suggestion, provided by the group of AD caregivers, was to develop a life memory album that could be available via the robot. The idea was to design a digital support tool for life history, including multimedia material, such as a genealogy tree, photographs or videos, that could be used to help the user remember significant moments of his/her life and to promote communication between family members and the person with cognitive impairment.

Assessment of the robot's physical features

Regarding the question of how a robot should look like, two aspects were assessed: First, the general appearance of the system based on the different designs presented (e.g., human-like, animal-like, machine-like, humanoid, etc.). Second, the use of some design features to represent the robot's affective capabilities (e.g., the humanness of the head and simulation of emotional capabilities).

As far as the general appearance of the robot was concerned, results showed that most of the users preferred a human-machine robot with designed facial features (e.g., Pearl, Mamoru) (Figure 28). Animal-machine (iCat), animal-like (Paro) and machine-like robots (Robulab) obtained similar ratings. Only a few persons chose an android robot (Geminoid) (table x, 1). Human-like robots (Telenoïd, Nexi) did not get any votes.

Overall results revealed that the representation of affective capabilities was not considered as an essential requirement for the robot. Concerning the humanness of the robot's head, results showed that HOA were less interested in this kind of design than participants in the MCI or AD caregivers group (Table 23). The representation of emotional capabilities through facial expressions obtained a moderate score in the MCI and HOA groups, but participants in the AD assigned a low score to this feature.

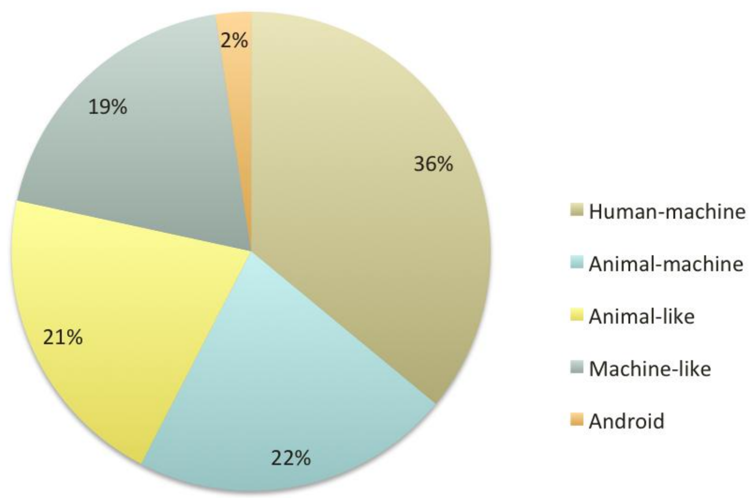


Figure 28 Users' preferences concerning robot appearance

Table 23 Rating of design features related to the representation of affective capabilities

Robot features	MCI 0-3 (*SD*)	AD caregivers 0-3 (*SD*)	HOA 0-3 (*SD*)
Humanness of the head	1.22 (0,97)	1.86 (1.21)	0.75 (1.04)
Exhibiting emotional capabilities	1.4 (0,7)	0.86 (1.21)	1.5 (1.2)

4.1.4.2 Focus Groups

Discussions were analyzed using an open coding system (i.e., identifying, naming and categorizing relevant content). Two researchers conducted open coding and the differences were discussed until a coding agreement was reached. Throughout the coding process six root codes or primary topical organizers, 54 child codes, and 39 grandchild codes were defined. A total of 373 excerpts were extracted from discussions and assigned at least one of these codes. Codes were applied 1721 times to the total transcripts. Occurrences were then analyzed by parent code and sub-codes. Table 24 presents the coding tree and the percentage of participants having discussed each topic at least once.

Table 24 Open coding system and percentage of participants having raised each topic

Theme Root codes	Category Child codes	Subcategory Grandchild codes
System characteristics (96%)	Interaction modalities (36%)	*Direct Input (12%)* *Voice command (36%)*
	Mobility issues (36%) Personalization (64%)	
	Physical features (64%)	*Design (32%)* *Height (24%)* *Size (24%)* *Voice (32%)*
	Robot appearance (60%)	*Machine-like (20%)* *Non-familiar animals (8%)* *Human-like (36%)* *Animal-machine (16%)* *Human-machine (12%)*
	Usability issues (64 %)	*Training needs (24%)* *Well-adjusted ergonomics (64%)*
	Safety use (12%)	
User characteristics (84%)	Cognitive profile (28%)	*Memory (28%)* *Language (4%)* *Planning, initiating and completing actions (4%)* *Attention (8%)*
	Physical disability (40%)	
	Sensory impairment (36%)	*Vision (28%)* *Hearing (16%)*

Theme Root codes	Category Child codes	Subcategory Grandchild codes
	Disability degree (32%)	
	Psychological symptoms (20%)	*Apathy (8%)* *Depressed mood (20%)*
	Social environment (16%)	*Isolation (16%)*
	Technology experience (28%) Preferences and habits (36%)	
Potential applications (96%)	Cognitive support (64%)	*Formulating procedures (8%)* *Initiating actions (12%)* *Locating items (8%)* *Life memory album (24%)* *Orientation (16%)* *Task or event reminding (48%)*
	Communication (36%)	*Video calls (28%)* *Email (4%)* *Telephone (16%)*
	Robotic companionship (44%) Emotion detection (36%) Entertainment (56%)	
	Health monitoring (16%)	*Medical follow-up (4%)* *Physiological data collection (8%)* *Remote medical consultation (4%)*
	Home safety control (4%) Information (12%) Intervention in case of emergency (32%) Object manipulation (4%)	
	Support for everyday functioning (20%)	*Basic daily activities (8%)*
	Assisting informal caregivers (28%)	*Support caregiver's tasks (16%)* *Alleviate stress/burden (16%)*
	Assisting formal caregivers (8%) Assistance for mobility (4%)	
Subjective judgment (96%)	Acceptance of robot's services (32%) Acceptance of robot's social features (40%) Compliance to use (4%) Mistrust (52%)	
	Perceived usefulness (80%)	*For oneself (24%)* *For others (64%)*
	Reject (20%) Positive appreciation (88%) Negative appreciation (56%) Cultural representations of robots (16%)	

Theme Root codes	Category Child codes	Subcategory Grandchild codes
Ethical and societal issues (80%)	Autonomy (28%) Confidentiality (24%) Dignity (8%) Infantilization (24%) Stigmatization (4%) Justice and equity (16%) Privacy (24%) Vulnerability (12%) Self-esteem (4%) Risk of social isolation (8%) To deceive users (16%) Robot as a mediator (4%) Intergenerational relationships (4%) Fear of robots replacing humans (40%) Costs of the service (40%) Generational gap (20%)	
Everyday problems (36%)		

Table 25 presents the frequency with which each parent code has been applied to an excerpt, number of transcripts associated to each parent code, and some example excerpts of the five most frequently used sub-codes.

Table 25 Frequency of parent codes, number of excerpts and sub-codes occurrences

Parent code	Occurrences		Sub-codes (Occurrences)	Sample excerpts (Group, gender, age)
	Excerpts *N* = 373	Transcripts *N* = 25		
System characteristics	159	24	Personalization (43)	*"I think the interest thing about the design is to let people put whatever they want as the robot's head…and that it has meaning for the person. To make the robot more personal. Customization is important"* (MCI, m, 72)
			Physical features (34)	*"I'm projecting myself as the user. I think the robot should have a less medical appearance, be more appealing, more human. You could disguise it to be something more fun, less computerized"* (Caregiver, m, 60)
			Robot appearance (34)	*"I don't like it [humanoid robot] because it gives you the illusion of being with someone and in fact you are still alone"* (MCI, f, 73)
			Usability issues (34)	*"Shouldn't it [the robot] be designed to be as simple as possible?, easy to handle and move?"* (HOA, f, 86)
			Well-adjusted ergonomics (25)	*"It is important to be able to set the height of the robot. If the person is bedridden it might be a little high. You have to consider that there are tall people, small people, people who are seated, bedridden…"* (MCI, f, 64)
User characteristics	83	21	Physical limitations (16)	*"If you can still go out that means that you're independent enough to not need a robot of this kind. This robot should be intended for people who are unable to go out of their homes"* (HOA, f, 71)
			Disability degree (14)	*"For me this robot could be useful to people who have a significant degree of disability. I'm not sure that persons with Alzheimer's will be able to use the e-mail function for example. I think it is good that the function exists but I don't know if it's really necessary"* (HOA, f, 71)
			Preferences and habits (13)	*"You say the robot could offer some video-games. But you have to recognize that people who are in their eighties now are from a generation that is not used to play. They were taught to work, that's all. It is difficult to ask people to do something that they have never done in their entire life"* (Caregiver, f, 81)
			Sensory impairment (12)	*"It is difficult to understand what the robot is saying, and many elderly people use a hearing aid. I am using a new one that I acquired two weeks ago, and I'm a little disappointed because when I'm in open spaces I don't hear better. Also when we get older we have slower reaction times, and when people speak too fast you miss half of what they're saying"* (MCI, f, 83)
			Memory problems (12)	*"Something that worries me is for example that I make a trip. I see beautiful things that I say to my self I must remember. I go home, and two or three months later it is over. I know I've been to that place, and if someone asks me, I'll say, yes, I've seen that. But I won't be sure of what I've seen, unless I take a look at the pictures. Otherwise, these memories are wiped away"* (MCI, f, 65)
Potential applications	132	24	Cognitive support (36)	*"When he is doing nothing, or depressed, or complains that nobody comes to visit him… the robot could be able to store some personal information, for example, on Sunday we did this, we went there… Memories from the last eight days, that would be interesting"* (Caregiver, f, 58)
			Entertainment (22)	*"I'm so sentimental and sensitive that I would like it [the robot] to recite poetry to me, to play some music for me, the*

Parent code	Occurrences		Sub-codes (Occurrences)	Sample excerpts (Group, gender, age)
	Excerpts *N* = 373	**Transcripts *N* = 25**		
				concerts that I love…" (MCI, f, 83)
			Task or event reminding (19)	*"The robot could be used to remind the person of simple things that people with Alzheimer's usually forget: to open the windows from time to time, to drink water, to take a walk if the weather is nice. Not like an order but more like a recommendation, and then to remind them of their appointments one or half an hour before it's time to leave…"* (MCI, f, 65)
			Communication (16)	"*There is something that would please me if I was isolated. To have the possibility to communicate with someone, like a contact person, a caregiver, clicking on his or her picture on the screen, and to speak to him or her regularly about how I am"* (HOA, f, 80)
			Robotic companionship (15)	*"My wife closes herself in her own world. She doesn't want to have visitors, not even close family. She doesn't want to go out and she always finds an excuse. It is more likely that she accepts the companionship of a small robot that moves, that is fun"* (Caregiver, m, 69)
Subjective judgment	199	24	Positive appreciation (83)	*"The robot can be a great aid, but above all it can be a companion. Besides reminding you about important things, it can distract you. In 95% of cases elderly people live alone at their homes. The don't go out, so, it would be nice to have some distraction"* (MCI, f, 65)
			Perceived usefulness (75)	*"I accepted to take part in this study because I want to help research progress, to meet people in the same situation as the one I live with my husband [person with AD]. Actually, he doesn't go out much, and it is difficult for me to handle this situation, to have some free time. I'm really interested in having a robot like this because I think it could influence our relationship in a positive way"* (Caregiver, f, 72)
			Finding useful for others (45)	*"I've met many young people, who are in their forties or fifties, who would be interested in a robot like this because they are paralyzed. For example, people who have multiple sclerosis would be much more interested in it than an older person who has no experience with technology"* (HOA, f, 79)
			Negative appreciation (27)	*"It is quite worrying. We're giving elderly people virtual companions, machine companions. It is undoubtedly much better to have human companionship. Perhaps in some cases there is not choice, and that's sad. If research to make this kind of robots is being done it is because it has been calculated that there won't be enough people to take care of elderly people…"* (Caregiver, f, 65)
			Mistrust (17)	*"You have to test it [the robot] with people who need it. Won't they be afraid? Won't they be stupefied? How are they going to get familiar with it? How are they going to integrate these new devices into their life?"* (Caregiver, m, 60)
Ethical and societal issues	68	20	Cost of the service (15)	*"A robot of this kind will be very expensive. It's crazy how we are creating unnecessary expenses. Otherwise, it will be reserved for high-income households and out of reach for the rest of the population"* (Caregiver, f, 65)
			Robots replacing humans (15)	*"What is really scary is the suppression of the human. I've always said that machines have cut-off the hands of people. And that [humanoid robots] is actually like alienating the whole person. With robots like those, pretty soon*

Parent code	Occurrences		Sub-codes (Occurrences)	Sample excerpts (Group, gender, age)
	Excerpts *N* = 373	**Transcripts *N* = 25**		
				real people won't be needed anymore. Robots will take the place of teachers, of everyone" (MCI, m, 81)
			Infantilization (9)	"*Giving an animal-robot to an elderly person is a form of infantilization, it's almost pejorative"* (MCI, f, 83)
			Privacy (8)	*"It may be intrusive [telesurveillance service], but at the same time a security camera can be useful … For example, my mother [person with AD] is alone at home during the night. We bought an alarm that is activated when no movement is detected in a period of time. But if there was a camera I could check from time to time if everything is OK. Between privacy and safety, is it not better to give priority to safety?"* (Caregiver, f, 58)
			Autonomy (7)	*"We can not accept to do that [using the robot for surveillance] to someone who has been free and independent during all his life. It is awful. Human freedom is a wonderful thing, and we must keep it during our entire lives"* (MCI, m, 68)
Everyday problems	15	9	--	*"Repetitive questioning always comes back. What day is it today? What are we doing today? What do we do now? And immediately after he checks his schedule on the agenda he forgets. So a system like this [robot] that repeats him constantly what day it is, and stuff like this, could be useful to him"* (Caregiver, m, 60)

Content analysis and individual factors

Code occurrence was analyzed according to the most relevant individual factors. For each topic percentages indicate the proportion of occurrences found in a particular group and were normalized based on the relative number of cases. This section presents some key trends observed in the data.

With regard to *robot characteristics,* the analysis showed that participants in the HOA group had more opinions (45.7%) than participants in the MCI (24.2%) or AD caregivers group (30.1%) on how the system should be conceived and on what worked in the design and what did not (i.e., robot appearance, physical characteristics, need for customization). Most of the design suggestions came from young (56.2%), active (65.8%), and healthy participants (61.4%), who reported being familiar with the use of technology (66.5%). Personalization of the robot was a topic of much discussion (HOA 44.2%, MCI 33.4%, caregivers 22.4%) mainly with respect to the appearance of the robot, its voice, the graphical user interface, the degree to which a robot may exhibit human-like emotional and social behavior, the choice of services, and the possibility to adapt the system to people with disabilities. For instance, one of the people in the MCI group stated, *"for me the voice is important, it is much more important than the robot's head. I think you should leave the choice of a male or female voice as it works for GPS".*

AD caregivers were more concerned about usability issues (55.5%), including the need of good ergonomics, training, and support, than participants with MCI (16%) and HOA (28.5%). In general, most caregivers agreed that robot technology could be inaccessible for elderly people with cognitive impairment and no technology experience. One of the spouse-caregivers noted: *"I think the patient will be unable to use the robot. Somebody else would have to do it for him. Otherwise, training must be provided at the first stages of the disease. My husband now has difficulties using the telephone, even if he's used it for over 70 years. How can you expect him to learn to use an appliance that is completely new for him? This is completely utopian".*

Also about system characteristics, it is worth noting that the majority of HOA (75%), of individuals who did not perceive the utility of the system (100%), and those who had no current intention to use it (100%), had a strong negative opinion on giving a human appearance to the robot. In general, these persons considered that a robot was only a machine; consequently they argued that it should have a machine-like appearance. One of them mentioned, "*I'm completely opposed to these robots [androids]. If you have a scientific mind, you ask yourself, what is the purpose of this ventriloquist dummy anyway?"*

Participants in the MCI and AD caregivers group had more mixed opinions towards human-like robots. In these groups, the idea of the robot being capable of human-like communication was positively accepted: *"If the robot is going to be part of my life he must be capable of communicating with me, being helpful is not enough".* Overall, humanizing the robot to a certain degree was appreciated, but giving the robot too much of a realistic human appearance was considered problematic. In the caregiver group, the argument given was that hyper-realistic representations could lead patients to confusion; participants in the MCI group claimed that they would have the feeling of being deceived or misled. These diverse and sometimes contradictory opinions and beliefs also reflected older adults' attitudes towards cultural representations of robots: *"There was this film [Blade runner] in which robots resembled humans so closely that they were confused with them. It was terrible, but it was beautiful at the same time".*

User's characteristics were a matter of overall concern. This category referred to the definition of the end-user profile (i.e., the population for whom the robot was intended). Concerning this topic, a difference was observed between user-groups. Participants in the caregiver and MCI groups considered that the robot could be particularly useful to people who experience cognitive limitations (43.2% and 37.8% respectively). These perceptions were in line with their opinions about the *potential applications* of the robot. Indeed, they thought that the robot could be used as a cognitive support (caregivers 46%, MCI 36.8% MCI), to locate lost items (caregivers 58.8%, MCI 41.2%), to stock memories in a life memory album (caregivers 58.8%, MCI 41.2%), or for temporal orientation (caregivers 74.1%, MCI 25.9%). As expected, participants in the AD caregiver group found that the robot could be useful to support their caregiving duties (87.5%) and to alleviate their burden (82.1%).

These opinions were also in agreement with the fact that *everyday problems* were almost exclusively reported in the MCI (44.9%) and caregivers group (48.1%). For the caregivers, these problems concerned the care-recipient's memory problems, repetitive questioning, apathy, and loss of autonomy. In the MCI group, everyday difficulties resulted from their memory problems, the execution of complex tasks, mobility problems, the risk of falling down, or a feeling of solitude. Finally, data revealed that the acceptance of the robot's services was higher among caregivers (54%), compared with individuals with MCI (28.3%) and HOA (17.7%). Caregivers' views also reflected the highest level of perceived usefulness of the system (46.1%) and of current acceptance (65.8%).

On the contrary, participants in the HOA considered that the robot could be used to support people with physical limitations (73.3%), or sensory impairment in vision or hearing (71.4%). These opinions were consistent with the fact that none of the participants in this group perceived the robot as being useful for themselves. Potential applications mentioned by HOA were also in agreement with the representation they had of prospective users of SAR (e.g., frail elderly persons, being disabled, or isolated). In this group, the applications that were perceived to be the most useful were those associated with healthcare and reduced mobility: remote medical consultation (100%), physiological data collection (55.6%), assisting professional caregivers (55.6%), object manipulation (100%), and video calls (54.4%).

In general, there was a high perception of the utility of recreational and leisure applications that could be implemented into the robot. However, a particular concern was raised about the conformity of these activities with the preferences and interests of the potential user: *"You could build an application based on the history of the person, their past, what they enjoy doing, for example exploring a museum's collections online…"*

Regarding the *robotic companionship* aspects, opinions were rather mixed. For some of the caregivers, this idea was found valuable as long as the primary goal of the robot was not to replace human contact: *"For some people it can be more pleasant to be with a robot than to be alone. It would also allow the caregiver to have some time away from the patient. But its use [robot companionship] should not be generalized. For a person that still has a social life, seeing a real human face is better than looking at a screen. The robot can't take the place of the caregiver anyway".* Caregivers had a more positive perception of the robot's social features (64.8%), including human-like communication and the exhibition of social responses, than participants in the other groups (MCI 18.2%, HOA 17%). The acceptance of the robot's social features was also associated with a high interest in ICT (56.7%), younger age (87.4%), psychological symptoms (e.g., apathy, depressed mood) (64.5%), and being professionally active (80.8%).

Robotic companionship was considered an interesting feature, primarily for participants in the MCI group (39.5%) followed by AD caregivers (32.3%). Elderly persons with MCI tended to perceive a robot companion as a distraction, a confidant, and a company for lonely people: *"This robot could be like a friend. The person wouldn't have the impression of being completely alone… 24 hours it's a long time when you're alone".* Caregivers acknowledged the utility that SAR could represent for the person they cared for. Participants in the HOA group who agreed on the interest of this function (28.2%) estimated that robotic companionship could be helpful for isolated people or for those with depression, but they saw no benefit of this feature for themselves.

Participants in all groups discussed *ethical and societal issues* associated to the use of SAR. Interestingly, participants who reported a high perceived usefulness of SAR, or being ready to adopt the system at the present time, discussed these aspects to a greater extent (37.5% and 41.8% respectively) than participants who reported either no perceived usefulness (26%) or current acceptance of the robot (24.4%). However, only participants in the MCI group expressed their concern about the stigmatization that could result from the use of SAR. For instance, one of the MCI participants noted: "*Some work has to be done if you don't want people to think that if they are given a robot it's because they are screwed. People should think that the robot is there to help, there must be a way to present it in a positive way*".

MCI participants were more sensitive to privacy issues (56%) than caregivers (16%) and HOA (28%). A relatively common view among MCI participants was that monitoring and surveillance applications were an intrusion into their privacy. On the contrary, caregivers had a more positive perception of these applications considering their potential to ensure the safety of the care recipient at home. Nevertheless, individuals with MCI did express their interest in services that could contribute to their safety (100%) as long as they did not involve video data gathering, for instance fall detectors (42.7%) and the emergency and care call systems (49.1%).

Concerns about infantilization were principally pointed out by HOA participants (47.9%). These worries were mostly associated to the appearance of the robot, particularly to the use of human or animal-like robots. Participants who expressed their position regarding the risk of infantilizing elderly people also recognized having no interest in novel technologies (77.6%), no perceived usefulness of SAR (70.2%), and no current (67.1%) or future intention (83.6%) to use them.

A feeling of mistrust towards some applications of the robot was reported, especially among AD caregivers (44.4%) and participants with MCI (36.2%). These apprehensions were related to the following aspects: the idea that the robot would not be able to effectively perform the tasks that it will be assigned, accessibility barriers, the replacement of human caregivers by robots and the unemployment that could result from it, data confidentiality, safe use of the system, and the necessity of involving a third person to handle some of the robot's applications (e.g., entering events on the calendar, scheduling medication reminders). A feeling of rejection towards humanoid robots and the detection and recognition of emotional information by the robot was more frequently observed in HOA (67.3%) than in AD caregivers (19.2%) or participants with MCI (13.5%).

Finally, of particular concern among participants with MCI was the observation that the cost of social assistive robots could be prohibitively high (46.8%), a major factor that could hinder the acquisition of such systems. The majority of persons who brought up the subject of costs were younger (63.1%), professionally active people (78.5%) who reported being ready to use the robot at the present time (63.4%).

4.1.5 Discussion

This study had the purpose of examining attitudes and opinions of three groups of potential users of SAR: elderly with cognitive impairment, caregivers of persons with AD, and healthy older adults. In this section, findings are discussed with respect to the main factors that were identified as having an influence on SAR acceptance, in particular those associated to group characteristics, as well as to robot appearance.

Potential users of SAR will be looking for what they need

One of the key themes that emerged in the discussions was the demand for personalization of robot's features including services, interaction modalities, physicality, and behavior. The personalization of ICT, which refers to the design efforts made to tailor information, technological devices and interfaces to the user's needs, interests, knowledge, goals, and preferences, has indeed received much attention over the last decade (Alpert, Karat, Karat, Brodie, & Vergo, 2003; Cui, Chipchase, & Ichikawa, 2007; Ho & Lee, 2011; Melazzi, 2005); its primary goal is to help users find what they want in ICT products and services contributing in this way to enrich the user experience.

Kalyanaraman & Sundar (2006) investigated how the customization of content in Web portals affected user's attitudes and behaviors. In their study, several benefits of personalization were identified: increased positive user–interface relationships, loyalty (i.e., users are more likely to return to customized sites than to non-customized ones), and high perceived involvement, relevance, interactivity, and novelty. Oulasvirta & Blom (2008) have pointed out that besides improving performance and enjoyment of use, personalization promotes autonomy, sense of ownership (e.g., transforming technology to 'my technology'), engagement, identity, distinctiveness, social acceptance, and social status. Blom & Monk (2003) investigated the effects of personalizing the appearance of mobile phones and PCs. Their study concluded that this behavior has cognitive (e.g., increased perceived ease of use, improved aesthetics), social (e.g., reflection of personal and group identities), and emotional effects (e.g., familiarity, ownership, and attachment) on the user.

The issue of customization has also been adressed, although to a lesser extent, in the literature on assitive robotics for elderly people. Meng & Lee (2006) emphasized that assistive robotics design must give priority to the user's preferences, exclusively technological issues being of secondary importance. These authors argued that assistive robotics implies both a high degree of adaptability to a wide range of users' needs, tasks, and environments, and a "collaborative" relationship with the user, its role not being to replace but to support and enhance human abilities. From another perspective Sharkey & Sharkey (2010) studied ethical issues involved in robot care for the elderly. Their analysis concluded that customization of robotic solutions for elderly people would be the best way to implement useful and ethical systems that contribute to the physical and psychological well-being of potential users without restricting their individual rights.

Findings from the present study revealed that a wide range of heterogeneous needs should be taken in consideration when designing SAR for elderly people with cognitive impairment. This heterogeneity resulted from the complex and dynamic nature of the situations these persons experienced because dealing with situations such as Alzheimer's disease, involves different actors (e.g., patients, formal and informal caregivers, family) and consequently, diverse needs. In addition, these needs may evolve over time. Based on the opinions gathered in this study the demand for customization of SAR could be analyzed at two levels:

(1) *Group-related interests:* each participant in this study belonged to a group in which people shared a particular situation (e.g., role of caregiver), a health-related condition (e.g., MCI), or similar self-representations (e.g., considering themselves independent, active, and healthy elderly individuals). The demand for personalized services responded at this level to the search for solutions that met the needs resulting from their particular circumstances (e.g., caring for a dependent person, experiencing cognitive decline and being aware of such difficulties, having some physical or sensorial limitations, feeling isolated). Consequently, there was a rather large heterogeneity among the three groups regarding the services expected from a robot.

Participants in the caregivers and MCI groups sought to identify solutions that could help them deal with everyday problems they faced. For instance, caregivers expressed their interest in applications that could contribute to improve the living environment of persons with cognitive disabilities and make it easier to care for them. Therefore, they perceived the robot as a tool for stimulating and supporting the person they cared for, as an extra assistant for caregiving tasks, and in some cases as a potential mediator between them and their loved ones. These findings are in line with results from previous studies that have identified the following needs of caregivers of people with dementia that could be met by technology: safety issues, reducing caregiver's stress and burden, the lack of stimulating and meaningful activities, social withdrawal of care recipients (for a review, see Topo, 2008). Participants with MCI focused on cognitive and social support services intended to help them increase their autonomy and overcome social isolation and loneliness. These findings are consistent with those of Gross et al. (2011) and Wu et al. (2011) that found that persons with MCI had a positive view on SAR functions related to cognitive and social support (e.g., cognitive stimulation, items locator, event reminder, communication services).

Participants in the HOA group had a different view on the purpose of the robot. There was no inherent demand for personalization of the system because these individuals did not identify themselves as potential users of the robot, which should rather target isolated frail elderly people. HOA considered priority services those that could meet the needs of people with various disabilities (e.g., compensation for disabilities, health monitoring, aid for mobility) and personalization requirements were formulated in this direction.

There are similarities between the attitudes expressed by HOA in this research and those described by Neven (2010) in his study about the representations that elderly people and robot designers had of prospective users of SAR. This author found that having or needing a robot was a signifier of old age, loneliness, and physical and cognitive deterioration for the elderly people who participated in his study. Furthermore, it was observed that participants dissociated themselves from the representation they had of prospective robot users by presenting themselves as healthy, active, and independent persons, who were helping the “others” by taking part in that research. It is possible that the negative representations that HOA had of prospective users of the robot in our study would have also led them to distance themselves from the group of potential users.

The identity-signaling approach to divergence proposed by Berger & Heath (2008) may prove helpful to interpret this finding. This approach claims that people often diverge from others, for example with regard to cultural tastes or practices, to make sure that their identity is correctly recognized and avoid misidentification (e.g., being associated to low-status or disliked others). If we acknowledge that SAR serve a symbolic function it is important to examine the meanings related to their use. Since the meaning that HOA attributed to prospective users of SAR was negative (e.g., the complete opposite of successful aging people) it is understandable that they have strongly avoided to be considered as such. This also lends support to the analysis of ageism conducted by Nelson (2005) in which he suggested that the negative perception of older adults that some persons exhibit is a way of denying the self-threatening aspects associated with old age (e.g., becoming frail, dependent, isolated) and to reduce the anxiety associated with considering themselves as future older people.

(2) *Individual preferences, self-representations, and expectations:* The majority of participants agreed on the importance of being able to configure the robot according to their preferences to make it more personal. Actually, personalization was

the most used child code in our analysis besides subjective judgments. Personalization suggestions primarily dealt with robot appearance, but also its name, gender, personality, voice, interaction modalities, and the configuration of applications according to the user's interests and previous experiences.

Although most of the participants felt that physical attributes of the robot were a secondary aspect, with respect to functionality, the frequency with which robot appearance issues were raised allowed us to conclude that physicality might have a greater influence on robot acceptance than initially thought. For example, some of the types of design presented (e.g., animal-like, humanoid, medical appearance) caused rejection among certain participants because they were associated with negative representations of aging or unethical care practices (e.g., infantilization, stigmatization, deceptiveness). These findings confirmed that ethical issues described by Sharkey & Sharkey (2010), and Sparrow & Sparrow (2006), such as the risk of infantilization (i.e., disempowering effect associated with the conception of elderly with dementia reverting back to childhood) and deception (i.e., being induced to believe that robots are something that they are not) are issues of concern for older adults. On the contrary, several participants argued that appearance could have a positive influence on robot acceptance, if it conveyed representations associated with pleasure, entertainment, confidence, friendliness, and company; most of these positive features were related to the social capabilities of the robot and will be discussed later in this paper.

The evidence from this study suggests that it is important to allow potential users to customize the appearance of the robot because negative judgments about its design may affect compliance and be a reason for rejection or abandonment. On the contrary, positive perceptions could improve technology acceptance, attachment to the system, and make the integration of the robot into the home easier. In this sense it could be expected to observe positive effects of personalization of SAR similar to those observed for mobile phones (Blom & Monk, 2003; Cui et al., 2007; Ho & Lee, 2011), PCs, or domestic vacuuming robots (Sung, Grinter, & Christensen, 2009). In this respect, Broadbent et al., (2009) have pointed out that allowing the user to personalize the robot would help not only to accommodate individual differences but also to give users a sense of autonomy and control over the robot.

However, further work needs to be done to establish whether personalization of SAR actually adds value for users. One of the main limitations of the studies conducted on SAR acceptance is the way robots are presented to potential users. Most of these works have used questionnaires, visual media, or very advanced prototypes leaving little room for personalization. The following logical step could be to conduct user studies employing more generic and flexible prototypes with the purpose of determining which specific personalization features would be rated as the most usable, valuable, and attractive in SAR by different subgroups of older adults. Finally, another issue that should be taken into account for future research is how experience over time influences user's preferences, attitudes and expectations towards robots, and how SAR can accommodate the changing needs, goals, and contexts of elderly people with cognitive impairment and their caregivers.

Functionality and "looks" are important, but they are not everything

AD caregivers and participants with MCI agreed about the fact that the robot should not only be useful, but also pleasant and fun to use. These findings are consistent with those of Heerink et al. (2008) who observed that there was a strong correlation between "perceived enjoyment" and "intention to use" when assessing interactive robots among elderly users. In the same line of reasoning, Young et al. (2009) indicated that satisfying users' need for fun and entertainment increased the acceptance of SAR.

However, as pointed out by Heenrik et al., (2006) one of the challenges of SAR design is to reach a balance between functionality, resulting from the technical configuration, and enjoyment, supported by the physical and "psychological" attributes of the robot (e.g., appearance, voice, social capabilities, personality). These authors have suggested that SAR acceptance covers both functional and social aspects. The first refers to the perceived usefulness of the system, and the second to the willingness of end-users to engage in a social interaction with a robot. Indeed, potential users of SAR need to have a clear understanding of the practical gains that result from the use of these systems. The way perceived usefulness influences attitudes towards a given technology, and subsequently, behavioral intention to use it has been conceptualized in the Technology Acceptance Model (Davis, 1989). Moreover, behavioral intention to use a system has been found to predict its actual use (Legris, Ingham, Collerette, 2003).

Social acceptance is a more complex variable since it implies several aspects that go beyond utility and robot appearance. In the present study, 40% of the participants had a positive view of the social capabilities of the robot, in particular those in the MCI and AD caregiver group, younger and active persons with a high interest for technology, and who reported psychological symptoms in them or their loved ones. Participants who were interested in robotic companionship also considered that some physical properties of the robot (e.g., human-like voice and suggested human-like facial features) could facilitate social human-robot interaction (i.e., allowing the users to identify the robot as a conversational partner). Nevertheless, realistic human-likeness was not considered the optimal solution to characterize the robot's social capabilities. These observations are consistent with the most frequent choice of human-machine robots as the preferred design followed by animal-machine robots, a design that incorporates human features as well. Results in the same direction were observed with regard to the rocèsze of the robot's head and the exhibition of emotional capabilities: it is good to have some of it but not too much.

These results share a number of similarities with those of Dautenhahn et al. (2005) who found, among a group of 28 subjects of different ages, that 40% of them had a positive opinion about robotic companionship, in particular the younger individuals. In addition, although the majority of respondents agreed that they would like the robot to communicate in a human-like manner, they felt that human-like behavior and appearance were less important features. Arras & Cerqui (2005) had also observed that acceptance of the humanoid appearance of robots decreased with age. Our results further support these previous findings since we found that some of the design features that could contribute to robot adoption are having a familiar appearance, but not too human-like, and a caring and empathic personality, (Broadbent et al., 2009; Forlizzi, DiSalvo, & Gemperle, 2004; Wu et al., 2012). As long as it refers to determining the optimal robot design, our findings are in line with the view of Young et al., (2009) of successful domestic robotic interfaces as being somewhere in between a mechanical and a human-like appearance.

Participants in the AD caregivers group had a higher perceived usefulness of the social capabilities of the robot than participants in the HOA and MCI groups. Since AD caregivers are confronted daily with specific cognitive and psychological symptoms of

AD such as apathy, social withdrawal, gradual loss of verbal communication abilities, or depressed mood (Allegri et al., 2006), they considered the robot as a potential instrument to stimulate the person with AD. This is in good agreement with Ryan et al., (2010) findings about the strong correlation existing between support service needs among AD and MCI caregivers and the presence and severity of neuropsychiatric symptoms. Furthermore, some of the caregivers expressed that a robot caregiver could be better accepted by the patient than a professional caregiver and others stated that they would personally prefer a robotic than a personal assistant.

In the HOA group, opinions on this subject were rather mixed, but in a general way priority was given to the practical and functional aspects of the robot. These individuals did not manifest any interest for the features that could contribute to affective human-robot interaction, at least with respect to themselves. They eventually raised the subject of robot companionship, but only because they had other prospective users in mind. Conceptually, the robot was viewed in this group as a device or machine whose goal should be to ensure the safety of persons who live alone and provide them with tools for supporting everyday tasks and communication with other persons.

Intention to use and level of insight about SAR possibilities and implications

Acceptance of the current system was higher among AD caregivers, who felt very concerned by the need of support services. Therefore, for these individuals the use of an assistive robot was seen as an added contribution to the pre-existing care. For people with MCI, current acceptance of the robot was lower than for AD caregivers. Still, it is important to acknowledge that they expressed some degree of acceptance. On the contrary, current acceptance of the robot in the HOA group was almost inexistent. These results have further strengthened our conviction that perceived usefulness of SAR depends on user's characteristics. Indeed, the difference of current acceptance scores among the three groups could be explained by the fact that individuals with AD have more functional disabilities and neuropsychiatric symptoms than individuals with MCI, who in turn have more functional disabilities and neuropsychiatric symptoms than healthy older adults (Ryan et al., 2010).

It is interesting to note that participants in all three groups reported a higher intention to use the robot in the future than in the present. This trend was less evident among AD caregivers because they took in consideration the changing conditions in health status and functional capacity observed in patients with dementia. Consequently, they believed that the use of a robot would no longer be possible at later stages of AD.

People who felt more concerned by a current need of support services, specifically AD caregivers and persons with MCI, seemed more disposed to discuss practical issues related to the use of the robot, for example, the costs of the service and financing alternatives. This is understandable since these individuals had a more pronounced intention to use the system in the present time than HOA. In accordance, they could more easily project themselves using it. In this sense, participants with MCI were concerned with ethical issues related to the intrusion into privacy, and AD caregiveres raised several questions about accessibility, usability, and the need of training and support to use the robot.

Finally one of the most striking results to emerge from the data was the significant difference observed between current and future acceptance in the MCI and HOA groups. It would seem that these individuals, even those who considered themselves healthy and independent in the present time, were influenced by ageist conceptions and accordingly anticipated a future-self that corresponded to those stereotypes (e.g., being lonely, ill, dependent, demented, or disabled) (McGuire, Klein, & Chen, 2008; Nelson, 2005)

Ethical issues

While requirements gathering helped us to define which characteristics of the robot had value and utility for potential users, and to prioritize these requirements, it also contributed to the examination of ethical and societal factors that appeared to influence technology acceptance. Some of the topics that were identified in this study were: the importance of clearly defining of the roles of human and robotic assistance and establishing clear boundaries between them; the respect of privacy, dignity and autonomy; finding a balance between the benefits and risks of these systems; avoiding considering potential robot users as a homogeneous group; and the need for a regulatory framework for the use of SAR.

Methodological issues

The diversity and richness of the opinions expressed by participants in this study has demonstrated that mixed-method approaches are particularly well suited to explore potential users' attitudes towards SAR. Questionnaires and focus groups have also proven to be complementary methods: the first allowed the identification of general trends of SAR acceptance whereas focus groups were useful to explore in-depth views on SAR.

The use of multiple support materials for presenting product-related information was successful and could be of general interest for future studies in the field (e.g., live demonstrations, pictures, videos, scenarios). Proof of this is the fact that participants in all groups were able to understand and give their opinion on the scenarios for SAR that were provided, develop their own scenarios based on their own experience and projections, discriminate between the different types of robot design, and to realize the potential of content and hardware personalization.

The use of diverse need gathering practices is in line with the conclusions of Flandorfer (2012) about how user opinions about SAR might be influenced by the way information is presented to them. Research teams from different robotics projects have claimed that the distrust of robots by the general public through distant relationships (e.g., media communications) has never materialized when people interact with them in person (Sofge, 2010). Developing appropriate means to measure the change in attitudes towards SAR, before and after a direct encounter is an important issue for future research.

The current study was limited by some methodological shortcomings. The first is the small size of the sample that did not allow deep examination of the interactions between some individual factors (e.g., education level) and SAR acceptance. Moreover, given the small sample size and the possibility of selection bias (i.e., participants who agreed to take part in this study were, in principle, individuals that had some interest in discussing the use of technology for healthcare purposes) findings cannot easily be generalized to the entire population. The second is the lack of direct interaction between the users and the robot. It has been explained before that direct experience of robots might influence users' expectations and opinions about these systems. Lastly, another weakness of this study was that persons with AD, who are considered prospective primary-users of SAR, were not included in the sample. Further studies, which take these factors into account, will need to be undertaken.

4.1.6 Conclusions

It is expected that the field of SAR will continue to develop. However, ensuring the design of acceptable and efficient systems is a complex endeavor. The results of this study support the idea that the development of senseful and appropriate robotic solutions for older adults with cognitive impairment, and their caregivers, requires giving special consideration to the role of individual factors and the wide range of needs and preferences that exists among these potential users. There is no configuration that fits all scenarios. An implication of this is the demand for personalized systems.

People with MCI and AD caregivers considered that the goal of SAR, along with meeting users' functional needs, should be to support them in maintaining current valued relationships, playing the role of an additional caregiver or a temporary companion. These persons also expressed their intention to use a robot either in the present or in the future time. Healthy older adults felt that SAR should have a primarily utilitarian purpose and that such systems would be of some benefit for others but not for themselves, at least in the present time. These different views and the social and self-representations that underlie them must be carefully heard and respected.

Results so far have been encouraging in the sense that they reflected that elderly people are increasingly recognizing the possibilities of SAR for functional and social purposes. Although the current state of the research on SAR does not allow us to conclude that elderly people are ready for robots that care for them, this idea is no longer unimaginable. Nevertheless, many technical, methodological, ethical, and societal challenges must still be addressed before these systems can be proven reliable, acceptable, and effective enough to be introduced in the market.

4.1.7 References

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4.1.8 Appendices

Appendix A

Questionnaire used for data collection

PRAMAD PROJECT

I. Socio-demographic data

Age: Education Level:
Gender:

1- What are the principle difficulties you have in your daily life? :
☐ memory troubles, forgetfulness
☐ difficulty finding words and proper names
☐ falling or being afraid to fall
☐ difficulty walking or moving around
☐ difficulty taking care of administrative paperwork and your finances
☐ sadness, depression
☐ anxiety
☐ apathy, inactivity, not motivated
☐ pain
☐ chronic diseases that must be followed by a healthcare professional, i.e. diabetes ; hypertension, etc.)
☐ solitude; isolation)
☐ others

II. Technology use

2- Amongst the following technologies which do you use?
☐ radio
☐ television set
☐ fixed line
☐ cell phone If yes: *Touch-screen* *No touch-screen*
☐ answering machine
☐ dvd player
☐ digital camera
☐ walkman
☐ computer If yes: *regular use* *rocèszed use* *has used at least once*
☐ Internet If yes: *regular use* *rocèszed use* *has used at least once*

What it is used for:

3- What interest level do you have for new technologies in general?
☐ very interested
☐ fairly interested
☐ slightly interested
☐ not at all interested

4- How do you normally react to a new technology-related service or product?
☐ I always try new products that are available
☐ I have my habits but I am interested in new products and services
☐ I sometimes change my habits
☐ I rarely change my habits

III. Appreciation of social assistive robots

5- Please indicate your three favorite robots in terms of physical appearance

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6– The idea that a robot has a head with human traits seems:

☐ very interesting
☐ fairly interesting
☐ not very interesting
☐ not at all interesting

7–What degree of realism seems adequate to you when concerning the expressions of the robot on his face

☐ very realistic, like a human (humanoid robots)
☐ fairly realistic (human like robots)
☐ not very realistic (animal-like or human-machine)
☐ not at all realistic (machine like)

8- What are the three functions that are indispensable for a robot of this type. Please write your response in order of importance

1
2
3

III. Opinions about the robot

9 –Do you think a robot of this type is useful for you in your current situation?

☐ absolutely
☐ fairly yes
☐ fairly non
☐ not at all

why?

---

10. Will you be ready to use the robot in your home now?

☐ absolutely
☐ fairly yes
☐ fairly non
☐ not at all

why?

---

11. And in the future?

☐ absolutely
☐ fairly yes
☐ fairly non
☐ not at all

why?

Thank you for your participation!

Appendix B

Variables explored in the study

Domain	Category	Sub category	Value
Demographics	Gender	n/a	Female/Male
	Age		In years
	Education level		Elementary/High school/University
	Group		Caregiver (Spouse/Child)/MCI /Cognitively healthy older adults
	Activity status		Retired (0)/Active (1)
Self rated health status	Cognitive trouble	Memory impairment	No(0)/Yes (1)
		Difficulties in word-finding	No(0)/Yes (1)
		Difficulties managing household finances	No(0)/Yes (1)
	At least one cognitive limitation		No(0)/Yes (1)
	Mobility trouble	Fall or fear of falling	No(0)/Yes (1)
		Difficulty to walk or to move	No(0)/Yes (1)
	At least one mobility limitation		No(0)/Yes (1)
	Psychological symptoms	Depression	No(0)/Yes (1)
		Anxiety	No(0)/Yes (1)
		Apathy	No(0)/Yes (1)
		Loneliness	No(0)/Yes (1)
	At least one psychological symptom		No(0)/Yes (1)
	Physical health problem	Pain	No(0)/Yes (1)
		Chronic diseases	No(0)/Yes (1)
	At least one physical health problem		No(0)/Yes (1)
	Self-rated health status (0-12)		*Rated from 0 – 12* Excellent (0)/ good (1-4)/fair (5-8)/poor (9-12)
Technology	Use of current technologies	Radio	No(0)/Yes (1)
		TV	No(0)/Yes (1)
		Phone	No(0)/Yes (1)
		Mobile phone	*Rated from 0 – 2* No (0)/yes non tactile (1)/ yes tactile (2)
		Answering Machine	No(0)/Yes (1)
		DVD player	No(0)/Yes (1)
		Digital camera	No(0)/Yes (1)
		Portable audio player	No(0)/Yes (1)
		Computer	*Rated from 0 –3* No (0)/has already used (1)/occasional use (2)/regular use (3)
		Internet	*Rated from 0 –3* No (0)/has already used (1)/occasional use (2)/regular use(3)
	Overall score use of current technology (0-15)		*Rated from 0 –15* 0: No technology used 1-5: Little use of technologies 6-10: Moderate use of technologies 11-15: Important use of technologies
	Attitude towards new technologies	Interest in ICT	*Rated from 0 – 3* No interest (0)/limited interest

Domain	Category	Sub category	Value
		Behavior towards new technologies	(1)/average interest (2)/high interest (3) *Rated from 0 – 3* Resistance towards change (0)/change sometimes his habits (1)/open to change(2)/very open to new technologies (3)
	Overall score attitude towards technology (0-6)		*Rated from 0 – 6* 0: Reject 1-2: close minded 3-4: open minded 5-6: very open minded
Opinion about the robot	Perceived usefulness	n/a	*Rated from 0 – 3* None (0)/few (1)/moderate (2)/important (3)
	Current acceptance		*Rated from 0 – 3* Nul (0)/low (1)/moderate (2)/high (3)
	Future acceptance		*Rated from 0 – 3* Nul (0)/low (1)/moderate (2)/high (3)

n/a = not applicable; ICT = Information and Communication Technology

4.2 Robot Services for Older Adults with Cognitive Impairment: Testing Usability of Graphical User Interfaces with Target End-Users[12, 13]

Socially assistive robotics for elderly care is a growing field. However, although robotic devices have the potential to support elderly people in daily tasks by offering specific services, the development of usable interfaces is still a challenge. Since several factors, such as age-related changes in perceptual or cognitive abilities and familiarity with computers, influence technology use in older adults, they must be considered when designing interfaces for these users. This paper presents findings from the testing of two services provided by a robot intended for elderly persons with cognitive impairment: a grocery shopping list and an agenda application. The button icons of the main menu that give access to these services were also evaluated on three aspects: interpretation, identification and meaningfulness. Socio-demographic characteristics and computer experience were examined as factors that could have an influence on task performance. A group of 11 elderly persons with Mild Cognitive Impairment and a group of 11 cognitively healthy elderly individuals took part in this study. Performance measures (task completion time and number of errors) were collected. No significant differences between groups were found in the evaluation of main menu icons. While some of the icons did not meet the interpretation and meaningfulness criteria others were adequately rated with regard to these aspects. All the icons were accurately identified. In the shopping list and agenda tasks cognitive profile, age and computer experience were found to impact task performance, particularly task completion time. Participants with MCI experienced more difficulties in completing the shopping list task. Younger participants, as well as those with previous computer experience, performed the tasks faster and more accurately than older and less experienced users, confirming previous findings in the literature. Overall results suggested that interfaces and content were usable by older adults with cognitive impairment. However, some usability problems were identified and should be addressed to better meet the needs and capacities of target end-users.

Key words: GUI; usability testing; elderly users; cognitive impairment; graphical user interface; social assistive robots.

[12] This study was conducted within the framework of the QuoVADis project

[13] This work was conducted together with C. Granata and G. Legouverneur. J. S. Vidal contributed with the statistical analysis of the data.

4.2.1 Introduction

Age-associated memory impairment, Mild Cognitive Impairment (MCI), and Alzheimer's disease (AD) are among the most common forms of cognitive decline that elderly individuals are likely to face (Bishop, Lu, & Yankner, 2010; Rogers, Kang, & Miller, 2007). Cognitive impairment most commonly impacts memory, but it can affect other aspects of cognition such as attention, language, perceptual skills, orientation and problem solving. While mild cognitive deficits can interfere with the performance of instrumental activities of daily life (e.g., driving, managing finances or medication) (Aretouli & Brandt, 2010), severe deficits often lead to complete disability and institutionalization (Desai, Grossberg, & Sheth, 2004; Luppa et al., 2009). Thus, older adults suffering from cognitive impairment may require varying degrees of assistance to perform daily tasks.

Responding to the needs of these populations has become a major aim of Socially Assistive Robotics (SAR) (Broekens, Heerink, & Rosendal, 2009; Feil-Seifer & Mataric, 2005; Flandorfer, 2012). SAR encompasses all robotic systems capable of providing assistance to the user by means of social interaction. Their scope covers a wide range of tasks for which assistance can be provided without physical interaction. In general, SAR systems have the potential to contribute to a user's daily life at different levels (Rich & Sidner, 2009):

- By supporting and/or compensating functional abilities through different technology-based services (e.g., task reminder, task monitoring, schedule-management systems, navigation aids).
- By contributing to the social and psychological wellbeing of end-users (e.g., communication and social networking services, companionship aspects, recognition and expression of emotional states, collaboration and engagement capacities).
- By providing monitoring that contributes to healthcare and safety. With regard to this issue, SAR can be associated with other devices capable of collecting data on the physiological activity of the person (e.g. fall detector).
- By making a continual assessment of the user's cognitive functioning through the analysis of daily behavior. This aspect pertains to applications that collect

performance measures during task execution and facilitate the follow-up of cognitive deficits.

Different modalities can be employed to ensure interaction between social robots and users (Feil-Seifer & Mataric, 2005). Individual interaction modalities include speech (voice user interfaces), gestural interfaces, and direct input (e.g., touch-screen interface). Furthermore, multimodality constitutes an alternative interaction solution in which individual modalities are combined. In general, robots that use a touch-screen as input device provide their services through a Graphical User Interface (GUI). However, GUI design for Human-Robot Interaction (HRI) that suits the needs of non-expert computer users and elderly people with cognitive impairment is still a challenge (Broekens et al., 2009; Gregor, Newell, & Zajicek, 2002; Young, Hawkins, Sharlin, & Igarashi, 2008).

In this study, we focus on the design of a Graphical User Interface (GUI) for a social assistive robot. More specifically, we present results from the usability testing of two of the services accessible through the GUI (i.e., grocery shopping list and agenda) with two user groups: elderly persons with MCI and elderly healthy controls. The graphical menu that gives access to these applications was also evaluated. Findings are analyzed with regard to user performances, individual factors, and GUI design.

4.2.2 GUI Accessibility and Usability

The influence of usability (e.g., interface complexity, functionality) and individual factors (e.g., age, computer experience, cognitive abilities) on technology acceptance and use by older adults has been largely documented (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Lunn & Harper, 2011; Pak & McLaughlin, 2010; Wagner, Hassanein, & Head, 2010). Among the factors that have proven to be problematic for older adults when interacting with software applications or browsing the Web are: demands on working memory to storage and process contextual information, use of navigation menus, discrimination of relevant information on a visual display (e.g., hyperlinks, buttons), use of dynamic Web content, and use of windows and scrolling bars (Arch, 2008; Chadwick-Dias, McNulty, & Tullis, 2002; Fisk et al., 2009). Indeed, improving the accessibility of Web content and GUIs for elderly users has become a critical issue over the last years (Arch, 2008; Chadwick-Dias et al., 2002; Gregor et al., 2002; Lunn, Yesilada, & Harper, 2009; Reisenwitz, Iyer, Kuhlmeier, & Eastman, 2007). In contrast, little work has been conducted on Web accessibility, interface and software design for elderly persons with cognitive impairment (MCI, AD) (Alm et al., 2003; Astell et al., 2010; Boulay, Benveniste, Boespflug, Jouvelot, & Rigaud, 2011; Riley, Alm, & Newell, 2009; Topo & Östlund, 2009). Nevertheless, in recent years, an effort has been done to understand the specificities of individuals with cognitive impairment as technology users, which has lead to the formulation of general guidelines for designing technology usable by this population (Maki & Topo, 2009; Orpwood et al., 2004).

In the field of assistive robotics some studies have assessed acceptability and interaction modalities with elderly with cognitive impairment (Broadbent et al., 2010; Dario, Guglielmelli, Laschi, & Teti, 1999; Libin & Libin, 2004; Montemerlo, Pineau, Roy, Thrun, & Verma, 2002; Schraft, Schaeffer, & May, 1998; Wada, Shibata, Saito, Sakamoto, & Tanie, 2005). However, research to date has mostly focused on general HRI rather than usability of interfaces. This is a shortcoming since, when robots use a touch-screen as an input device, applications are normally accessed through the GUI. Then, once the application is running, the user has to navigate through the system using next and previous buttons, pull-down menus or other navigation controls. If target users face difficulties in understanding and navigating through the system there will be a reduction or even a total lack of effectiveness and productivity of the system (Lunn et al., 2009).

Nowadays, guaranteeing GUI usability is a fundamental factor since interaction with digital information is dominated by GUI-based systems. Still, basic actions required to operate these systems, such as icon comprehension and use of navigation controls, are likely to be error-prone for elderly persons with cognitive impairment (Leung, McGrenere, & Graf, 2011; Riley et al., 2009; Savitch & Zaphiris, 2006; Scialfa et al., 2008). Consequently, GUI specifications are an important issue that must be addressed when designing interactive systems for this population.

4.2.3 Assessing Usability and Technology Acceptance with Older Adults

A number of factors, such as usability, perceived usefulness, ease of use, trust, costs, technology experience, and attitudes towards technology affect technology acceptance by older adults (Charness & Boot, 2009; McCloskey, 2006; McCreadi &

Tinker, 2005; Pak & McLaughlin, 2010; Valkila, Litja, Aalto, & Saari, 2010). Consequently, successful design of interfaces requires considering users' preferences, skills and needs. In this context a user-centered design approach may prove very useful (Rubin & Chisnell, 2008).

In the case of elderly users one must carefully consider the presence of perceptual deficits related to visual acuity, contrast sensitivity, speech and sound discrimination, and of cognitive impairments such as memory decline, comprehension problems, attention deficits (e.g. multitasking capacity), slower processing speed, and decreased executive functioning (initiating, scheduling and monitoring actions for goal-directed behavior) (Fisk et al., 2009; Pak & McLaughlin, 2010; Rogers & Fisk, 2010; Schaie, 2001). However, other factors should be taking into consideration when defining user profile (e.g., socio-demographic characteristics, lifestyle, technology experience, goals, needs, and preferences with regard to the product).

Based on this information a prototype of the product can be developed for analysis through iterative assessments. At this stage of the design cycle, usability evaluation with the target population is the best way to detect ergonomic problems, and thus to improve the design. Usability refers to a set of quality attributes to assess the ease of use of technological products including: (a) Learnability: How easy it is to learn the functionalities of the system; (b) Efficiency: Number of tasks users can perform in a given amount of time or speed of performance, (c) Retention over time: How easy it is to remember how to use the system after a period of nonuse, (d) Error rate: Number of commission or omission errors that users make while performing a task, (e) Satisfaction: How pleasing it is to interact with the system to accomplish a goal (Ferré, Juristo, Windl, & Constantine, 2001; Harada, Mori, & Taniue, 2010; Thyvalikakath, Monaco, Thambuganipalle, & Schleyer, 2009).

Different usability techniques exist for evaluating GUIs and in general interactive systems (e.g. usability testing, cognitive walk-troughs, heuristic evaluation) (Rubin & Chisnell, 2008). The most appropriate method for collecting empirical data of representative end-users while they use a system is usability testing. This approach allows researchers to discover interface problems that may hinder user experience and provides information to solve them. Furthermore, through this method, it is possible to analyze the impact of different variables on task performance (e.g. when comparing two or more groups of users with different cognitive profiles). These tests are usually conducted in a laboratory setting under controlled conditions.

4.2.4 The Development of the Robot's GUI

4.2.4.1 Project Background

QuoVADis was a collaborative research project whose main goal was to support people with cognitive impairment in their functional capacities, through a system integrating assistive robotics within a smart home environment. Moreover, the project aimed to optimize the quality of daily living of end-users, enabling them to compensate for their cognitive deficits and promoting social inclusion. Consequently, support for cognitive training, medication reminding, as well as other functionalities, were designed in this perspective.

The robot used in this study is Kompaï (Figure 29), a social assistive mobile platform developed by Robosoft[14] and intended to provide cognitive and social support to older adults with cognitive impairment. Robot input devices include a set of microphones (for voice-based control) and a touch-screen (for GUI-based control). For high-level control and user interfaces, the Kompaï uses a Tablet PC with a 12.1" Premium WXGA (1280 x 800) display running Windows 7.

Figure 29 Robot Kompaï (Robosoft)

[14] Robosoft Website. "Kompaï, user's manual v3.0. Interact with Kompaï" http://85.31.145.61/index.php?title=Kompa%C3%AF_home_page/Technical_documents/RobuBOX-Kompa%C3%AF/User%27s_manual

Among the services that the robot provides are: (a) Shopping list management, (b) Agenda, (c) Medication reminder, (d) Robot control, (e) E-mail, (f) Video calls, (g) Web Games, (h) Weather forecast, and (i) Cognitive stimulation. These services were selected from results of two previous needs assessment studies carried out with elderly persons with cognitive impairment and their caregivers (Faucounau, Wu, Boulay, Maestrutti, & Rigaud, 2009; Wu, Faucounau, Boulay, Maestrutti, & Rigaud, 2011).

After starting the system, the GUI displays a menu with a set of icons that give access to each function (Figure 30). For designing the first version of this menu a preliminary study was conducted to examine the kind of images that users matched intuitively to robot functions (Granata, Chetouani, Tapus, Bidaud, & Dupourque, 2010). Based on users' preferences a set of icon features was determined: Use of realistic and concrete images of objects or actions related to each represented function; use of a three color-palette (blue, red and white); use of standalone icons which do not include text labels; icon size on the screen of approximately of 3 x 3 (cm) and 200 x 200 (pixels).

From upper left to lower right: Email, Video Calls, Cognitive Stimulation, Shopping List, Weather Forecast, Agenda, Web Games, Medication Reminder,

Figure 30 Main menu of Kompaï's GUI

The software architecture was programmed in C# using the MRDS (Microsoft Robotics Dev Studio) platform. In this development phase, only the shopping list and agenda services were completely operational. For the management of these two functions we used the Google API developed for .NET applications.

4.2.5 Research Questions

In this study we conducted usability testing of the first GUI prototype focusing on the main menu, the agenda and the shopping list applications as means of answering the following questions:

(1) Are main menu icons accurately interpreted, identified and judged meaningful by elderly users regardless of their cognitive status, age, or computer experience?

(2) Are there any significant differences between elderly people with MCI and elderly people with normal cognition with regard to task performance (task completion time and number of errors) when using the aforementioned services?

(3) Do individual factors such as age, gender, computer experience, and education level affect user performance?

The primary objective of the study was to identify usability problems of the current interfaces and suggest ways to improve them to better suit end-users' needs and capacities.

4.2.6 Methodology

4.2.6.1 Participants

A total of 22 older adults, aged between 60-86 years took part in this study. They were distributed in two groups: elderly with a diagnostic of MCI [43] (N=11) and elderly healthy controls (HC) (N=11). Participants in the MCI group were recruited through the Broca Memory Clinic, HC were recruited through local senior associations. All participants volunteered for the study. The criteria for inclusion of participants in the study were: both genders; being over 60 years old; living in Paris or Ile de France; having a diagnosis of MCI according to the criteria of Petersen et al., (1999) (MCI group). The exclusion criteria out-ruled those with psychiatric conditions, behavioral problems, or sensory deficits that would influence their ability to comprehend or perform the tests. The University Paris Descartes ethical committee, the CCTIRS (Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé), and the CNIL (Commission Nationale Informatique et Liberté) endorsed this project. Socio-demographic characteristics of the sample are presented in Table 26.

Table 26 Socio-demographic characteristics of the sample

Group	MCI	HC
N	11	11
Gender	m=5; f=6	m=0; f=11
Age mean (*SD*)	76,63 (7,92)	76,36 (7,85)
Range	73-86	66-88
EL (years)	<7=5 ; ≥7=6	<7=6 ; ≥7=5
Computer experience	none=6; regular=5	none=4; regular=7

MCI= Mild Cognitive Impairment; HC= Healthy controls; f=female, m=male; EL= Educational Level

4.2.6.2 Material

Subjects performed the experimental tasks on the tablet PC of the Kompaï robot. A stylus pen was used to enter commands on the computer screen. Two cameras were employed to capture screen activity and user behavior. The Observer XT software was used to analyze behavioral data. Statistical analysis was performed using R (version 2.13.2).

4.2.6.3 Procedure

First, the test moderator described the purpose of the research. All participants read and signed an informed consent form prior to enrollment. A structured questionnaire was used to collect socio-demographic data. Then, a test moderator explained the general characteristics of the robot. Participants were also instructed on the use of the touch-screen. Participants were asked to complete a series of tasks detailed in the next session. Tests were conducted individually and all sessions were video recorded.

4.2.6.4 Evaluation Tasks

Main Menu

The main menu display was presented to participants (Figure 29). Participants were invited to observe the visual display and answer a series of questions.

(1) Interpretation: With the aim of exploring user interpretation of icons, participants were asked to infer the meaning of each icon, without having previous knowledge about the specific service that it represented. During the introduction, participants had been told that the robot provided support for everyday activities and healthcare. Responses were scored using a binary value (*1= accurate interpretation, 0= erroneous interpretation*).

(2) Identification: The name of each service was given and participants were asked to match each one of the nine icons to a specific function. Answers were scored using a binary value *(1= identified, 0= non identified).*

(3) Meaningfulness: Participants were asked to rate how meaningful the icon was with regard to the function it referred to. Icon meaningfulness was rated using a binary value *(1= completely meaningful, 0= completely meaningless)*.

(4) Satisfaction: We assessed participant's appreciation regarding some general icon features (i.e., size, color palette, and labels). Each feature was rated using a 5-points Likert scale *(1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree).*

Identification, interpretation and meaningfulness scores were then evaluated according to the International Organization for Standardization (1988) that recommends 67% of correct interpretation in a comprehension test for public information and safety symbols (ISO, 1988). This criterion was already used outside its original context in previous studies of symbol comprehension showing its adequacy (Murungi, McLaren, & Chen, 2003; Shen, Prior, Chen, & You, 2007; Thatcher, Mahlangu, & Zimmerman, 2006).

Agenda

Participants were asked to enter a medical appointment at Broca Hospital on December the 12^{th}, 2011 at 10 o'clock (Figure 31). The task consisted of five steps that required different actions:

(1) Selecting the month by clicking on month back and forward navigation arrows.

(2) Selecting the day by clicking on the day.

(3) Adding an event by using the plus sign button on the left of the screen.

(4) Entering event details in a pop-up window: hour (using an up-down menu), kind of event (clicking on specific icons), subject and location (using a virtual keyboard).

(5) Confirming the event by clicking on the add button.

For each step we collected two performance measures: Execution Time (T), which refers to the task completion time, and Errors (E) referring to the number of failed actions while completing the task. Table 27 presents the list of dependent variables for each subtask and global performance measures.

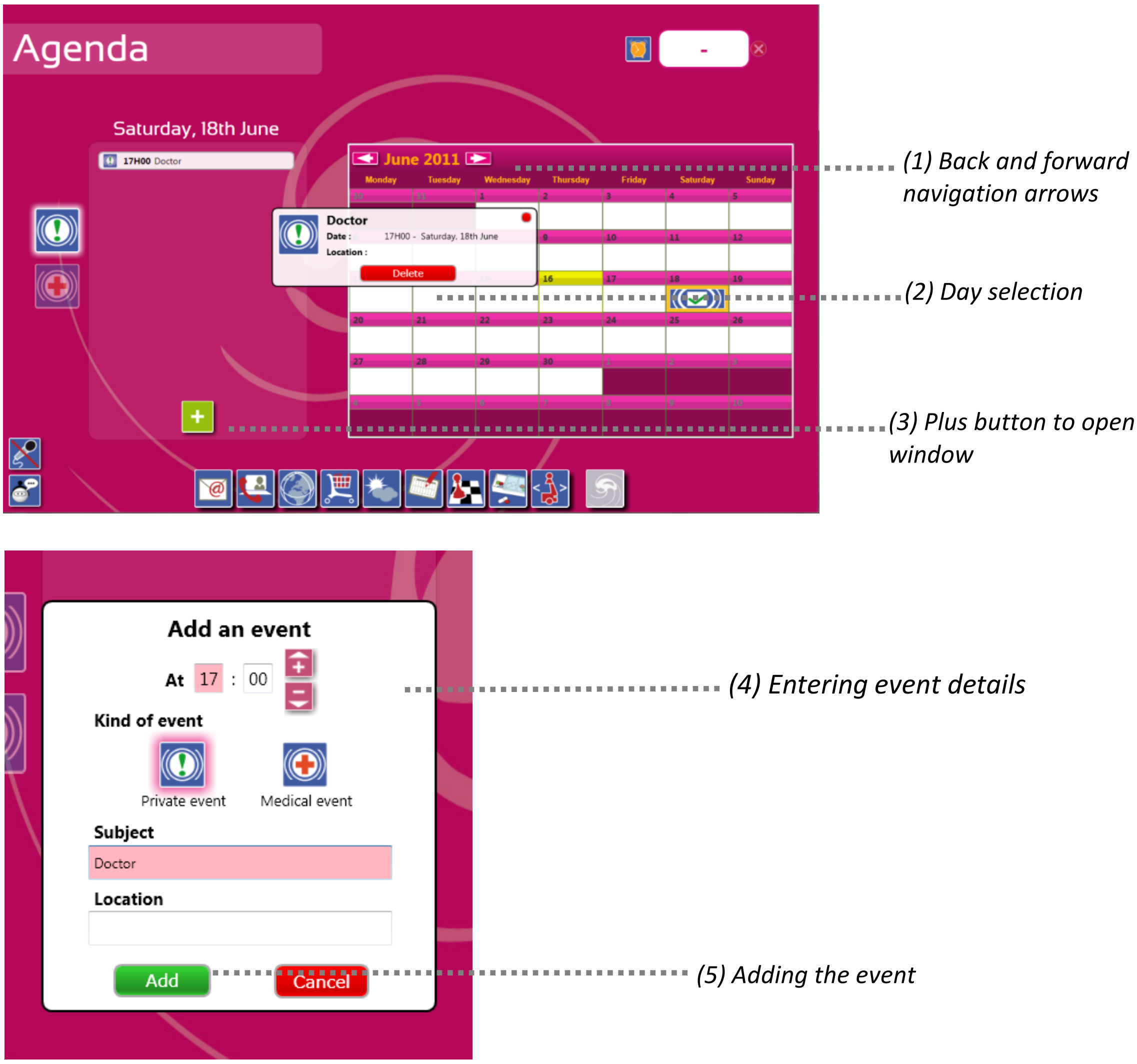

Figure 31 Agenda application and set of steps to enter an event

Shopping list

Participants were asked to compile a shopping list (Figure 32) by choosing two products of different categories (fruits and meats). For each product subjects were required to:

(1) Select product category by clicking on the corresponding icon (repeated measure for the second product).
(2) Select the product by using the navigation up/down arrows (repeated measure for the second product).
(3) Select product quantity by using the numeric up/down control.
(4) Adding the product to the list using the plus sign button (repeated measure for the second product)

For each step we collected two performance measures: Execution Time (T) and Errors (E). See Table 27 for the list of dependent variables corresponding to this task.

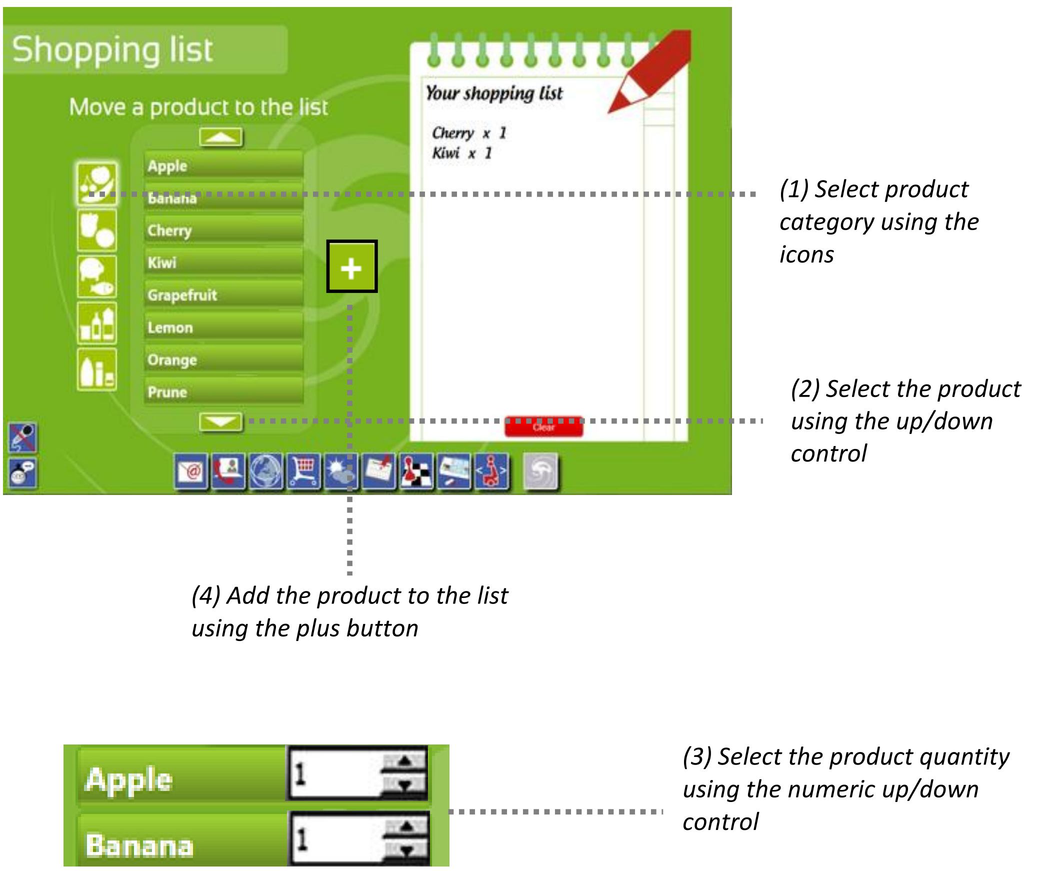

Figure 32 Grocery shopping list and set of steps to add a product to the list

Table 27 List of dependent variables used for the analysis of the shopping list and agenda tasks

Agenda	
Dependent variable	**Description**
DateT, DateE	T* and E** on selecting date
AddT, AddE	T and E on adding the appointment to the calendar
DetailsT, DetailsE	T and E on adding appointment details (time, place, subject and type of appointment)
ConfirmT, ConfirmE	T and E on confirming the appointment details
Shopping List	
Depend variable	**Description**
Cat1T, Cat1E	T and E on choosing the category corresponding to the first product
Prod1T, Prod1E	T and E on selecting the quantity of the first product and on adding it to the shopping list
Cat2T, Cat2E	T and E on choosing the category corresponding to the second product
Prod2T, Prod2E	T and E on selecting the quality of the second product and on adding it to the shopping list
Combined Measures	
Dependent variable	**Description**
AgentaT, AgendaE	Total T and E on performing the whole agenda task
Shop1T, Shop1E	Total T and E on adding the first product to the shopping list
Shop2T, Shop2E	Total T and E on adding the second product to the shopping list
ShopT, ShopE	T and E on performing the whole shopping list task

** Task completion time*
*** Errors*

4.2.7 Results

This section presents main findings of this study with respect to two criteria, the characteristics of the sample and the role of group and individual factors on task performance (Execution Time and Errors).

4.2.7.1 Sample Characteristics

The sample consisted of 17 women (77%) and five men (22%), aged between 60 and 86 years old (*M* = 76.5, *SD* = 7.7). The number of participants with MCI and HC was the same (*N* = 11 for each group).

Age was considered as a binary variable when the test required the use of categorical variables (< 78 years = 0; ≥ 78 years = 1). In these cases the median was chosen as cut-off value. Participants were then distributed into two groups: oldest-old adults (*N* = 11, *M* = 82.4, *SD* = 2.9) and young- old adults (*N* = 11, *M* = 70.5, *SD* = 6.2). Concerning education level (EL), 50% of the sample had less than 7 years of education, and 50% more than 7 years of education (< 7 = 0; ≥ 7 = 1). Participants in the MCI and in the HC groups did not differ in age as confirmed by a Kruskal-Wallis chi-squared test (χ^2) (*p* = .97), years of formal education (*F*-test *p* = .99), or computer experience (*F*-test *p* = .67). On the contrary there was a significant difference between groups concerning gender since the HC group was composed exclusively of women (*F*-test *p* = .01).

Subjects were asked to indicate whether they had previous experience with computers or not (*none or little* = 0; *regular* = 1). 12 participants (45%) had either none or little previous experience with computers and 10 participants (55%) had a regular experience. There was a significant negative relationship between age and computer experience, the group of oldest-old adults having less experience (*r* = - 0.60, *p* < .005).

4.2.7.2 Main Menu Task

For analyzing these results, first the percentages of accurate icon interpretation, identification and meaningfulness were calculated for the whole sample (Figure 33). Results revealed that all the icons obtained an *identification* score that met the ISO criteria (67%). However, in the *interpretation* task only the icons that represented the video calls, shopping list, weather forecast, medication reminder, agenda and Web games functionalities met this standard. Icons corresponding to the e-mail, cognitive stimulation, and robot control applications obtained an interpretation score lower than 67% (Figure 34). The robot control obtained the lowest interpretation score (9%).

An interesting finding was that icons corresponding to video calls, cognitive stimulation, medication reminder, agenda and robot control, despite being correctly interpreted, obtained low meaningfulness scores (Figure 35). All the other icons, on average, obtained a satisfactory score with respect to meaningfulness.

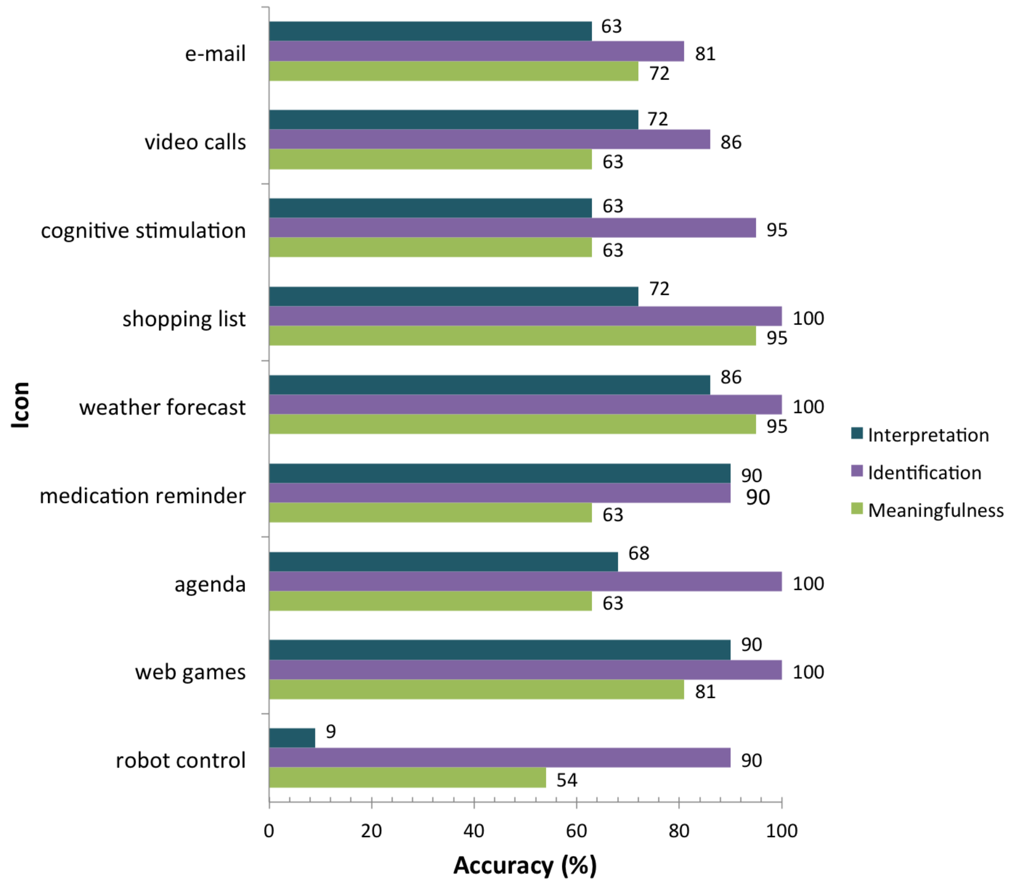

Figure 33 Percentage of accurate interpretation, identification, and meaningfulness for all icons in the whole sample

Figure 34 Icons that failed to meet the interpretation criteria: e-mail, cognitive stimulation and robot control

Figure 35 Icons that failed to meet the meaningfulness criteria: video calls, cognitive stimulation, medication reminder, agenda, robot control

When considering the average number of icons that were correctly interpreted, identified and found meaningful by participant, results showed a correct rate of interpretation (6 out of 9 icons), identification (8 out of 9 icons), and meaningfulness (6 of 9 icons) (Figure 36). Best scores were obtained in the identification task.

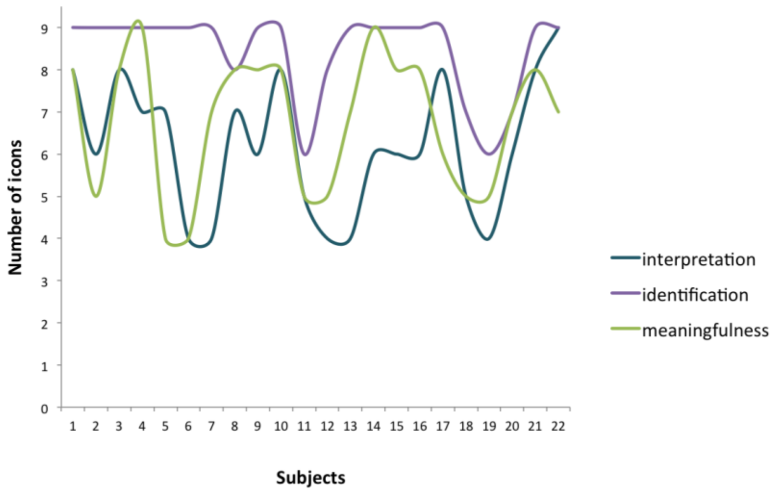

Figure 36 Average number of icons correctly interpreted, identified and found meaningful by participant

A series of Fisher's exact tests (*F*-test) were performed to examine the differences in icon assessment between groups with respect to cognitive status (MCI, HC), age (younger < 78, older ≥ 78), and computer experience (experienced, inexperienced).

No significant differences were observed between user groups (MCI vs. HC) with respect to icon assessment in any of the three criteria (Table 28). The single most striking observation to emerge from the comparison between these two groups was that meaningfulness rating for six icons, in the HC group, and five icons, in the MCI group, did not reach the defined criteria, whereas most of them had been correctly interpreted and identified.

Table 28 Percentage of accurate icon interpretation, identification and meaningfulness by group

Icons	Interpretation (%)			Identification (%)			Meaningfulness (%)		
	MCI	HC	*p*	MCI	HC	*p*	MCI	HC	*p*
Mail	**63**	**63**	0.99	81	81	0.99	81	**63**	0.64
Video Calls	72	72	0.99	90	81	0.99	**63**	**63**	0.99
Cognitive Stimulation	**63**	**63**	0.99	100	90	0.99	**63**	**63**	0.99
Shopping list	72	72	0.99	100	100	0.99	100	90	0.99
Weather forecast	90	81	0.99	100	100	0.99	100	90	0.99
Medication reminder	100	81	0.48	100	81	0.48	**63**	**63**	0.99
Agenda	72	63	0.99	100	100	0.99	**63**	**63**	0.99
Web games	90	90	0.99	100	100	0.99	81	81	0.99
Robot control	**9**	**9**	0.99	81	100	0.48	**45**	**63**	0.67

MCI = Mild Cognitive Impairment; HC = Healthy controls; p value from the F-test

Older participants' ratings were lower than those from younger participants (Table 29). However none of these differences were statistically significant. Finally, when comparing experienced and inexperienced user ratings, no significant differences between groups were found either (Table 30). However, it is interesting to note that experienced participants were more prone to question the meaning of the icons than inexperienced participants.

Table 29 Percentage of accurate icon interpretation, identification and meaningfulness by age-group

Icons	Interpretation (%)			Identification (%)			Meaningfulness (%)		
	Y	O	*p*	Y	O	*p*	Y	O	*p*
Mail	**63**	**63**	0.99	100	**63**	0.09	90	**54**	0.15
Video Calls	90	**54**	0.15	100	72	0.21	72	**54**	0.66
Cognitive Stimulation	**54**	72	0.66	100	90	0.99	**54**	72	0.66
Shopping list	81	**63**	0.64	100	100	0.99	100	90	0.99
Weather forecast	90	81	0.99	100	100	0.99	100	90	0.99
Medication reminder	100	81	0.48	100	81	0.48	72	**54**	0.66
Agenda	81	**54**	0.36	100	100	0.99	**63**	**63**	0.99
Web games	90	90	0.99	100	100	0.99	90	72	0.59
Robot control	**9**	**9**	0.99	90	90	0.99	**45**	**63**	0.67

Y = younger participants; O = older participants; p value from the F-test

Table 30 Percentage of accurate icon interpretation, identification and meaningfulness by computer experience

Icons	Interpretation (%)			Identification (%)			Meaningfulness (%)		
	Exp	Inexp	*p*	Exp	Inexp	*p*	Exp	Inexp	*p*
Mail	**58**	70	0.67	91	70	0.29	83	**60**	0.35
Video Calls	75	70	0.99	100	80	0.08	**58**	70	0.67
Cognitive Stimulation	83	**40**	0.07	100	90	0.45	**50**	70	0.67
Shopping list	83	**60**	0.35	100	100	0.99	100	90	0.45
Weather forecast	83	90	0.99	100	100	0.99	100	90	0.45
Medication reminder	91	90	0.99	91	90	0.99	**58**	**60**	0.99
Agenda	75	**60**	0.65	100	100	0.99	**58**	70	0.67
Web games	83	100	0.48	100	100	0.99	91	70	0.29
Robot control	**16**	**0**	0.48	91	90	0.99	**50**	**60**	0.69

Exp = experienced; Inexp = inexperienced; p value from the F-test

Icons preference measures

With respect to icon features, most participants found the actual icon size acceptable (72,7%). In contrast, few of them (18%) were satisfied with the use of unlabeled icons. Actually, the majority of respondents considered that the use of text labels could improve icon interpretation. Also, over half of the participants (54,54%) were satisfied with the use of a homogenous color palette (Figure 37).

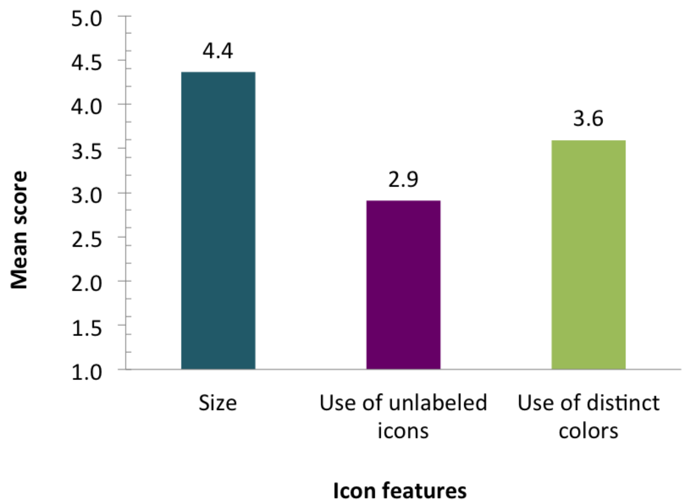

Figure 37 Average preference scores for the whole sample

4.2.7.3 Shopping List and Agenda Tasks

Table 31 provides average results by group (MCI, HC), age (younger, older), and computer experience for each task and subtask with regard to task completion time and number of errors.

Group effects

A Wilcoxon test (Z) was conducted to evaluate whether MCI had different task completion times than HC in the shopping list and agenda tasks but no significant differences were observed (p = .77). However, results revealed that in general, participants in the MCI group were slower than HC at completing tasks (Table 31). Entering the details of the event on the agenda was the subtask that took participants in both groups the most time to complete. Finally, when performing the shopping list task, results showed that speed of performance improved significantly in both groups when adding a product to the list for the second time (MCI: z = 2.38, p = .009; HC: z = 2.2, p = .01) (Figure 38). However, the reduction in time (Shop1 vs. Shop2) did not differ significantly between both groups as shown by the Kruskal-Wallis chi-squared test (χ^2 (1;N = 22) = 0.39, p = .53).

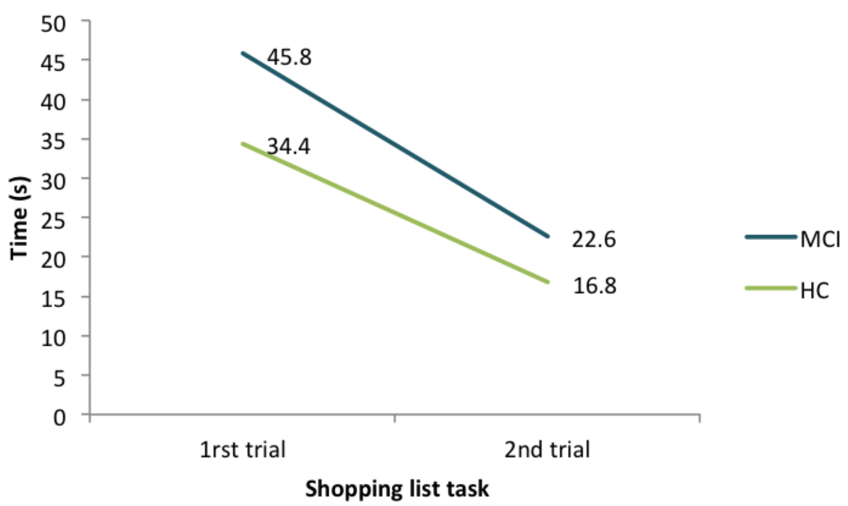

Figure 38 Task completion time for the shopping list task measured at two instants by group

Concerning the Errors variable, testing for statistically significant differences between groups using the Kruskal-Wallis chi-squared test showed that MCI participants committed more errors than participants in the HC group in the shopping list task (χ^2 (1;N = 22) = 4.76, *p* = .03) and in some of the subtasks associated: Cat1 (χ^2 (1;N = 22) = 3.73, *p* = .05) and Shop1 (χ^2 (1;N = 22) = 4.52, *p* = .03) (Figure 39). On the contrary, no statistically significant differences were found between the two groups for the agenda task. In general, the highest rate of errors was observed for the subtask of entering the details of the event in the agenda for both groups.

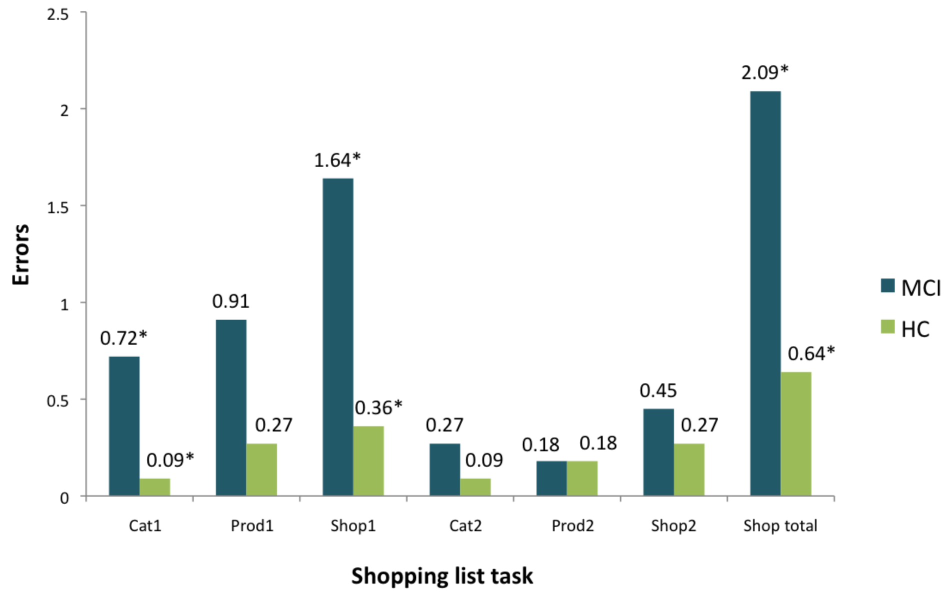

Figure 39 Average number of errors in the shopping list task by group

Table 31 Average scores in performance measures by groupe, age, and computer experience

Errors (frequency)

	CAT1	PROD1	SHOP1	CAT2	PROD2	SHOP2	TOTAL SHOP	DATE	ADD	DETAILS	CONFIRM	TOTAL AGENDA	TOTAL
MCI	0.72	0.9	1.63	0.2	0.18	0.45	5.72	0.36	0.54	1.36	0.36	2.63	8.35
HC	0.09	0.27	0.36	0.09	0.18	0.27	3.45	0.39	0.54	1.18	0.36	2.45	5.9
Younger	0.36	0.45	0.81	0.18	0.18	0.36	3.27	0.18	0.45	0.63	0	1.27	4.54
Older	0.44	0.55	1	0.22	0.22	0.44	6	0.55	0.55	2.11	0.66	3.88	9.88
Inexp	0.3	1	1.3	0.2	0.2	0.4	5.8	0.6	0.6	1.7	0.7	3.6	9.4
Exp	0.5	0.25	0.75	0.16	0.16	0.33	0.33	0.16	0.5	0.91	0.08	1.66	1.99
TOTAL	0.4	0.59	1	0.18	0.18	0.36	4.59	0.36	0.54	1.27	0.36	2.54	7.13

Execution Time (s)

	CAT1	PROD1	SHOP1	CAT2	PROD2	SHOP2	TOTAL SHOP	DATE	ADD	DETAILS	CONFIRM	TOTAL AGENDA	TOTAL
MCI	23.58	22.2	45.78	11.85	10.78	22.63	221.79	22.7	27.51	87.34	15.61	153.37	375.16
HC	15.53	18.86	34.4	10.01	6.76	16.77	193.47	24.67	19.36	89.23	9.02	142.29	355.76
Younger	13.25	12	25.25	11.22	5.44	16.66	133.69	15.29	16.53	55.77	4.16	91.77	225.46
Older	27.52	28.91	56.44	10.89	14.11	25	292.17	33.05	31.12	130.57	14.96	210.72	502.89
Inexp	16.09	31.24	47.34	14.01	11.08	25.09	255.27	31.11	30.43	100.04	21.22	182.82	438.09
Exp	22.44	11.6	34.04	8.36	6.84	15.21	167.93	17.49	17.79	78.48	4.9	118.67	286.6
TOTAL	20.53	20.53	20.09	10.93	8.77	19.07	207.63	23.68	23.53	88.28	12.32	147.83	355.46

MCI = Mild Cognitive Impairment; HC = Cognitively healthy controls; Younger = participants < 78; Older = participants ≥ 78 ; Inexp = participants with no computer experience; Exp = participants with computer experience

Effects of individual factors

User performance was analyzed with respect to education level, computer experience and age. The gender factor was excluded from this analysis because sample group sizes were very unequal in this variable.

When analyzing user performance by considering their education level, no significant differences were observed on task completion time (Z, p = 0.53) or on number of errors (Z, p = 0.53). On the contrary, computer experience turned out to be a very discriminative factor both on Execution Time and Errors. Participants having regular computer experience were faster and committed fewer errors than those who had no computer experience at all (Figure 40). For instance, with respect to the Execution Time variable, significant differences between experienced and inexperienced users were found for the total duration of the experience (Z, p = .03), the shopping (Z, p = .02) and the agenda task (Z, p = .05). The same trend was observed in some of the subtasks: Prod1 (Z, p = .003), Cat2 (Z, p = .03) from the shopping list task, and Date (Z, p = .02) and Confirm (Z, p = .0002) from the agenda task. Regarding the number of errors, a significant effect of computer experience was observed for the entire evaluation (Z, p = .04), the agenda task (Z, p = .02) and for the subtasks Details (Z, p = .03) and Confirm (Z, p = .01) in the agenda task.

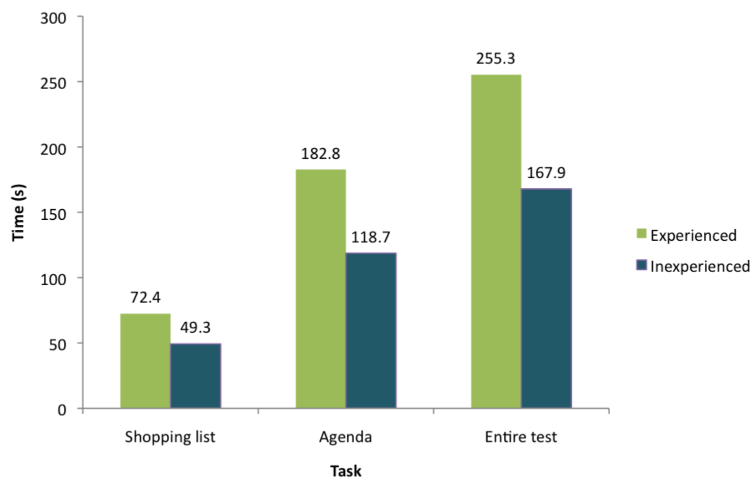

Figure 40 Average time by task and computer experience

Another factor that was found to have an influence on task performance was age. Younger participants were faster than the older ones to complete the entire evaluation (Z, *p* = .001), the shopping list (Z, *p* = .02) and the agenda task (Z, *p* = .002) (Figure 41). This trend was also confirmed for some of the subtasks, for example, Prod1 (Z, *p* = .02) and Shop1 (Z, *p* = .008) in the shopping list, and Date (Z, *p* = .006) and Confirm (Z, *p* = .003) in the agenda task. Younger participants also committed significantly fewer errors during the entire experience (Z, *p* = .005), in the agenda task (Z, *p* = .001) and in the confirm subtask of the agenda (Z, *p* = .002).

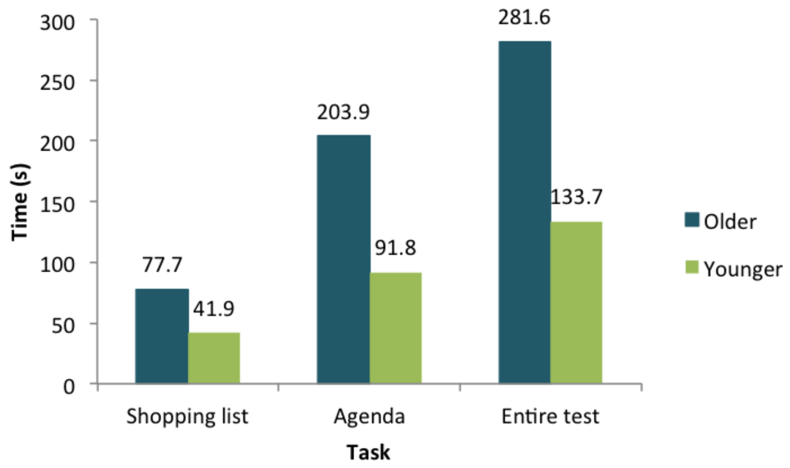

Figure 41 Average time by task and age-group

Individual factors also played a role in initial learnability. In the present study this criterion was evaluated by the shopping list task that comprised two identical steps: selecting the product category (Cat1, Cat2), choosing the product and adding it to the list (Prod1, Prod2). Repeating a sequence of identical procedures can be used to evaluate the learnability of an interface. Results revealed that, on average, all participants spent more time completing the first step than the second one, which suggests that the task procedure was quickly acquired.

It was therefore interesting to examine to what extent certain factors could affect learnability. Statistical analysis showed a significant improvement in task completion time for the older participants when performing the shopping task in the second trial (Z, *p* = .001). Younger participants also improved their task completion time but the difference between the first and the second trial was not significant (Z, *p* = 0.28). Indeed, older participants took more time to complete the first phase of the task (Cat1+Prod1) than younger subjects. In the second phase (Cat2+Prod2), while younger subjects showed only a slight improvement in task completion time, participants in the older group significantly improved, obtaining almost the same results as younger participants (Figure 42). The difference between the two groups with regard to performance in the two trials was also significant (χ^2 p = 0.02). These findings suggest that two trials were enough to see initial speed differences between age groups disappear.

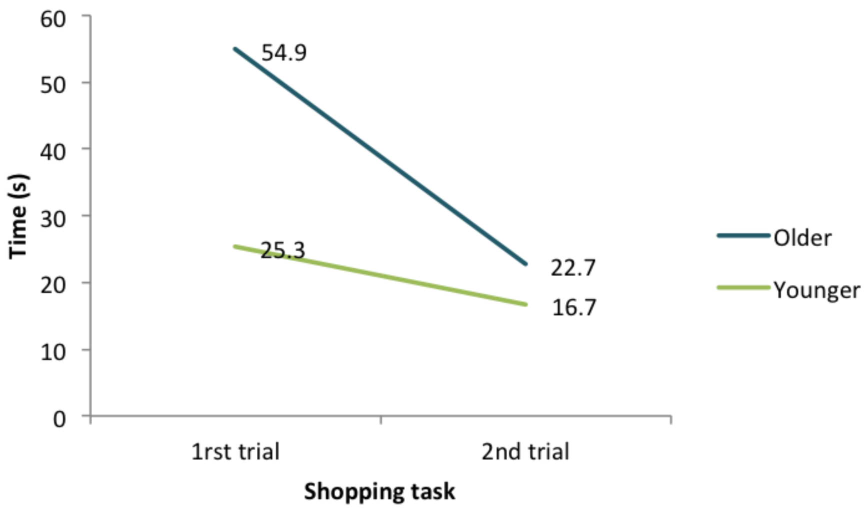

Figure 42 Task completion time for the shopping list task at two instants by age-group

4.2.8 Discussion

The main goal of this study was to evaluate the usability of the GUI of an assistive robot for elderly persons with cognitive impairment (MCI). We focused on the main menu that gives access to the robot's services and two of these services: the agenda and shopping list. Findings from this assessment allowed us to answer the research questions formulated above (Sec 4.2.5).

(1) All the icons were correctly identified, but some of them failed to meet the interpretation and meaningfulness standards. There were no significant differences between groups in icon assessment with respect to cognitive status, age or computer experience.

(2) There was a significant difference between elderly people with MCI and elderly people with normal cognition regarding the number of errors made in the shopping list task.

(3) Some individual factors such as age and computer experience were found to have a significant influence on both task completion time and number of errors. Older and inexperienced users took significantly more time to complete the tasks and made more errors.

In this section the influence of cognitive profile and of other individual factors on GUI usability is discussed. Furthermore, some graphical elements of the interface that prevented users to satisfactorily complete the tasks are examined.

4.2.8.1 Main Menu Task

Icon assessment results revealed that all the icons presented were accurately identified; six of them were adequately interpreted and only five of them were found meaningful. Usability testing also made it possible to identify a number of factors that influence icon interpretability and could be improved by redesign. With respect to this task, two aspects merit further analysis.

First, the differences observed between interpretation and identification scores (Figure 33). In the icon interpretation task, which required inferring the meaning of the image without having any previous knowledge about robot functions, only six of the icons met icon comprehension criteria (ISO, 1988). On the contrary, all the icons met this standard in the identification task, in which participants were asked to match the name of each service to an icon. One possible interpretation of these findings is that icon interpretation was a more demanding task than icon identification because in the former case participants had to deal with the representation of services they were not aware of. For the identification task, participants had acquired some semantic information that could have guided their choices, despite the fact that some of the robot's services were unknown to them. The difference between interpretation and identification scores for the Robot Control icon (9% vs. 90% respectively) shows this point clearly. Participants had never seen the robot in movement before the interpretation task. Once this functionality was introduced (i.e., the function that allows users to control the robot movement) it was easier for them to identify the icon among the others. These observations also confirmed the importance of assessing icon usability within the context of use and not in an isolated manner (McDougall & Reppa, 2008).

Other factors that can explain differences between the two scores are familiarity and initial learnability issues. Familiarity has been defined as the level of experience that a user has with an icon (McDougall, Curry, & de Bruijn, 1999). Initial learnability pertains to the degree to which an interface enables novice users to perform basic and then more advanced tasks (Leung et al., 2011). All participants in our study were novice users of the main menu icons in the interpretation task; it was their first exposition to these stimuli. In the identification task, participants were already familiar with the set of icons. Considering that the three cognitive stages involved in picture naming were completed during the interpretation task: object identification, search of matching representations and response execution (Johnson, Paivio, & Clark, 1996), it may be that participants benefited from this preliminary experience to match function labels to icons with less effort in the second task. The act of providing a semantic framework could have also encouraged participants to use an elimination strategy for identifying the less evident icons (e.g., e-mail, cognitive stimulation and robot control).

The second aspect involves icon features that appeared to influence identification, interpretation and meaningfulness rates. Previous studies have concluded that an icon's qualities, such as concreteness, semantic distance to the referred function, and familiarity, determine its usability (Isherwood, 2009; S. McDougall & Curry, 2004; S. J. P. McDougall & Reppa, 2008). Our results are in agreement with these works. For instance, in the interpretation task, icons that were accurately rated by more than 67% of participants consisted of concrete and familiar images, that were also semantically close to the function represented (e.g., the sun for weather forecast, a chessboard for web games, a shopping cart for the shopping list). In contrast, icons that had a low interpretation score did not met these criteria (e.g., an envelope with an @ sign for e-mail, a person solving a crossword puzzle for cognitive stimulation, and a robot with wheels and two back-and-forward arrows for robot control). For these icons, semantic association was difficult to establish in the absence of a particular referent. First, they represented services that were not familiar at all for users, although the e-mail and robot control icons depicted concrete objects. As suggested by Leung et al. (2011), icons that use computer metaphors can be particularly difficult to interpret for older adults because of their limited computer experience (e.g., e-mail icon). Second, familiarity also means being familiar with the object depicted in the icon (McDougall et al, 2004) in addition to the icon itself. The evidence of object familiarity can be clearly seen in the case of the robot control icon. Unfortunately, due to the study design used in this experiment it was not possible to investigate which of the three characteristics (i.e., concreteness, semantic distance, or familiarity) was the best predictor of icon usability.

It is interesting to note that meaningfulness scores can be very informative for icon design since they provide a subjective appreciation of the image/meaning association that users made. In our study, contradicting our expectations, five out of nine icons did not meet the meaningfulness criteria: video calls, cognitive stimulation, medication reminder, agenda, and robot control. For instance, the medication reminder icon depicted a syringe and although the icon was adequately interpreted and identified, approximately two-thirds of the participants (63%) agreed that it conveyed little meaning. For these persons, the image of a syringe was not associated to home medication; they suggested using a bottle or a blister pack of pills instead. Similarly, the agenda icon was well interpreted and identified, but it was not found meaningful because the chosen image was often mistaken with that of a calendar.

Finally, the fact that video calls, cognitive stimulation and robot control icons represented novel concepts for older adults could also explain their low meaningfulness rating. Understanding the link between an image and an unknown service can be a very demanding task. Thus, for these novel functions, first-time comprehension should not be a usability requirement. In this sense, assessing learnability, by conducting repeated assessments over time, can help to examine whether the function represented by the icon can be recalled later. Since older adults can exhibit difficulties in understanding the meaning of unfamiliar icons, it seems important to find alternative solutions to represent these novel functionalities. One solution could be the use of efficient metaphors to represent these novel services (Marcus, 1998). An interesting experiment could be to explore the semantic fields in which representative end-users intuitively situate these novel functions in order to decide on the best pictographic representation. In conclusion, designing icons that represent novel services for older users with cognitive impairment is also a challenge that needs further study.

Icon preferences

Participants in the current study considered that adding text labels to the icons would contribute to their interpretation (Figure 43). This is in complete agreement with other icon comprehension studies that showed that icons with text labels were more easily interpreted than exclusively pictorial icons by elderly users (Leung et al., 2011; Scialfa et al., 2008). A similar effect should be expected in elderly persons with MCI. Several facts can account for this finding. First, the use of text labels can compensate for the lack of familiarity with regard to robot functions. Second, text labels can help to reduce the demands on cognitive capacities (e.g., working and semantic memory, visuo-spatial abilities and speed of information processing), which tend to decline with age. In this sense, a compelling research question is whether the use of labels would help to reduce the time a user requires to search for a particular icon on a display. Repeated observations could also help to understand if icon usability over time is more dependent on the use of text labels, images, or even on position in the interface (Moyes, 1994).

Figure 43 Alternative version of the main menu GUI displaying icons with text labels

Regarding the assessment of icon features one limitation of this study was that participants were not confronted to alternative versions of the GUI (labeled icons, icons with differentiating colors). Preference ratings were based exclusively on the opinions that participants had of how an alternative design would look like. When conducting usability assessments comparing alternative designs, GUIs that offer similar functionalities but different navigation layouts could help to better assess user preferences (Rubin & Chisnell, 2008). Thus, future research on icon interpretability should include a higher number of participants, consider the context of use of the robot's GUI, use more robust icon databases and assess icon comprehension in various conditions (comparative tests, multimodality, assessments over time, etc.).

4.2.8.2 Shopping List and Agenda Tasks

Effects of cognitive profile on GUI usability

Results revealed that participants in both groups (MCI and HC) were able to complete the tasks without major assistance. However, users with MCI made more errors and had a longer task completion time, even if the differences observed with regard to HC did not reach statistical significance in all the subtasks.

It seems possible that these results are due to cognitive deficits in memory and other functions (e.g., visuo-spatial skills, executive function, and information processing speed) associated with MCI. These findings further support the idea that MCI has a negative influence in the execution of complex instrumental tasks, such as the use of everyday technological devices (Nygård, 2003). When designing a GUI for these end-users, the demands on working memory could be reduced by providing environmental support (Hawthorn, 2000) (W. Morrell, 2000). For instance, interface design could take advantage of recognition processes, preserved in MCI, instead of using graphical elements (e.g., buttons, hyperlinks, menus) and navigation controls that are dependent on free recall processes, which show some decline in MCI.

Studying the cognitive deficits that affect the interaction between individuals with MCI and a GUI requires the use of very sensitive tasks and a refined task analysis. Including a larger sample of subjects for each group could help to control for this variable in future studies. Conducting a crossed analysis of error types and specific cognitive deficits could also help to better illustrate which commands and controls are more demanding for elderly persons with MCI. In addition, this will help designers to conceive adapted GUI solutions to compensate for cognitive deficits.

Effects of individual factors on GUI usability

Results revealed that age and computer experience had an effect on user performance. Younger and experienced participants performed the tasks faster and more accurately than older participants and those who had no computer experience.

These results corroborate previous findings from several studies in which the comparison of computer task performance between older and younger adults showed that age and computer experience predicted task completion time (Wagner, Hassanein, & Head, 2010b).

To interpret these results, one must consider that in our sample there was a strong correlation between age and computer experience: older participants had less computer experience than younger ones. These results are consistent with a sociological reality about older adults: participants in the group of oldest-old adults (M = 82.4 years) were retired before computers were widely used at work. In contrast, younger participants (M = 70.5 years) had contact with computer technology before their retirement age.

This study has been unable to demonstrate a correlation between other individual factors, such as education level and gender, and task performances. This was probably due to the small size of the sample, since several authors have found that education is one of the factors that explain computer performance in older adults (Czaja et al., 2006; Wagner et al., 2010). As to gender effects, it was not possible to carry out an analysis of this variable since groups were very unequal with respect to this factor.

Furthermore, age has proven to play a role in initial learnability, assessed in the current study by the shopping list task that was conducted in two trials. This finding is in complete agreement with results from a number of works that have compared training effects on elderly and young individuals. In summary, it has been confirmed that age-related differences in task performance can be substantially reduced after training (Mykityshyn, Fisk, & Rogers, 2002). In this study, older participants significantly improved their task completion time in the second trial whereas younger participants also improved their execution time, but no significant difference was observed between the first and second trial.

Although this result is rather encouraging for promoting the use of computer devices among older adults, it does not prove that a real learning has occurred. Indeed, it is possible that improvement in task performance between the two trials was due to a priming effect. The subject could have implicitly reproduced the sequence of actions previously performed, without explicit learning. In order to study learnability, we suggest examining task performance over time, by conducting multiple assessments in different sessions, or introducing some interference tasks between the first and the second trial. In any case, these findings confirmed the benefits of providing computer training in older adults (Czaja, Sharit, Ownby, Roth, & Nair, 2001; Wagner et al., 2010).

4.2.8.3 Recommendations for Design improvement

Based on the results of user testing and on the analysis of the source of errors a list of modifications that the interface required to improve its usability was elaborated (Table 32).

Table 32 List of design recommendations for interface improvement

Application	Usability problem	Solution
Main menu icons	Icons are not adequately interpreted (e-mail, cognitive stimulation, robot control)	Adding text labels to icons; evaluating semantic fields associated to each service with target end-users to select more representative pictures
Shopping list	Icons used to select product category are not adequately interpreted	Adding text labels to icons
Shopping list	The up/down control to select the product was difficult to use	A complete list of products for each category should be displayed avoiding the use of drop-down menus
Shopping list and agenda task	The numeric up/down control was difficult to use	Once the product is selected the user is asked to enter the quantity
Shopping list and agenda	The “plus” button to add the product to the shopping list or to enter the event details in the agenda was not understood by some users	Buttons should be labeled
Agenda	Users experienced some problems to understand the sequence of steps required to enter an event in the agenda	The interface should provide a direct and timely support
Agenda	Users experienced problems in understanding how to use the “add” button to confirm an event	Button labels should be more explicit and provide a clear instruction (e.g., click here to confirm the event)

4.2.9 Conclusions

In this study we assessed the initial usability of the user interfaces from two services provided by a robot intended for elderly persons with cognitive impairment. Taken as a whole, results showed that older adults who took part in this study faced some difficulties when using different elements of the GUI for the first time. However, after receiving some guidance, all the participants were able to use the system and complete the tasks. Cognitive status, age and computer experience appeared to influence task performance. Participants with MCI experienced more difficulties than cognitively healthy participants in completing the tasks. Younger and experienced participants performed the tasks faster and more accurately than older participants and those who had no computer experience.

Usability testing allowed the identification of some graphical elements of the interface that prevented users from completing the tasks satisfactorily. Based on these results changes and refinements will be made to the interface to fix usability problems and improve design quality.

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4.3 Designing Cognitive Training Software for Older Adults with Cognitive Impairment: The Importance of Iterative User Testing[15, 16]

Software applications for cognitive training have gained momentum over the last decade. Mainstream products, in particular brain-fitness programs, are increasingly used to promote cognitive wellness in older adults. On the contrary, only a few computerized training programs have been particularly designed for elders with cognitive impairment and no computer experience. As a consequence, little experimental research has been done on usability issues concerning these end-users and such technological applications. In this paper, we present results from two usability studies that were carried out to evaluate the prototype of PRIMO, a cognitive training software application for older adults with cognitive impairment. The software was developed using an iterative design process. In the first usability study a group of older adults with Alzheimer’s disease and other of healthy elderly individuals took part in four testing sessions using the first version of PRIMO. Results revealed that the initial prototype was not adapted for individuals with dementia because several usability problems, which caused confusion and frustration among users, were identified. However, participants in both groups improved in task performance across the sessions. In the second iteration of the software, the most significant interface problems were addressed and a series of user-tests involving a group of older adults with mild cognitive impairment and other of healthy elderly individuals was conducted again. Results from the second study confirmed that design changes and the use of touchscreen technology improved the usability of the application for older adults with cognitive impairment. After discussing the key findings and limitations in this study, we suggest guidelines for future research.

Key words: Usability, interface, cognitive training, older adults, Mild Cognitive Impairment, Alzheimer’s disease

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[15] These studies were conducted within the framework of two projects: the LUSAGE laboratory project that was financed by France Alzheimer association and by the French National Research Agency (ANR) through TECSAN program (Project QuoVadis ANR-07-TECSAN-019-03)
[16] This work was conducted together with Mélodie Boulay under the supervision of Anne-Sophie Rigaud. Jean Sébastien Vidal contributed to data analysis.

4.3.1 Introduction

Several cognitive changes are associated to the human aging process. These changes involve a decline in fluid abilities such as memory, reasoning, and speed of processing (Ball, Ross & Viamonte, 2010). Furthermore, elderly individuals at an advanced are at higher risk of developing cognitive impairment beyond the expected levels for their age and education. Under this category fall two common conditions: Mild Cognitive Impairment (MCI) and Alzheimer's disease (AD).

MCI is usually characterized by memory loss but other cognitive deficits can prevail (Petersen et al., 2009). One of the characteristics of MCI is that cognitive decline does not compromise the overall functional ability (Winblad et al., 2004). Nevertheless, persons with MCI can experience some difficulties in everyday functioning, particularly, in complex activities such as cooking, medication or management of personal finances (Aretouli & Brandt, 2010; Peres et al., 2006). Those with MCI also have a higher risk of developing AD, or any other form of dementia, than the general population (Albert et al., 2011).

AD is a neurodegenerative disorder and the most common cause of dementia among older adults. Several cognitive functions may be impaired by AD: memory, language, perceptual skills, attention, constructive abilities, orientation, problem solving and functional capacities (McKhann et al., 2011). As a consequence, AD progressively compromises independent living at home and in community settings (Malloy & McLaughin, 2010). Because of the strong association between cognitive and functional decline, dementia is one of the main causes of disability among older adults (Alzheimer's Disease International [ADI], 2010).

In this context, different Cognitive Training (CT) programs have been developed with the intent to help older adults with MCI or AD preserve their level of cognitive functioning (Acevedo & Loewenstein, 2007; Boccardi & Frisoni, 2006; Boot and Blakely, 2011; Park, Gutchess, Meade, & Stine-Morrow, 2007; Willis & Schaie, 2009). CT refers to regular practice on a set of standardized tasks related to specific aspects of cognition, such as memory, language, attention, or executive functions (Clare & Woods, 2004).

CT can use a variety of methods. Traditional programs usually involve face-to-face sessions led by a professional that include paper-and-pencil exercises. Computer-based tools such as software packages, virtual reality techniques, brain-fitness programs, or videogames, are an alternative to the traditional tools (Zelinski, Dalton, & Smith, 2011). The use of computer-based approaches has gained momentum over the past decade because they offer cost-effective, self-administered, and more accessible flexible training programs (Rebok, Carlson, & Langbaum, 2007).

Advances in Information and Communication Technology (ICT), and a common concern for healthy aging, have encouraged the development of computer-based cognitive training tools and commercial brain-fitness products (Gates & Valenzuela, 2010; Papp, Walsh, & Snyder, 2009; Zelinski et al., 2011). Although most these programs have not been specifically conceived for people with cognitive impairment, some of them have been tested on this population with encouraging results (Cipriani, Bianchetti, & Trabucchi, 2006; Hofmann et al., 2003; Tarraga, 2006). As expected, the literature focuses on the impact of CT on the skills and abilities targeted by the programs. However, few works have addressed the question of how to design software for people with cognitive impairment and general usability issues (e.g., user-friendliness, acceptance, technology experience, satisfaction) (Alm et al., 2003, 2004; Astell et al., 2006, 2008, 2010; Mahendra et al., 2005; Rebok, et al., 2007; Riley, Alm, & Newell, 2009; Topo & Östlund, 2009).

This paper focuses on the development of PRIMO, a CT software application aimed at the elderly with MCI and AD. This paper has been divided into three parts. The first part deals with the topic of software design for people with cognitive impairment, including the specificities of iterative design approaches and user involvement. The second part provides an overview of the context of this study, describing the system and research objectives. The third part presents two usability evaluations, summarizes the main findings, and provides a general discussion of the results.

4.3.2 Software Design for Elderly Persons with Cognitive Impairment

4.3.2.1 Accessibility and Usability

ICT products and services are playing an increasingly significant role in care for the elderly with cognitive impairment. Consequently, it seems necessary to assess which technological devices are most adapted to them and to empirically validate the features that would ease their use. Different authors have pointed out that when designing software for this population, three critical factors should be taken into consideration:

(a) *Computer experience:* Familiarity with computer technology has been found to be an important predictor of performance (e.g., execution time, task accuracy) when completing computerized tasks (Czaja & Sharit, 1993; Czaja, Sharit, Ownby, Roth, & Nair, 2001; Czaja et al., 2006). In general, older adults are less familiar than younger adults with the use of computer technologies and Internet. They are also slower and tend to be more error-prone when interacting with computer technologies (Pak & McLaughlin, 2010). Computer experience is also correlated to motivation of use and perceived usefulness of computer applications (Brajnik, Yesilada, & Harper, 2011). With this respect, it has been highlighted that providing computer training and good support has a positive effect on both of the aforementioned variables (Czaja et al., 2001; Wagner, Hassanein, & Head, 2010).

(b) *Cognitive impairment:* Cognitive limitations may prevent the use of computer technologies. Some of the cognitive abilities that have been found to influence task performance are working memory, processing speed, comprehension, attention, and executive functioning (i.e., initiating, scheduling and monitoring actions for goal-directed behavior) (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Pak & McLaughlin, 2010). Interface design should take into consideration all age-related effects on cognition to avoid design barriers that are relevant for cognitively impaired users.

(c) *Age-related sensory deficits:* perceptual deficits, such as diminished visual acuity, contrast sensitivity or speech and sound discrimination, and diminished movement control (e.g., slower and more variable movement control), appear to be a limiting factor in performance (Fisk et al., 2009; Ketcham & Stelmach, 2001; Pak & McLaughlin, 2010). Interface design should take into consideration age-related effects on perceptual and movement control capacities to avoid design barriers that are relevant for older users.

In the literature on Web accessibility and the use of computer interfaces, several age-sensitive accessibility problems have been identified (Fisk et al., 2009; Lunn, Yesilada, & Harper, 2009; Pak & McLaughlin, 2010; Wagner et al., 2010). General recommendations on these issues include: using sufficient color contrast, adaptable content size (links, text, icons), adaptable sound volume; avoiding scrolling bars, pull down menus and cluttered visual displays; reducing the number of links and buttons and allowing sufficient space between them; providing parallel visual and auditory information. Furthermore, some accessibility and usability issues have been found to be particularly challenging for individuals with cognitive impairment (Alm et al., 2003, 2004; Astell et al., 2006, 2008, 2010; Chadwick-Dias, McNulty, & Tullis, 2002; Orpwood et al., 2007; Riley et al., 2009; Savitch & Zaphiris, 2006). Table 33 presents the some accessibility barriers faced by older users that are particularly challenging for those with cognitive impairments.

Table 33 Accessibility barriers in Web content or software aplications for older adults with cognitive impairment

Type of barrier[17]	Description	Cognitive skill involved
Understandable Concerns the understandability of the information and content presented in the interface	Cluttered display (text, links, images, background images)	Selective attention, working memory
	Ambiguous links	Reasoning, executive function, working memory
	Use of icons to convey information can be challenging if users are not familiar with the graphical representation	Reasoning, semantic memory
	Inconsistent navigation elements and layout	Memory, executive function
	Complex text: complexity of the sentences, structure of phrases or words; use of acronyms and abbreviations; use of technical terms (e.g., Home, or Back); or spelling errors	Sustained attention, language comprehension, working memory, semantic memory
	Page with flickering and flashing content	Attention (Visual)
	Missing orientation cues for location and	Selective attention, working

[17] These categories are defined in the Web Content Accessibility Guidelines 2.0 (WCAG 2.0) (Caldwell, Cooper, Reid, Guarino, & Vanderheiden, 2008).

Type of barrier[17]	Description	Cognitive skill involved
	position in a site	memory (Visual)
Operable Concerns the operability of user interface components and navigation elements	Unlabeled or indistinctive hyperlinks	Memory, executive function
	Cascade or pull down menus, scrolling bars	Visuo-spatial abilities
	Steps to reach content: finding content that is buried within deep hierarchies	Working memory, sustained attention
	Overlapping windows, pop-up windows	Visuo-spatial abilities, reasoning, divided attention
	Not providing visual feedback for actions	Reasoning, working memory, executive function
	Mouse control	Visuo-spatial abilities, movement control

Note: Sources for these barriers include Fisk et al. (2009); Lunn, et al. (2009); and Pak & McLaughlin (2010)

Maki & Topo (2009) identified some general principles of Universal Design that are particularly applicable to the design of technological solutions for people with dementia. These are:

- *Equitable use:* the design should be useful for any group of users. When designing for people with dementia, a design for adults, without any particular sign that refers to cognitive impairment, is recommended. The design should also encourage social interaction.
- *Flexibility in use:* the design should be adaptable to a wide range of user preferences and abilities.
- *Simple and intuitive use:* The design should be easy to understand by all users, independent of their capacities, knowledge or experience. Particular attention must be paid to the navigation system and the graphical user interface when designing for people who have memory or reasoning problems (e.g., requiring minimal learning, or preferably none at all, using familiar metaphors, providing positive feedback and an aesthetic experience).
- *Perceivable information:* A key design principle is to present the information in a clear and effective way (e.g., using the middle of the visual field, plain text). Multimodality may be used appropriately to attract the attention of the user and provide promptings (e.g., color, sound, text, movement).
- *Tolerance for error:* The design should minimize errors and hazards. Reliability is important to compensate for possible attentional deficits.
- *Low physical effort:* The design should only require minimal effort for efficient and comfortable use.

- *Size and space for approach and use:* The design should accommodate to user's size, posture and mobility. Environmental factors, and the context of use, must be taken into account by the designer (e.g., use of assistive devices, space needed for assistants).

When designing computer applications for the elderly with cognitive impairment, examining age-related changes in elders' skills and limitations and studying accessibility guidelines for older users is a fundamental starting point. However, it does not replace involving users in the design and testing processes. Usability testing is a way of ensuring that technological systems are adapted to the end-users and of guaranteeing that there are no potential negative outcomes that could result from their use (Rubin & Chisnell, 2008). There are several methods of usability inspection aimed at discovering usability problems in a user interface (e.g., heuristic inspection, cognitive walk-through, user testing). However empirical methods, such as user testing, are the most commonly used methods (Nielsen, 1994).

The basic methodology for conducting user testing consists in observing how target users interact with prototypes, or final technological products, to perform realistic tasks (e.g., solving a sequence of exercises from a computerized cognitive training program, using an electronic pill organizer). Performance and preference measures are collected during the experience (e.g., task completion time, number of tasks completed with and without assistance, ease of use, ease of learning). In a general way, the usability of a system is determined by using the following criteria (Ferré, Juristo, Windl, & Constantine, 2001):

- Learnability: How easy it is to learn the functionalities of the system.
- Efficiency: Number of tasks that users can perform in an amount of time.
- Retention over time: How easy it is to remember how to use the system after a period of non-use.
- Error rate: Number of commission or omission errors that users make while performing a task.
- Satisfaction: How pleasing the experience with the system is.

4.3.2.2 Iterative Design Process for User Interfaces

An iterative design process consists in a cyclical process in which the product is refined progressively based on user feedback resulting from repeated usability testing. Results from user tests allow the identification of usability flaws and problems that are then fixed in a new iteration of the design that is submitted again to evaluation for the validation of changes and the identification of additional or persisting problems, that will be improved and tested over again, until a desirable level of usability is achieved (Nielsen, 1993). In summary, an iterative design process encompasses a number of stages of design/test/redesign/retest involving user feedback.

The iteration of design solutions is one of the basic principles of user-centric design. Other characteristics of this methodology are: (a) the design is based upon an explicit understanding of users, tasks and environments; (b) users are involved throughout design and development; (c) the design addresses the whole user experience, (d) the design is driven and refined by user-centered evaluation; and (e) the design team includes multidisciplinary skills and perspectives (ISO 9241-210, 2010).

4.3.2.3 Involving Older Adults with Cognitive Impairment in Design and Testing

There is a large volume of published studies describing the benefits of involving end-users in the development and evaluation of technological products. For instance, Shah & Robinson (2007) conducted a literature review in which they examined several studies that involved users in the technological development of medical devices. Among the most commonly found benefits associated with user involvement were: the generation of ideas by users, having access to users' perspectives, and improvement in the design: user interface, functionality, usability and quality of medical devices. However, the authors pointed out some barriers in user involvement, such as the difficulty of finding a representative group of end-users, and time and costs factors. They concluded though that both users and manufacturers benefit from this collaboration. On one hand, users will have access to technological products that really fulfill their needs and expectations. On the other hand, manufacturers will increase the likelihood of their products finding acceptability on the market.

Moreover, some researchers have addressed the topic of involving people with cognitive impairment (e.g., dementia) in the design process of AT solutions. In this respect, LoPresti, Bodine, & Lewis (2008) have argued that even if design guidelines and user modeling has proven to be useful when designing for people without disabilities, it is difficult to design for an "average" elderly person with cognitive impairment. Indeed, there is a large variability in this population concerning physical, cognitive and sensory capacities. It is also expected to observe an important heterogeneity among individuals with cognitive impairment concerning needs and wants, and different environmental factors (e.g., housing, social network, etc.). For these reasons, it has been widely recommended to include an end-user group in each project stage, from planning to data collection and analysis. Establishing this partnership with end-users would allow the understanding of the context of use of assistive and support technological devices (Alm & Newell, 2008).

For instance, Astell et al. (2006, 2008, 2010) described the design and development process of CIRCA, a multimedia computer system intended to support and promote communication between people with dementia and caregivers. Following a user-centered approach, the design team consulted 40 people with dementia and their caregivers. A range of techniques such as interviews, focus groups, demonstrations with paper and photograph prototypes was used to develop the system in an iterative and incremental way. Results of user testing revealed that elderly persons with dementia were able to use the system and engage in the activities offered by the program. Both caregivers and persons with dementia were satisfied with the system as measured by the different criteria (e.g., verbal and nonverbal measures). Regarding the user interface, iterative user-testing allowed the identification of some technological solutions to make the system usable by people with dementia, such as (Alm et al., 2007):

- Using a touchscreen, because it provides a direct sense of manipulation.
- Implementing a flexible failure-free navigation system, to encourage users to explore the content of the software without the risk of “getting lost” within the application.
- Using a large format screen and large font sizes to improve accessibility to the application.
- Making minimal use of text, to avoid overloading working memory.
- Placing navigation controls at the bottom of the screen, to reduce arm fatigue.
- Offering an attractive design that depicts familiar objects, to encourage an intuitive interaction (e.g., representation of a reel-to-reel tape recorder).

4.3.3 The PRIMO Application

The PRIMO application was developed within the framework of the QuoVadis project, which focused on the development of a social assistive robot for the elderly with cognitive impairment. The primary objective of the project was to provide basic assistance for everyday tasks through a suite of applications: (a) Shopping list management, (b) Agenda, (c) Medication reminder, (d) Robot control, (e) E-mail, (f) Video calls, (g) Web games, (h) Weather forecast, (i) Cognitive training (CT). The secondary objective of the project was to contribute to the social and psychological well being of end-users (e.g., communication and social networking services, companionship aspects, collaboration and engagement capacities).

The robot's applications were selected based on findings from two previous needs gathering studies carried out with the elderly with cognitive impairment (Wu, Faucounau, Boulay, Maestrutti, & Rigaud, 2011) and their caregivers (Faucounau, Wu, Boulay, Maestrutti, & Rigaud, 2009). Specifically, the elderly with cognitive impairment and their caregivers considered CT as the most important and useful application to be delivered by the robot. Therefore, one of the work packages of the project was assigned to the design and development of this CT application. An iterative design approach was used for its development.

4.3.3.1 Characteristics of the System

The project consisted in developing PRIMO, a software application for CT geared towards users with MCI and AD and who have little or no computer experience. The primary objective of the project was to devise a usable and enjoyable system. The design of the first prototype was based on the researchers' experience on traditional cognitive stimulation programs and gerontechnology. The system comprised two different components: a) the back-office interface for the administrator (i.e., health professionals), which allows the creation of a bank of questions, management of user accounts, and monitoring statistical information, b) the user interface, which consists of a home page where users enter their username and password to login. Once users are in their own session a set of exercises is presented.

In PRIMO, CT exercises, or tasks, target different cognitive domains (e.g., memory, language, attention, or executive functions). It was also decided that the content of the program should be tailored to the user's interests and preferences. For this reason a scalable and flexible bank of exercises had to be implemented. Different types of questions were created: typing simple verbal or numerical answers, matching two items, classifying elements into categories and multiple-choice questions. To complete them, the user had to be able to use a computer keyboard and mouse (i.e. selecting checkboxes, drawing lines to connect items, and executing drag-and-drop actions with the mouse).

4.3.3.2 Study Plan

The purpose of this study was to assess the usability of PRIMO, a software application for CT. This study was conducted in two phases, each one concerning an iteration of the software. It was expected to use the findings from the first evaluation to improve the software application in a second iteration, which would be evaluated again for user adaptability. The following aspects were examined:

- Ease of use of the interface: does the user understand the type of question and action required to complete each exercise (e.g., drag and drop, typing the answer)?
- Ease of use of the hardware (e.g., mouse, keyboard, touchscreen).
- User preferences regarding the interface, its components, and general satisfaction with the CT software.
- Usability problems that prohibit effective and successful use.

4.3.4 First Study

4.3.4.1 Objectives

The objectives of this first evaluation were: (1) to evaluate the first prototype of PRIMO and the use of the keyboard and mouse as input methods in order to identify usability problems resulting from the interface design; (2) to examine whether persons with cognitive impairment are capable of using the system without major support and assistance; (3) to compare general task performance between users with cognitive impairment and cognitively healthy controls, and (4) to assess user acceptance of the system.

4.3.4.2 Participants

Eleven elderly persons took part in this study, seven persons with AD according to the NINCDS-ADRDA diagnosis criteria (MCKhann et al., 2011), and four healthy controls (HC). Participants in the AD group were recruited in a senior center for AD patients; those in the HC group were recruited through senior associations. Criteria for inclusion of patients in the study were: both genders; being over 60 years old; living in Paris or Ile de France; having a diagnosis of AD according to the MCKhann et al. (2011) criteria (AD group); having a MMSE score below 16 (AD group). The exclusion criteria out-ruled those with severe cognitive impairment, behavioral problems, or sensory deficits that that would influence the ability to comprehend or perform the tests.

Table 34 Descriptive summary of participants in the first usability study

Subject	Group	Age	Gender	Education level	MMSE	Computer experience	Motivation	Test completed
1	HC	76	F	High school	29	Regular	High	Yes
2	HC	66	F	High school	29	Regular	Low	Yes
3	HC	69	F	High school	30	Regular	High	Yes
4	HC	82	M	University	29	Regular	High	Yes
5	AD	87	M	Primary	24	None	High	Yes
6	AD	81	M	Primary	24	None	High	Yes
7	AD	78	F	High school	24	None	High	Yes
8	AD	83	F	University	22	Regular	High	Yes
9	AD	86	F	High school	19	None	High	No
10	AD	82	F	High school	16	None	Low	No
11	AD	80	F	High school	22	None	Low	No

HC = cognitively healthy controls; F = female; M = male; AD = Alzheimer's disease; MMSE = Mini Mental State Examination, Motivation = level of interest in the activity, Test completed = participant has completed the five testing sessions

The global cognitive assessment of patients was based on the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). This standardized questionnaire is composed of 30 items, providing a global evaluation of cognitive functions (orientation, encoding and retrieval, calculation, language and constructive abilities); the maximum score is 30. Socio-demographic data for each participant was collected including age, education level (primary/high-school/university), computer usage history (none/regular), and level of motivation for the study (high/low). All the participants volunteered for this study. Written informed consent to participate in the study was obtained from each participant, and their guardian for individuals in the AD group, before the beginning of the study. The University Paris Descartes ethical committee, the CCTIRS[18], and the CNIL[19] endorsed this project. A descriptive summary of the eleven persons that took part in this study is provided in Table 34.

4.3.4.3 Material

The first prototype of the software application PRIMO was submitted to user testing. Tests were conducted using a laptop, a keyboard and a mouse. Two camcorders were employed to record the sessions. A satisfaction questionnaire, using a five-point Likert scale, was used to assess user preferences.

4.3.4.4 Procedure

Before commencing with the study the participants received an explanation of its purpose. Each participant was asked to attend five sessions. If they agreed to participate they then signed a customized consent form understandable by AD and MCI participants. A pre-test interview was conducted with the objective of collecting socio-demographic data, computer usage history (experienced/inexperience), and the assessment of the participants' level of motivation for the study (high, medium, low).

The user-test protocol consisted in: one exploratory session and four thirty-minute long testing sessions, with a set of 15 exercises. A test moderator and an observer were present during the exploratory and the first three of four testing sessions. The moderator conducted the test and the observer collected data and supervised video recording. With the intent of observing the participant using the application without any assistance, the last test session was unaccompanied. In this last session the test moderator observed the user through a one-way mirror ready to intervene in case of need. Testing sessions were performed on a laptop equipped with a mouse. Interface use and hand movement while completing the tasks were video recorded to analyze what difficulties were encountered during the study.

The satisfaction questionnaire was completed with the test moderator after the first and the last testing session to assess user preferences. The purpose of administering the questionnaire, twice, was to evaluate if being familiar with the application had an influence on users' satisfaction.

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[18] Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé

[19] Commission Nationale de l'Informatique et des Libertés

Exploratory sessions

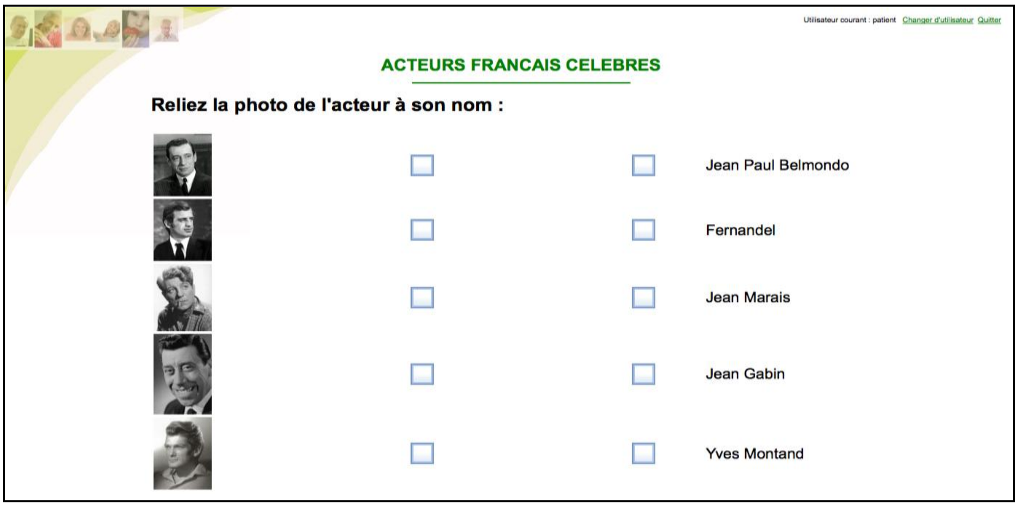
The exploratory session introduced users, especially first-time users, to computer input devices (mouse and keyboad). The session familiarized the participant with the types of actions that would be required of them to perform during the study, such as: moving the cursor with the mouse (Figure 44-1); clicking on a checkbox (Figure 44-2); typing a word, matching two items (Figure 44-3), dragging and dropping an element (Figure 44-4).

Testing sessions

Each testing session consisted in a set of 15 exercises. Since the focus of the study was usability, each testing session included the same 15 exercises with the purpose of assessing interface learnability (Figure 45). Varying the content of the exercises would have added a superfluous variable.

(1) Move the cursor with the mouse; (2) Select checkboxes; (3) Draw a line between two items; (4) Drag & drop some elements into a box

Figure 44 Exercises used in the exploratory sessions



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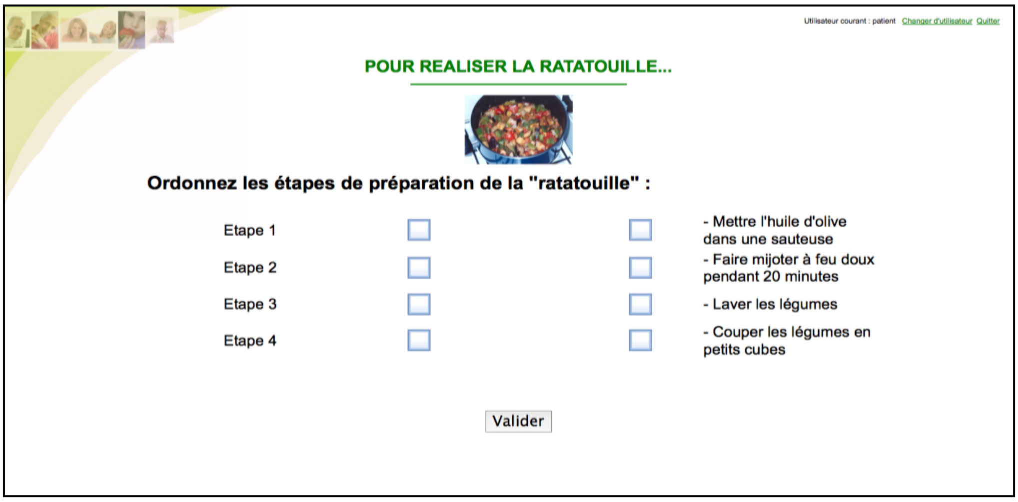


2

(1) Draw a line to match the picture of the actor to his name; (2) Arrange the steps to prepare the "ratatouille" in the order in which they should be carried out

Figure 45 Task examples from the exploratory session

4.3.4.5 Data Collected

Performance and preference measures collected during the exploratory and testing sessions are shown in Table 35.

Table 35 Performance and preference measures collected in the first PRIMO study

Performance measures	Preference measures
Overall task completion time (task time)	Ease of use (computer)
Average question completion time* (question time)	Ease of use (mouse)
Frequency of handling errors	Ease of use (keyboard)
Misuse of the mouse (cursor)	Visual layout (aesthetic)
Wrong action with the mouse button (button)	Font size
Drag and drop error (D&D)	Image size
Typing error (keyboard)	Enjoyment
Frequency with which assistance was provided in completion of each task (assistance)	Usefulness
Verbal prompting (prompts)	System acceptance
Physically showing the participant how to use the system (guidance)	

* Question time was only measured in the testing sessions

In addition to general usability performance and preference measures, the number of errors committed in the CT exercises was also collected (i.e., cognitive errors)[20]. Moreover, during the testing sessions, observational notes were recorded with the purpose of identifying other usability problems than those covered by the measures presented above, which also caused incorrect performance. Statistical analysis was performed using R (version 2.13.2).

4.3.4.6 Results

This section provides the quantitative results of the study. It is structured in accordance with the research objectives that were introduced above.

Socio-demographic data

The sample consisted of eight women (72%) and three men (27%), aged between 66 and 87 years old (*M* = 79.09 years; *SD* = 6.56). Seven participants had a diagnosis of AD and 4 participants constituted the cognitively healthy controls group (HC). Participants in the AD group had a lower MMSE score than participants in the HC group; this

[20] This variable was named « cognitive errors » since it refers to thought-process errors that are not related to the usability of the system, but rather to a lack of knowledge, memory failures, attention lapses, planning deficits, etc.

difference between groups was significant (Wilcoxon test, Z, *p* = .009). Participants in the AD group were older than participants in the HC group, but this difference was not significant (Z, *p* = .06).

All participants in the HC had regular computer experience. In the AD group, only one participant had regular computer experience. The groups differed significantly with regard to this computer usage history as assessed by a Fisher's exact test (*p* = .02). The majority of participants in both groups were motivated to use the computer (72%). Finally, concerning education level 63% had a high-school education, 27% a primary education, and 18% had a university degree. Table 36 presents socio-demographic characteristics for each group.

Table 36 Socio-demographic characteristics for AD and HC groups

Group	**AD**	**HC**
N	7	4
Gender	M (2); F (5)	M (1); F (3)
MMSE; range	21.57 16-24	29.25 29-30
Age mean (*SD*); range	82.4 (3.2) 78-87	73.25 (7.18) 66-82
Education level	Primary (2) High school (4) University (1)	Primary (0) High school (3) University (1)
Computer experience	None (6); Regular (1)	None (0); Regular (4)
Motivation	High (5); Low (2)	High (3); Low (1)

AD= Alzheimer's disease; HC= Healthy controls; N=number of participants; M=male; F=Female; MMSE= Mini Mental State Examination; SD= Standard deviation

Exploratory Sessions

All participants in the HC group completed the exploratory session. In the AD group, only four of the seven participants recruited were able to complete this session. Because of the serious comprehension difficulties, three participants dropped out the study after the exploratory session. Broadly, these users had a lower MMSE score than participants in the AD group that completed all the testing sessions (19 vs. 23.5 MMSE) and were also less motivated to use the computer (Table 30). Therefore, for analysis purposes, we present only data from the participants in the AD group who did complete all the test sessions.

Table 37 provides a summary of average usability performance measures. Wilcoxon tests were conducted to examine the differences between the AD and HC groups. Results showed that participants in the AD group were significantly slower than HC (Z, *p* = .03). Moreover, AD users received assistance from the test moderator more frequently than HC users in the form of verbal prompts (Z, *p* = .03). Nevertheless, no one in either group required physical guidance to complete the tasks. Data revealed that participants in both groups experienced some handling difficulties. However, on average, these problems were significantly more frequent in the AD group than in the HC group (Z, *p* = .03).

Table 37 Average usability performance measures for the exploratory session

Usability measure	**AD** *M, SD*	**HC** *M, SD*
Task completion time (s)	938.75 (562)	235.25 (33.2)
Frequency of assistance	10.25 (7.9)	0.75 (1.0)
Verbal prompts	10.25 (7.9)	0,75 (1.0)
Physical guidance	--	--
Frequency of handling errors	16.25 (3.1)	1.75 (0.96)
Cursor	8.25(4.65)	0.25 (0.5)
Button	2.5 (3.11)	--
D&D	4.25 (1.71)	1 (0)
Keyboard	1.25 (1.26)	0.5 (1.0)

Concerning specific handling errors, the misuse of the mouse to control the movement of the cursor was the problem most frequently observed (Figure 47), particularly for AD users (Z, *p* = .03). The second most common problem was to execute drag and drop actions (i.e., moving the mouse while holding the left button mouse down to drag images or blocks of text across the screen and then releasing the button). This problem was also significantly more frequent in AD than in HC users as confirmed by a Fisher's exact test (*p* = .03).

A few typing errors were observed in both groups but no statistically significant difference between them was found (*F*-test, *p* = .26). Some mouse button errors were noted in certain kinds of questions, for example, when selecting a checkbox. In the HC group mouse button errors were not observed. Considering that no physical guidance was necessary in any case, all the participants that completed the exploratory session were encouraged to continue with the testing sessions.

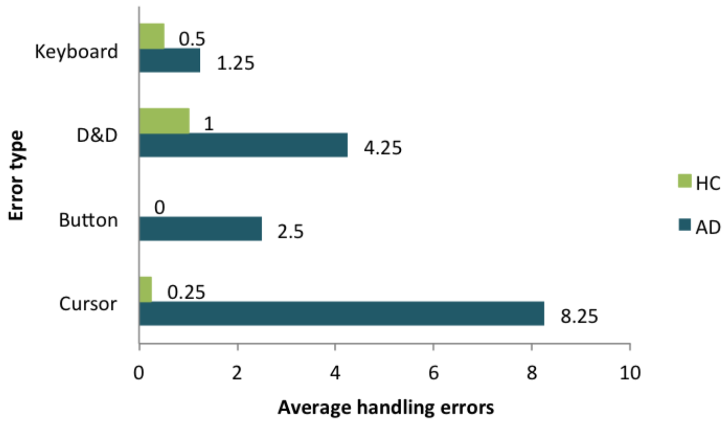


Figure 47 Average handling errors for the total sample in the exploratory session

Testing Sessions

Eight participants completed the testing sessions (AD N = 4; HC N = 4). Table 31 presents average results by group over the three testing sessions for each usability measure.

General findings

Focusing on performance measures, data showed that participants in the AD group took longer to complete the testing sessions than users in the HC group. Also, results suggest that most of the time users with AD were able use to use the system only if they received assistance from the test moderator. On the contrary, participants in the HC group were able to use the system with little or no assistance. With regard to the frequency of handling errors (e.g., cursor, button, D&D and keyboard errors) participants in the AD group were more error prone than HC users. Finally, cognitive errors, related to the performance on the CT exercises were very frequent in the AD group whereas in the HC group cognitive errors were almost inexistent. A series of Wilcoxon tests were conducted to examine whether there were any significant differences in the five performance measures (task time, mean question time, assistance provided, handling errors and cognitive errors) between the AD and HC groups. Statistical analysis indicated a significant difference between groups in all these variables (Table 31).

Differences between groups in task completion time were examined taking into consideration the following factors: group, age, and computer experience. Results showed that participants who were in the AD group, older and/or with no computer experience spent more time completing the tasks. Due to the small size of the sample it was not possible to make a factor analysis of these variables, however numerical differences showed that computer experience was the variable for which differences between groups were the most important (Figure 48).

Table 38 Average performance measures and cognitive errors by group in the first assessment of PRIMO

Measures	AD (*SD*)	HC (*SD*)	*z*	*p*
Task time (s)	2103.83 (457.26)	536.67 (147.83)	16	.03
Question time (s)	140.26 (30.48)	35.78 (9.86)	16	.03
Assistance	16.17 (4.69)	1.33 (0.95)	16	.03
Handling	17.67 (2.36)	2.67 (0.14)	16	.03
Cognitive	8.25 (0.50)	0.83 (0.29)	15.5	.04

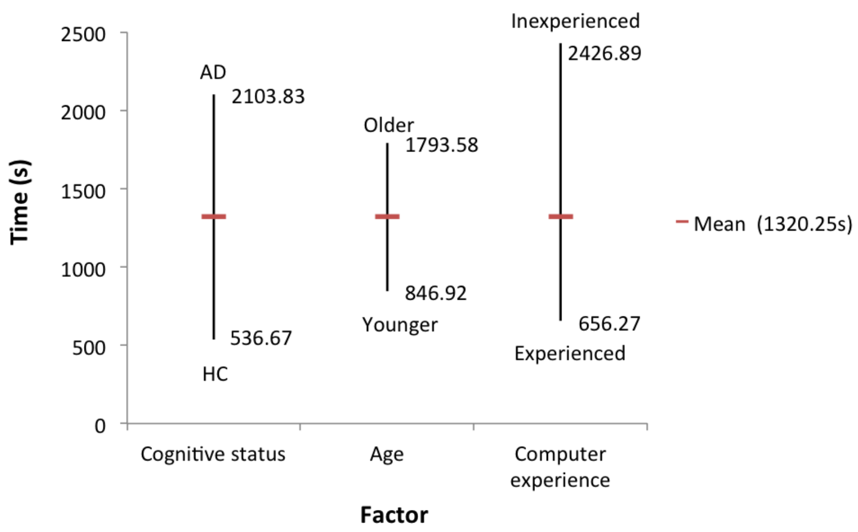


Figure 48 Difference in average task completion time between groups by cognitive status, age, and computer experience

Performance across sessions

Time to complete each session decreased for users in both groups from the first session to the last one (Figure 49). Results also suggested a decreasing trend in the number of handling errors for all the participants (Figure 50). The number of assistance requests diminished across sessions for AD users but remained stable for participants in the HC group (Figure 51).

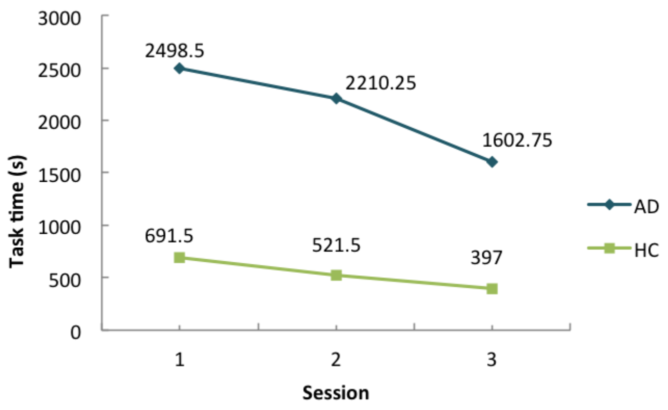


Figure 49 Average task times by group across sessions

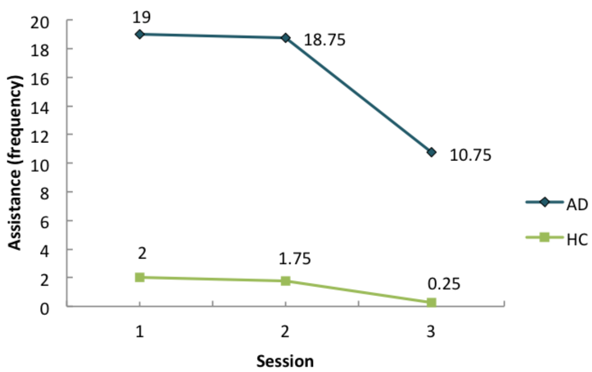


Figure 50 Average frequency of assistance by group across sessions

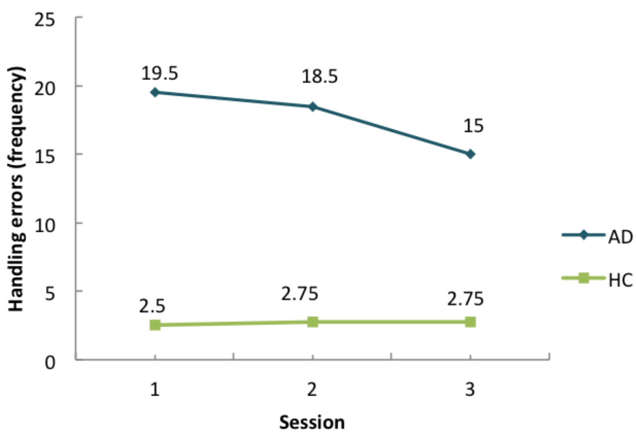


Figure 51 Average frequency of handling errors by group across sessions

Handling errors

Results revealed that AD users encountered made handling errors when using the mouse and the keyboard as shown in Figure 52. The problems more frequently observed concerned the drag and drop gesture and the control of cursor movement with the mouse. On the contrary, participants in the HC group encountered very few handling problems. A series of Wilcoxon sign rank tests were used to assess the difference between AD and HC participants with respect to handling errors. Results showed that participants in the AD group faced significantly more difficulties when executing drag & drop actions (Z, p = .04), controlling cursor movement (Z, p = .03), using the keyboard (Z, p = .03), and using mouse buttons (Z, p = 0.02).

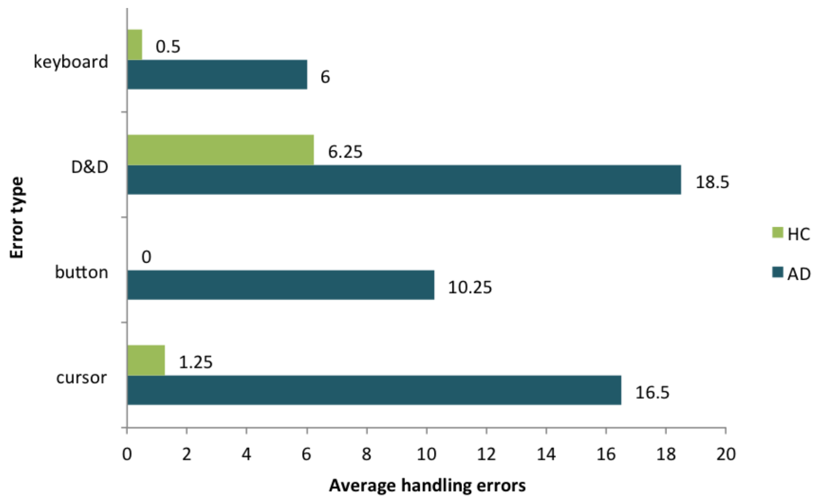


Figure 52 Average handling errors by group including all sessions

Cognitive errors

In both groups, the number of incorrect answers in the exercises tended to remain stable from one session to another (Figure 53). As expected, cognitive errors were significantly more frequent in the AD group than in the HC group (Z, p = .04). Incorrect answers were mainly related to attention deficits (e.g. answering without reading the question) and semantic memory deficits (e.g. deterioration of general knowledge).

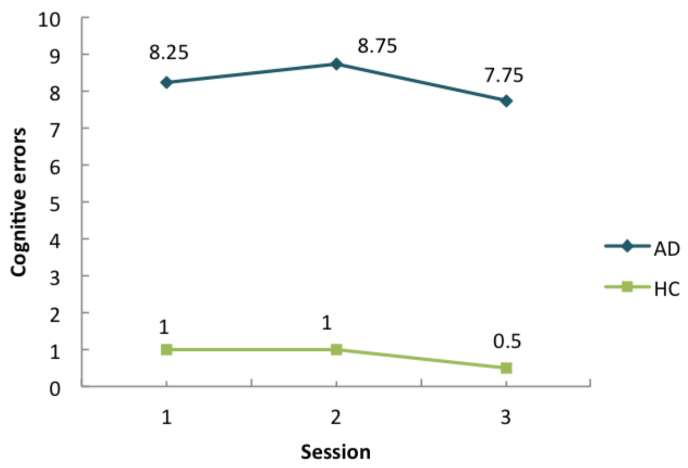


Figure 53 Cognitive errors across testing sessions

Unaccompanied session

All participants succeeded at completing the unaccompanied session (i.e., without any assistance from the moderator). Different handling and cognitive errors were observed through the one-way mirror, but in all cases users were able to recover from errors.

When comparing average task time between the third testing session (accompanied) and the unaccompanied session, results revealed that there was an improvement in task completion time for participants in both groups (Table 39). However, results from a Wilcoxon test showed that this improvement was not significant in either of the two groups (HC, p = 0.13; AD, p = .25). The team also checked for a difference between AD and HC participants regarding time improvement but statistical results showed no significant effect of group on this variable either (Z, p = .34)

Table 39 Comparison of average task time between the third and the unaccompanied session by group

Group	Task time 3rd session (s)	Task time Unaccompanied session (s)
AD *(SD)*	1602.75 (820.47)	1401.5 (658.51)
HC *(SD)*	397 (52.29)	339.25 (36.90)

Preference measures

All participants completed the satisfaction questionnaire after the first and third sessions. Table 40 provides average scores for each preference measure. Taken as a whole, results revealed that users in both groups were rather satisfied with the system, although rating scores were slightly lower in the AD group. Consequently, since the majority of preference scores in the AD group fell between 3 and 4 (i.e., “neither agree nor disagree” and “agree”), it was concluded that improving these features would contribute to enhance accessibility of the system for the target end-users.

Table 40 Preference scores assessed by the satisfaction questionnaire by group at two times

Preference measure	Mean* (*SD*)		Mean (*SD*)	
	AD (t1)	**AD (t2)**	**HC (t1)**	**HC (t2)**
I find the computer easy to use	3.25 (0.5)	3.75 (0.95)	4.25 (0.95)	3.75 (0.95)
I find the mouse easy to use	3.5 (0.57)	3.5 (0.57)	4.25 (0.95)	3.75 (0.5)
I find the keyboard easy to use	3.25 (0.95)	3.5 (0.57)	4.25 (0.95)	3.75 (0.5)
I find the visual layout pleasant	3.75 (0.5)	3.75 (0.5)	4 (0.81)	4.25 (0.5)
I think the font size is adapted	3.75 (0.5)	3.75 (0.5)	4 (1.154)	4 (0.81)
I think the image size is adapted	2.75 (0.5)	3.5 (0.57)	3.75 (0.95)	3.5 (0.57)
I find this activity enjoyable	4 (0.81)	4 (0)	4.25 (0.95)	4 (0.81)
I think this program can help maintain my memory in good health	4.25 (0.95)	4.25 (0.5)	4.5 (0.57)	3.75 (0.95)
I would like to use this program at home	3.5 (1.73)	4.25 (0.5)	2.75 (2.06)	4 (1.41)
Overall score	**3.55 (0.44)**	**3.8 (0.3)**	**4 (0.51)**	**3.86 (0.22)**

*Means based upon 5-points scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree

When comparing preference scores between the two assessments it can be noticed that there was little or no change in ratings. The single most striking observation to emerge from data analysis was the improvement of the acceptance of the system in both groups, assessed by the item “I would like to use this program at home”.

Other usability problems

Observational notes and video recordings from the testing sessions allowed the identification of errors that caused poor performance. Indeed, several problems were observed in both groups (Table 41). A severity rating scale (Rubin & Chisnell, 2008, p. 262) was used to rank each problem and prioritize the work required to improve the software in the next iteration.

Table 41 Severity rating of usability problems identified in the testing sessions

Usability problem	**SR (1-4)**	**User group concerned AD**	**HC**	**Possible reason User**	**Interface**
User does not use the scrolling bar or experiences difficulties using it	4	x		Not familiarized with the system; diminished control movement; episodic memory failure once the correct action has been shown by the moderator	Content is bigger than the screen size, thus scrolling up and down may be necessary; implies the use of the mouse
Useless information distracting the user is displayed on the screen	2	x		Deficits in selective attention impact the ability to focus on pertinent stimuli and ignore irrelevant stimuli	Task-irrelevant content for the user is displayed
User does not read the question text goes directly to the answer options	3	x		Deficits in selective attention; because of a reduced peripheral vision users tend focus their attention on the middle of the visual field	Design elements do not encourage focusing visual attention on specific content
Users do not position the cursor on the text box before typing their answer, preventing them from going further	4	x		Not familiarized with the system; episodic memory failure once the correct action has been shown by the moderator	Cursor is not placed automatically in the text box
When selecting a checkbox is necessary to complete an exercise users tend to click directly on the item (image or text) and not on the checkbox	4	x		Deficits in visuo-spatial attention and executive functioning (e.g., planning an action); episodic memory failure once the correct action has been shown by the moderator	The distance between the checkbox and the item is too large; the use of checkboxes and items may be redundant
Users does not click on the "VALIDATE" button to proceed to the next question	4	x	x	Not familiarized with the system; reduced peripheral vision; episodic memory failure once the correct action has been shown by the moderator	The purpose of the button is not easily understandable and no instruction is provided
Small size of the checkbox	2	x	x	Diminished visual acuity; motor difficulties to make precise mouse movements	Checkboxes are too small, requiring accurate mouse movements to select them; implies the use of the mouse

Usability problem	SR (1-4)	User group concerned AD	HC	Possible reason User	Interface
Small size of the images	2	x	x	Diminished visual acuity; difficulties in understanding or interpreting visual stimuli are affected by the quality of the image	The images displayed are too small
Executing drag & drop actions with the mouse	3	x	x	Not familiarized with the system; diminished control movement; difficulty in performing two tasks simultaneously (e.g., looking at the screen while manipulating the mouse)	Implies the use of the mouse
Misuse of the keyboard, some users have difficulties in finding or interpreting the keys (e.g., delete, space bar)	2	x		Not familiarized with the system; deficits in visuo-spatial attention and executive functioning (e.g., planning an action)	The virtual keyboard replicates the real one. Thus users encounter the same difficulties in finding and interpreting the keys
Users sometimes are lost in the transition from one screen to another and question feedback is not read	3	x		Slow information processing; deficits in visuo-spatial attention	Transitions from one screen to another is too fast and the feedback message is not salient enough for the user to perceive it or read it

1 = No problem- satisfies the benchmark; 2 = Minor hindrance-possible issue, but probably will not hinder the user; 3 = Serious problem-may hinder the user; 4 = Task failure- prevents this user going further

4.3.4.7 Recommendations for Design Improvement

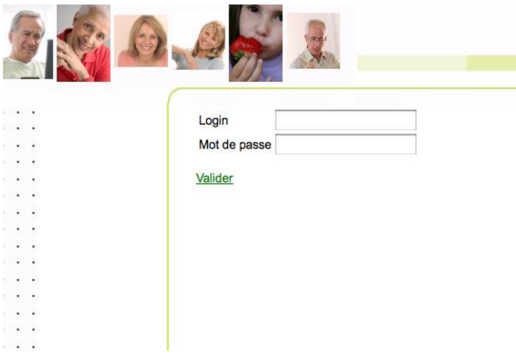
Based on the results of user testing and analysis of the source of errors, a list of modifications that the interface required to improve its usability was elaborated. Table 42 presents this set of recommendations and refers to some examples of screen displays developed to overcome the aforementioned shortcomings.

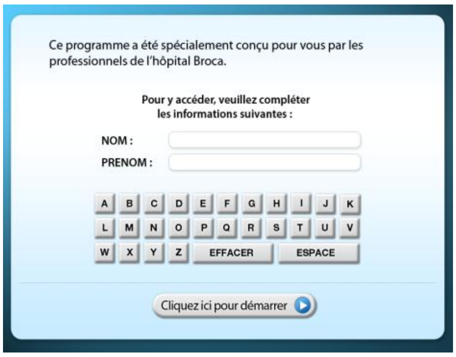
Table 42 Main usability problems observed in the first version of PRIMO and design recommendations

Usability problem	Recommendation	Example
Misuse of the mouse	Replace the use of the mouse and keyboard by a touchscreen	(1)
Misuse of the scrolling bar	CT exercise must fit the screen in order to avoid the use of the scrolling bar	(2)
Font and image size used by default are too small	Create a template that homogenizes page structure	(2)

Usability problem	Recommendation	Example
	Increase font and image size	
Users experienced some difficulties processing the information that is outside of the center of the visual field (e.g., content located in the upper or bottom part of the screen)	Reduce the length of the question text Remove task-irrelevant content Chunk the text into small pieces Use a frame in the template that helps to orient visual-attention to the center of the screen where information is presented	(2)
The "Validate'" button to proceed to the next question is not seen/used, preventing the user to go any further	Replace the button "validate", by the button "Go to the next question"	(3)
Feedback messages are not read/understood because the time of presentation is too short and the message is not visible enough; the user does not receive any feedback	Positive and negative feedback is displayed on the screen for a few seconds and their presentation is accompanied by a sound	(4)
The hyperlink used to exit the program is not seen/understood, preventing the user to go any further	Create a visible "Exit" button and removing task-irrelevant content	(5)
Using a checkbox next to an image to select the image may confuse the user	Remove checkboxes, multiple choice questions should allow selecting the items by clicking directly on them	(6)
Users can experience some difficulties using the keyboard (e.g., finding or interpreting keys).	A simplified keyboard (letters in alphabetical order, larger keys) is displayed for all questions that require typing an answer	(7)
Users do not place the cursor in a text box before starting to write, preventing them to go any further	The cursor is automatically placed in the answer box, without having to move the cursor	--

(1)





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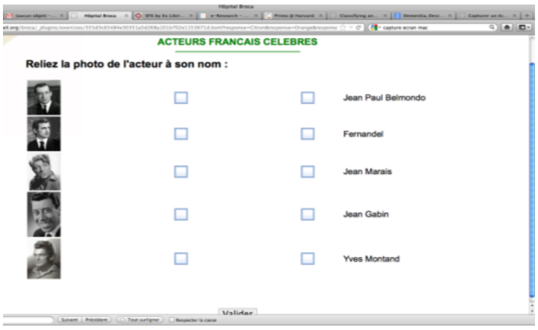

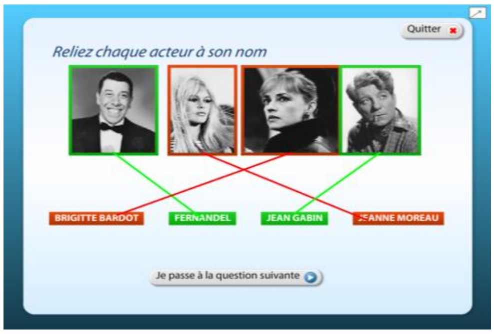

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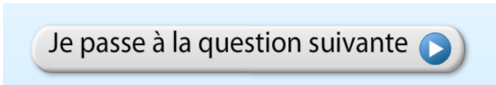

(4)

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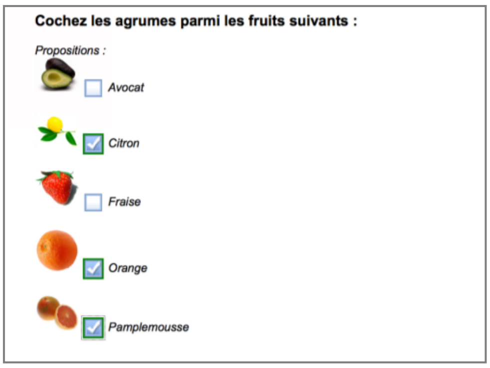
Utilisateur courant : patient Changer d'utilisateur Quitter

(6)



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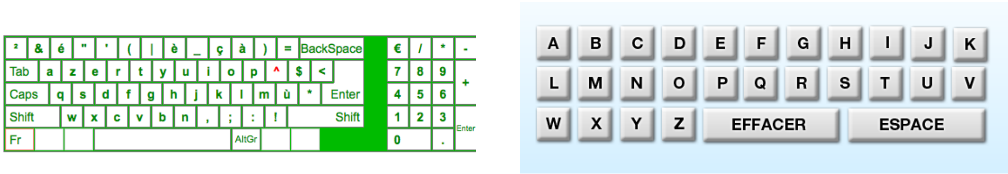

4.3.4.8 Discussion

One of the primary objectives of this study was to assess the suitability of the first version of PRIMO for older adults with cognitive impairment. In this section are discussed the main findings of usability testing undertaken with a group of older adults with AD and a group of cognitively healthy elders. Initial user testing revealed that the system, in its first version, was not entirely adapted to people with AD. Indeed, most of these users needed significant assistance to make appropriate use of the application. However, despite the problems encountered, all participants said that they enjoyed using the application and would like to have it at home.

The results of this study allowed inferring that cognitive status had a direct influence on the use of PRIMO. For instance, in the exploratory session, participants who were unable to complete the test were in a more advanced stage of AD. Moreover, throughout the three testing sessions, significant differences were observed between participants in the AD group and those in the HC group in all the performance measures. It seems possible that these results were due to deficits in episodic and working memory, executive functioning, and visuo-spatial processing, which are common in AD. For AD users, it was difficult to accomplish two tasks simultaneously (e.g., reading on the screen while operating the mouse), to control the GUI with the mouse (e.g., pointing, dragging, double clicking), or to carry out effective visual searches. In several cases, AD participants required prompting and support to complete the tasks.

Nevertheless, two additional factors must be considered for the analysis of these findings: computer experience and age. In fact, participants in the AD group had little or no computer experience whereas all the participants in the HC group were experienced computer users. Furthermore, participants in the AD group were older than participants in the HC group. These observations are in line with previous works in this field that have identified cognitive abilities, age, and computer experience as predictors of computer performance in older adults (Czaja & Sharit, 1993; Czaja et al., 2001, 2006; Laberge & Scialfa, 2005; Sjolinder, Höök, & Nilsson, 2003; Wagner et al., 2010). One limitation of this study was that, due to the small sample size, regression analysis could not be performed in order to estimate the contribution of each one of these factors on task performance. Thus, some questions remain about whether there is an independent effect of cognitive impairment on computer use, and if cognitive impairment effects can be explained by other factors, such as age or computer experience. Future studies using larger sample sizes would provide a better understanding on the role of these factors.

Two major usability problems were revealed during testing: the use of the mouse and the complexity of the visual display. First, difficulties in mouse control have been associated with the cognitive and motor demands it imposes on users, such as requiring transition between rotary and linear movement, translation between hand and screen, and learning time (Rogers, Fisk, McLaughlin, & Pak, 2005). Conversely, the use of direct input devices, like touchscreens, has been recommended for older adults because it promotes intuitive direct manipulation of software applications, especially for pointing tasks (Charness, Holley, Feddon, & Jastrzembski, 2004). In addition, touchscreen devices could help to compensate for deficits in spatial abilities (e.g., mental translation between the human body and the machine) usually observed in AD (Lineweaver, Salmon, Bondi, & Corey-Bloom, 2005). Touchscreen systems have proven to be easy to use by people with dementia (Alm et al., 2003, 2004; Astell et al., 2006, 2008, 2010; Riley et al., 2009). In our study, the initial prototype of PRIMO was not designed for a touchscreen device. For the second version of the software it was decided to implement this option.

Second, the complexity of visual displays has been found to hinder the use of computer-based applications in older adults, also because of the high cognitive demands associated with their use. Long task execution times observed in the AD group are a clear indicator of the difficulties experienced by these participants in processing the information displayed on the screen. Indeed, AD is characterized by significant impairment of visual processing capacities that affects visual search, visual short-memory and processing speed (Bublak et al., 2011). In this study, such deficits may thus have restricted the effective use of interfaces by users with AD.

However, age can also account for increased reaction times. For instance, earlier studies have shown how older adults tend to read all the text displayed on the screen and can experience significant difficulties accessing information when a large amount of text is presented (Chadwick-Dias et al., 2002). Other works have shown that visual search difficulties in elderly persons are also increased when the number of items to be searched is large (Pak & McLaughlin, 2010), and that the ability to interpret information outside of the central field of view decreases with age (Fisk et al., 2009). A possible explanation of our results is that there was a combined effect of cognitive abilities and age on visual information processing. Still, larger sample sizes and a finer task analysis will be required to isolate the contribution of these factors.

For interface design, some of the solutions suggested regarding this are to un-clutter the layout and ease the navigation by reducing unnecessary text, providing concrete instructions, and implementing a flexible failure-free navigation system (Alm et al., 2007). Accordingly, for the second iteration of PRIMO, usability problems related to the visual display will be addressed by simplifying interactions, providing environmental cues to direct visual attention to specific spatial locations on the screen, and by delivering automated help when there is no response from the user after a period of time.

An interesting result of this experiment was the improvement observed throughout the sessions in all performance measures for participants in the AD group in only three sessions of training. This finding is consistent with the fact that learning new motor and perceptual skills is possible for individuals with AD because it depends on procedural memory abilities, which are preserved at the early stages of the disease (van Halteren-van Tilborg, Scherder, & Hulstijn, 2007). Hofmann et al. (2003) had also demonstrated that after 12 sessions of computer-based CT, individuals with AD improved their task completion time and significantly reduced their number of mistakes. With respect to the use of computer-based applications by older adults, these results confirm the benefits of training and repeated practice on task performance (Czaja et al., 2001; Fisk et al., 2009; Wagner et al., 2010). On the contrary, for the same participants, the number of incorrect answers remained stable. This could be explained by the early decline in episodic memory observed in AD (Ergis & Eusop-Roussel, 2008), which affects the recall of recently learned information (e.g. trial-and-error learning method).

Finally, regarding usability testing methodology, results highlighted the advantages of conducting repeated test sessions when working with people with special needs. This method allowed us to examine the evolution of user performance over time and to study some factors, such as learnability issues, for which a single session would not have been sufficient. Carrying out accompanied sessions with AD users appeared to be a critical point, helping them feel comfortable while they were getting familiar with the application. Nevertheless, further research is needed on the independent use of the CT software.

4.3.5 Second Study

4.3.5.1 Objectives

The objectives of this second evaluation were: (a) to evaluate the usability of the second version of PRIMO with the purpose of validating the changes that were made to the interface based on results from the first usability study; (b) to identify potential remaining ergonomic problems and suggest a set of recommendations for solving them; (c) to examine whether persons with cognitive impairment are capable of using the system without major support and assistance; (d) to examine the role of individual factors such as age and computer experience in user performance.

4.3.5.2 Participants

Fifteen elderly persons took part in this study. Eleven persons composed the group of users with cognitive impairment (CI) and four elderly individuals with normal cognition the group of Healthy Controls (HC) users. In the CI group, three individuals had an AD diagnosis, according to the NINCDS-ADRDA criteria (MCKhann et al., 2011) and eight persons a diagnosis of MCI according to Peterson et al. criteria (1999).

Participants in the CI group were recruited in a memory clinic. Those in the HC group were recruited through senior associations. Criteria for the inclusion of patients in the study were: both genders; being over 60 years old; living in Paris or Ile-de-France; having a diagnosis of AD or MCI (CI group); having an MMSE score above 20 (CI group). The exclusion criteria out-ruled those with severe cognitive impairment, behavioral problems, or sensory deficits that would influence the ability to comprehend or perform the tests.

The global cognitive assessment of patients was based on the Mini Mental State Examination (MMSE) (Folstein et al., 1975). Socio-demographic data for each participant was collected including age, education level (primary/high-school/university), and computer usage history (none/regular). All the participants volunteered for this study. Written informed consent to participate in the study was obtained from each participant, and their guardian for individuals in the AD group, before the beginning of the study. The University Paris Descartes ethical committee, the CCTIRS, and the CNIL endorsed this project. A descriptive summary of individuals is provided in Table 43.

Table 43 Descriptive summary of participants in the second evaluation

Subject	**Group**	**Diagnosis**	**Age**	**Gender**	**Education level**	**MMSE**	**Computer experience**	**Test completed**
1	CI	AD	80	f	High school	24	Regular	No
2	CI	AD	85	f	High school	22	None	No
3	CI	AD	82	m	University	25	Regular	Yes
4	CI	MCI	78	m	High school	26	None	Yes
5	CI	MCI	80	f	University	28	Regular	Yes
6	CI	MCI	86	f	High school	27	None	Yes
7	CI	MCI	82	f	Primary	29	None	Yes
8	CI	MCI	77	m	University	28	None	Yes
9	CI	MCI	79	m	High school	27	None	Yes
10	CI	MCI	66	f	High school	29	Regular	Yes
11	CI	MCI	75	m	University	30	Regular	Yes
12	HC	--	78	f	University	30	Regular	Yes
13	HC	--	88	f	University	29	None	Yes
14	HC	--	71	f	University	29	Regular	Yes
15	HC	--	66	f	High school	30	Regular	Yes

CI = Cognitive impairment; HC = healthy controls; f = female; m = male; AD = Alzheimer's disease; MMSE = Mini Mental State Examination, Motivation = level of interest in the activity, Test completed = the participant has completed the five sessions

4.3.5.3 Material

For this study, we used the second prototype of the software application PRIMO. Tests were conducted using one DELL tablet (touchscreen) and its stylus. Two camcorders were employed to record the sessions.

4.3.5.4 Procedure

Before commencing with the study, the participants received an explanation of its purpose. Each participant was asked to complete a forty-minute session. If they agreed to participate, they signed a customized consent form comprehensible to AD and MCI participants. A pre-test interview was conducted with the objective of collecting socio-demographic data and computer usage history (experienced/inexperience).

The test procedure included a session with a set of nine exercises to be completed. Each exercise involved a different type of question requiring a specific operation, such as filling-in a response using the virtual keyboard (Figure 54-1), clicking and dragging the letters to complete a word (Figure 54-2), multiple choice question (Figure 54-3), memory question (Figure 54-4), drag and drop (Figure 54-5), or drawing lines to associate two items (Figure 54-6). A moderator conducted the user tests and an observer helped with data collection. The sessions were videotaped for data analysis.

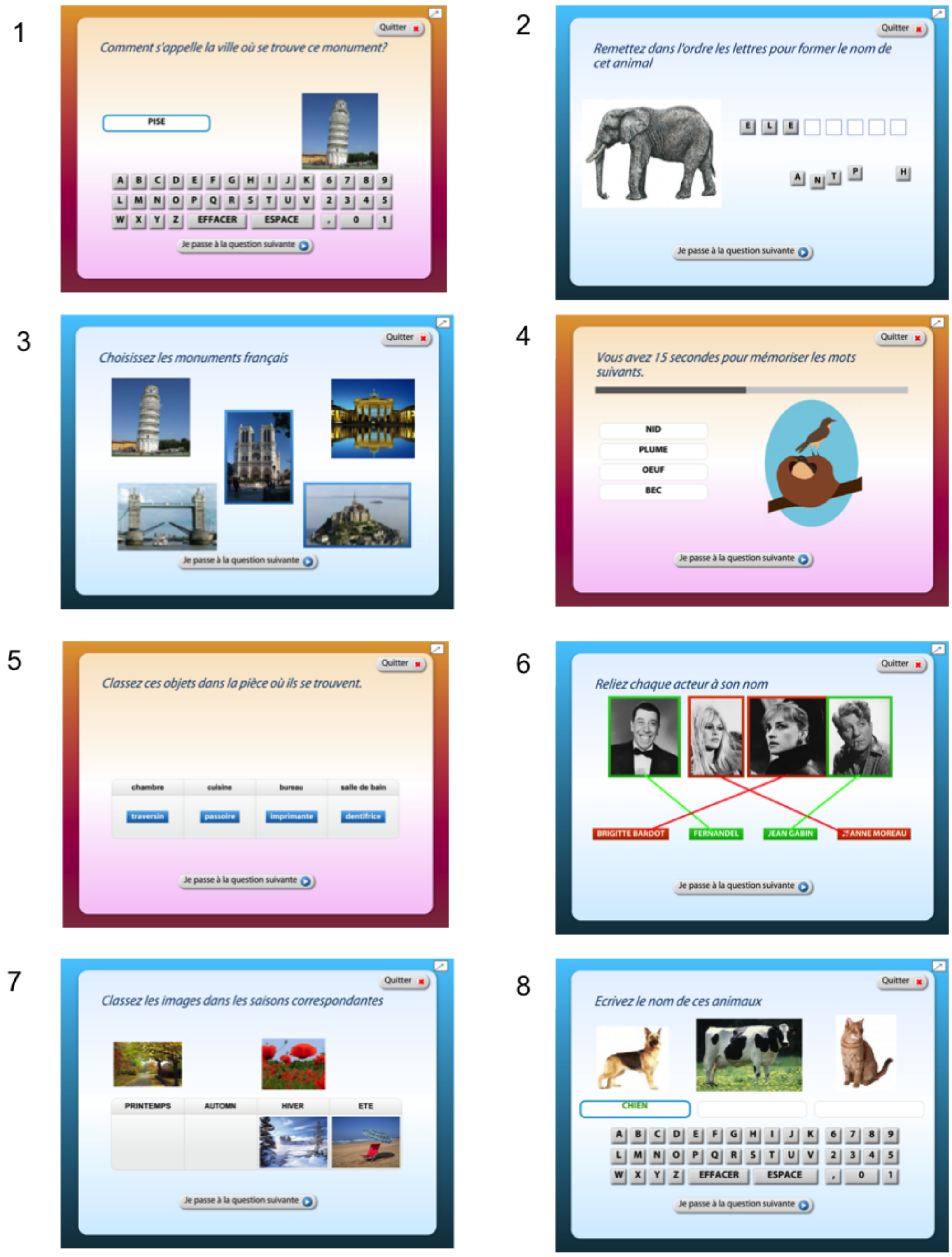

Figure 54 CT exercises in the second version of PRIMO

4.3.5.5 Data Collected

Performance measures collected during the exploratory and testing sessions are shown in Table 44. In addition to general usability performance measures, the number of errors committed in the CT exercises was also collected (i.e., cognitive errors). Moreover, during the testing sessions, observational notes were recorded with the aim of identifying usability problems beyond those covered by the measures presented above, which also caused incorrect performance.

Table 44 Performance measures collected in the second PRIMO test

Objective performance measures
Question completion time (question time)
Overall task time (task time)
Frequency of handling errors
Drag and drop error (D&D)
Position of the cursor with the stylus (cursor)
Excessive or not enough pressure on the screen with the stylus (pressure)
Gesture required to complete the exercise (gesture)
Frequency with which assistance was provided in completion of each task (assistance)

4.3.5.6 Results.

Socio-demographic data

The sample consisted in ten women (66%) and five men (34%), aged between 66 and 88 years old (*M* = 78.2 years; *SD* = 6.55). In the CI group, three participants had a diagnosis of AD and eight participants of MCI. Four participants constituted the cognitively healthy control group (HC). Participants in the CI group had a lower MMSE score than participants in the HC group but this difference between groups was not significant (Wilcoxon test, Z, $p = .07$). Participants in the HC group were younger than participants in the CI group, but the difference between groups with regard to age was not significant (Z, $p = .47$).

In the CI group, the number of participants who did not have any computer experience was higher (54%) than the number of experienced participants (46%). In the HC group only one participant was inexperienced. However, no statistical difference between groups was found for computer usage history as assessed by a Fisher's exact test ($p = .57$). Finally, concerning education level 47% of participants had a high-school education, 47% a university degree, and 6% a primary education level. The difference between groups with respect to education level was not significant (*F*-test, $p = .68$). Table 45 presents socio-demographic characteristics for each group.

Table 45 Socio-demographic characteristics of the sample for the second test of PRIMO

Group	**CI**	**HC**
N	11	4
Gender	F (6); M (5)	F (4); M (0)
MMSE; Range	27.8 22-30	29.5 29-30
Age mean (*SD*); Range	79.1 (5.4) 78-87	75.7 (9.5) 66-82
Education level	Primary (1) High school (6) University (4)	Primary (0) High school (1) University (3)
Computer experience	None (6); Regular (5)	None (1); Regular (3)

CI = Cognitive impairment; HC = Healthy controls; N = number of participants; M = male; F = Female; MMSE = Mini Mental State Examination; SD = Standard deviation

Testing sessions

Two participants with AD could not complete the test because of cognitive problems (e.g., attentional or comprehension difficulties). All other participants, regardless of their cognitive profile, completed all required tasks independently or with little assistance. Only the results from those who completed the test were analyzed (n = 13).

A series of Fisher exact tests were performed to examine the differences in performance measures between the AD and HC groups. Results showed that there was no significant difference between the two groups in any of these variables (Table 46). However, participants in the CI group were slower and faced more usability problems than those in the HC group.

Table 46 Average performance measures and cognitive errors by group

Measures	**CI (*SD*)** ***N* = 9**	**HC (*SD*)** ***N* = 4**	***p***
Task time (s)	410.78 (96.35)	390 (167.57)	.7
Mean question time (s)	42.64 (10.12)	40.81 (17.80)	.7
Assistance	6.56 (2.40)	3.75 (2.75)	.16
Handling	9.11 (3.79)	7 (3.65)	.31
Cognitive	1.56 (1.13)	0.75 (0.96)	.87

Performance measures were also analyzed with regard to age (Table 47). For this purpose, age was considered as a binary variable and the median chosen as cut-off value (79 years). Participants were then distributed into two groups: oldest-old adults (*M* = 82.3, *SD* = 3.5) and young-old adults (*M* = 73, *SD* = 5.3). A series of F-tests revealed that younger participants performed the tasks significantly faster and made less handling errors than older participants. Older participants made more cognitive errors and required assistance more frequently than the younger ones, but no statistical difference was demonstrated.

Table 47 Average performance measures and cognitive errors by age-group

Measures	**Young-old (*SD*)** ***N* = 7**	**Oldest-old (*SD*)** ***N* = 6**	***p***
Task time (s)	335.43 (83.78)	484.83 (95.35)	.03
Mean question time (s)	34.81 (8.42)	50.56 (10.50)	.02
Assistance	4.29 (2.14)	7.33 (2.58)	.07
Handling	5.71 (1.89)	11.67 (2.50)	.006
Cognitive	0.71 (0.95)	2.00 (0.89)	.13

With regard to computer experience results showed that experienced participants were faster at completing the tasks and made less handling and cognitive errors than inexperienced participants (Table 48). However, these differences were only statistically significant (*F*-test) for the task completion time.

Table 48 Average performance measures and cognitive errors by computer experience

Measures	**Experienced (*SD*)** ***N* = 7**	**Inexperienced (*SD*)** ***N* = 6**	***p***
Task time (s)	339 (79)	481 (106)	< .05
Mean question time (s)	35.2 (8.4)	50.1 (11.3)	.07
Assistance	4.29 (2.36)	7.33 (2.34)	> .05
Handling	5.71 (1.89)	11.67 (2.50)	.43
Cognitive	0.71 (0.95)	2.00 (0.89)	.64

Handling errors

Few handling errors were noted for participants in both groups (Figure 55). Participants in the CI group experienced more difficulties adapting the pressure of the stylus on the screen. Overall results showed that the use of a touchscreen made the control of the cursor on the screen easier than when using the mouse, considering that no position errors were registered in either of the groups. Moreover, most of the drag & drop errors were recorded when the subject did not exert enough pressure on the screen and executed a gesture that was too fast or unsteady.

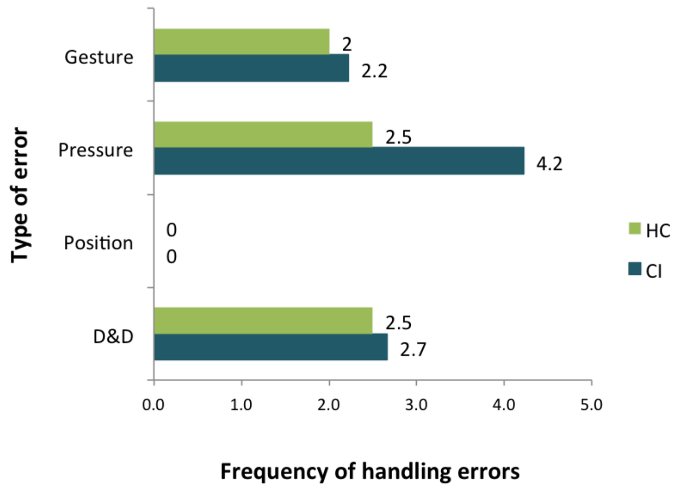

Figure 55 Average frequency of handling errors by type and group

Gesture errors were noticed when users were confused about the type of gesture they were required to use for a specific feature. For instance, when users had completed an exercise that required them to reorganize a set a letters to complete a word, and they were asked later to type an answer with the virtual keyboard, some of them tried to drag the letters of the keyboard instead of tapping on them (Figure 56).

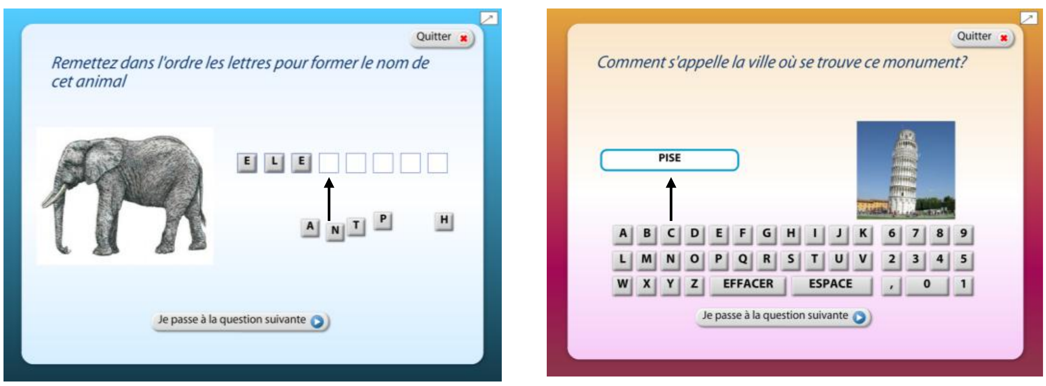

Figure 56 Confusing gestures between dragging the letters and tapping on them

A similar error was observed when participants tried to drag a text box in order to associate it with an image when they were actually expected to draw a line between the two items (Figure 57). In these cases users were replicating the drag & drop gesture used in a previous exercise.

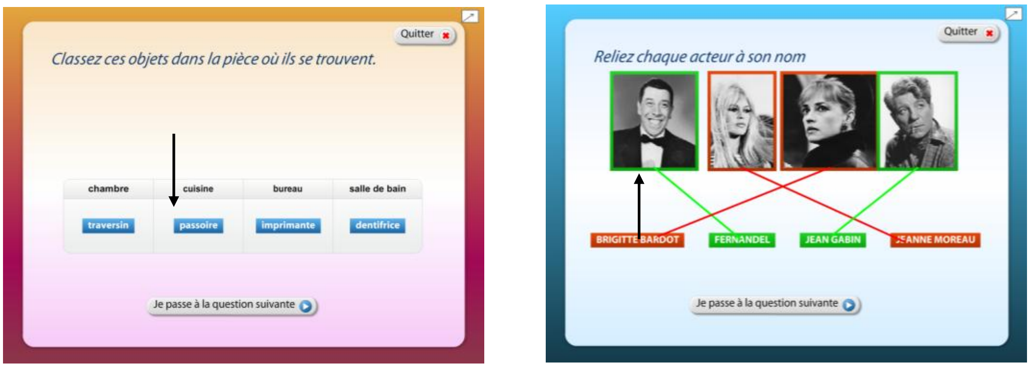

Figure 57 Confusing gestures between dragging an element and drawing a connecting line

In reference to the design improvements made from the first PRIMO version it is interesting to note that no single error was observed when using the “I go to the next question” button located on the low part of the screen, to move forward once the answer was selected. Also, no scrolling errors were noticed because, for this second iteration, content was designed to fit the screen without the need to scroll down. The default settings for the font, visual layout, and exercises templates have proven to suit older users’ requirements. Finally, the layout of the keyboard that displays the keys in alphabetical format (ABC keyboard) was easy to learn and use, particularly for novice computer users.

Other usability problems

Observational notes and video recordings from the testing sessions allowed the identification of other errors that caused poor performance or confusion among users. These problems included:

- Hand/arm fatigue caused by the necessity to lift the arm to use the touchscreen.

- For some users, decline in fine motor skills hindered the execution of precise gestures with the stylus.
- Some expert computer users complained about the ABC keyboard arguing that it was not the standard layout to which they were used. A few participants claimed that the ABC keyboard did not correspond to an adult-like design.
- The low sensitivity of the touchscreen had a negative influence on usability. Several subjects experienced some difficulties in adjusting the pressure exerted on the screen.

4.3.5.7 Differences in task performance between the first and second study

With the aim of examining the differences in task performance, between the first and second series of tests, average scores were calculated for each group taking in consideration the total number of questions in each test (Table 49). For the first evaluation only scores from the first testing session were used.

Results showed that the benefits of design improvement were clear for participants with cognitive impairment regarding task completion time, assistance required and handling errors. In the HC group only task completion time was improved in the second version. On the contrary, the number of handling errors and assistance requests were slightly worse in the second test, even if participants in this group completed tasks faster and more accurately than participants in the CI group. However, these data must be interpreted with caution because the characteristics of the groups were different in the two trials, particularly regarding the lower MMSE scores for participants in the CI group in the first evaluation.

Table 49 Comparison of performance measures between the first and second user testing of PRIMO

	PRIMO 1	PRIMO 2	PRIMO 1	PRIMO 2
	CI	CI	HC	HC
Average question time (s)	166.5	42.6	46.1	40.8
Average number of assistance	1.3	0.7	0.1	0.4
Average number of handling errors	1.3	1.0	0.2	0.8

4.3.5.8 Discussion

The primary objective of this study was to assess the suitability of the second version of PRIMO for elderly people with cognitive impairment. Overall results confirmed that design modifications implemented into the software contributed to improve its usability. The decrease in task completion time, number of errors, and assistance requests in the CI group provided a clear example of the benefits of design enhancement for this population.

In general, findings suggest that the presence of mild to moderate cognitive impairment did not impact the use of the application. For instance, no significant differences were observed between the CI and HC groups in task performance, even if users in the CI group were slower and made more errors than HC users. Although the small size of the sample might have biased this result, it also must be considered that differences in cognitive status between the two groups were not significant. Consequently, it can be expected that persons with MCI will use the software in a similar way than healthy older adults.

Nevertheless, if we consider that two of the three persons with AD were unable to complete the testing session, it should be acknowledged that the second version of the application was not entirely adapted to people suffering from severe cognitive deficits. Although we have managed to design a CT application that was usable by elderly people with MCI, developing CT applications for people with moderate to severe AD remains a challenge. Ensuring compliance with ergonomic guidelines is a fundamental step when designing software for people with special needs, but it is not always enough to compensate for deficits in attention, motivation, or executive functioning. These results are consistent with those of Sharit, Hernández, Czaja, & Pirolli (2008), who found that after accounting for individual differences in computer knowledge, significant predictors of task performance in older adults were reasoning abilities, working memory, and perceptual speed, all of them affected by AD. An additional factor that contributes to the complex process of designing interfaces for people with dementia is the heterogeneity of clinical profiles observed in this population, which makes it difficult to define one single profile that fits all potential users.

Accordingly, we recommend an accompanied use of PRIMO for individuals presenting significant cognitive impairment. In these cases, users with dementia will not be expected to be proficient in computer skills, as long as a caregiver plays the role of supporter or enabler. For future studies that focus on this population, it is then advised to involve caregivers in the development and assessment of software applications to ensure a successful implementation later at home or in institutions. Our conclusions in this regard are in line with those of Savitch & Milton (2009), who demonstrated the importance of training staff to work on a one-to-one basis for teaching people with dementia how to use computers and the Internet and how to provide them with encouragement and support. Similarly, Mahendra et al., (2005) suggested investigating the potential of training caregivers to provide technical and emotional support to people with dementia who are willing to follow a computer-based CT program. In summary, CT tools for elderly people with cognitive impairment should incorporate a design that is flexible enough to be used by people with different needs and in a variety of contexts.

Results from this second experience are also consistent with our earlier observations, which showed that age and computer experience are modulating factors influencing the use of computers by elderly people. Sharit et al., (2008) had found that in healthy older adults, after accounting for differences in computer knowledge and cognitive abilities, the influence of age on task performance (i.e., seeking information on the Web) was negligible. As stated before, future studies should examine if computer training can compensate for widespread deficits in cognitive abilities, such as those observed in MCI or AD.

Regarding usability issues, we noted that the introduction of touchscreen technology for the second version of PRIMO made the handling of the application easier for users with cognitive impairment. These results confirmed findings from previous works showing that the direct manipulation provided by touchscreen systems offers enough affordance to ease their use by people with dementia (Alm et al., 2003, 2007). Nevertheless, one unanticipated finding was that comparative scores between the first and the second tests showed a clear improvement in all performance measures for the CI group but not for the HC group. A possible explanation for this might be that in the first test all the participants in the HC were experienced computer users; however, this experience concerned traditional computers and not touchscreen technology. Computer experience represented an advantage for this group in the first test, but not in the second one. This can explain why in the second test there were no significant differences in handling errors between experienced and inexperienced users.

These results are consistent with those of Jastrzembski, Charness, Holley, & Feddon (2005) who compared the use of a light pen and a mouse in older adults who were experienced mouse users and were using the light pen for the first time. Results showed that the light pen was less efficient than the mouse for older adults early in training, but that after a period of practice the light pen achieved equivalent performance. Unfortunately, in our second assessment only a single test session was conducted, thus it was not possible to examine the learning curve for the use of the touchscreen and the stylus over time. Still, task completion times were better in the expert group, indicating that despite the novelty of the system these users were more comfortable using the software application than those who were using a computer for the first time.

The analysis of usability problems observed during the second test session revealed that most of them were associated with the sensitivity of the touchscreen. The choice of a reliable system is fundamental since older adults are less tolerant to usability problems, in part because of their fragile confidence in their ability to use computer-based systems (Newell, Arnott, Carmichael, & Morgan, 2007). With respect to this, our study confirmed findings of Pak & McLaughlin (2011) about older adults being more likely to attribute usability problems to themselves rather than to the interface. However, overall results from the two studies showed that some users were more comfortable with the use of the stylus and others with the mouse. In this sense, some degree of customizability should be expected from the system. The same question about system customization was raised when expert computer users complained about the alphabetical keyboard that the application provided. A design solution could be to allow the user to adapt some of the basic settings of the application to his/her preferences.

Finally, another usability problem related to the use of the touchscreen was gesture confusion. All the participants who completed the test were able to learn all the gestures required for the different exercises. Nevertheless, sometimes memories for different gestures ended up interfering with each other. Budiu & Nielsen (2010) had already noticed this problem on their usability study of Ipad Apps and websites. The fact that procedural memory is relatively well preserved in the earliest stages of AD supports the learning of the basic gestures required to handle a touchscreen device. However, careful attention should be given to the design of the visual layout in order to minimize the risk of cognitive interference between functions and gestures. Therefore, future studies on the use of touchscreen devices by people with cognitive impairment should explore which gestures are easily discovered by these users and have better affordances, and how training influences gesture learning and discrimination.

4.3.6 Conclusions

Successful design of usable and beneficial technologies for older adults with cognitive impairment requires their participation throughout the entire design, development and evaluation process. Usability assessment with these potential end-users is a particularly important step in order to create accessible and usable technological applications that will truly meet their needs. This two-phase study confirmed that cognitive abilities play an important role in learning to use software applications. Still, other factors such as age, computer experience, and attitudes towards computers also had a strong influence on the way older adults interacted with the CT application.

We have obtained encouraging results in taking some special considerations for usability testing with this population. For example, by conducting repeated test sessions, we were able to observe an improvement in performance measures. Also, carrying out exploratory sessions helped participants to gain some confidence in using the computer and allowed us to better understand their capacities, limitations and motivations. Finally, involving a group of cognitively healthy older adults was a useful way of obtaining information about how age and other variables influence task performance and gaining an insight on the specific design requirements for elderly with cognitive impairment.

Innovative methodological approaches should be developed to get reliable input from these users and to better understand cognitive workload and function allocation between the user and the system. In future projects, it would be interesting to integrate methods of cognitive neuroscience (e.g., psychophysics, eye tracking) in usability studies. These methods could provide understanding of cognitive and affective processes involved in the interaction with technological applications. Consequently, they could help to improve the design of applications intended for elders with cognitive limitations.

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4.4 Computer-Based Cognitive Interventions for Older Adults with Normal Cognition, MCI and Alzheimer's Disease: Last Decade's Findings and Prospective Challenges

Cognitive interventions for healthy and cognitively impaired older adults have the purpose of enhancing and/or helping maintain cognitive skills that reveal age-related decline or are affected by neurodegenerative diseases. In this paper we review and analyze the main studies on computer-based cognitive interventions in cognitively healthy older adults, elderly with MCI and Alzheimer's disease, conducted over the past decade. Training and transfer effects, at different levels, were found in most of these studies confirming that computer-based interventions potentially benefit cognitive function. Functional capacities, quality of life and psychological well-being have also proved to benefit from these interventions, albeit at a lesser extent. However, despite the potential positive outcomes these methods have, a number of methodological and practical issues must still be addressed. In fact, differences in experimental methodology preclude direct comparison of current studies. Further research should also examine the role of individual factors on intervention-related cognitive changes, on transfer effects and on their durability. Another challenging aspect of these interventions is their implementation outside the laboratory settings and their therapeutic adherence. Computer applications constitute a flexible and cost-effective alternative for delivering cognitive interventions to older adults. Still, future computer-based interventions should offer content related to daily life situations to promote the interest of participants and sustain motivation, target functional outcomes, better leverage the possibilities of computer applications currently available and take into consideration usability factors.

Key words: elderly, cognitive, intervention, MCI, Alzheimer's disease, computer applications

4.4.1 Introduction

Cognitive Interventions (CI), as a whole, refer to structured programs that aim to improve or help preserve cognitive abilities in different populations (Boot and Blakely, 2011; Park et al., 2007; Willis and Schaie, 2009). Over the past 40 years, many different terms have been used somewhat interchangeably to designate various types of CI: stimulation, training, rehabilitation, remediation, etc. In order to clarify these concepts, Clare and Woods (2004) suggested classifying CI into three broad categories:

- *Cognitive training* (CT) comprises a regular practice on a set of standardized tasks that target specific cognitive processes such as memory, attention or executive functions. Its main objective is the improvement of subject's performance on trained tasks and to achieve a transfer to other untrained tasks. Most computer-based Cis fall into this category.

- *Cognitive stimulation* (CS), on the contrary, encompasses a wide range of activities that globally involve different cognitive domains. In addition, social interactions constitute a key factor in CS programs, as most of them are delivered through group sessions.

- *Cognitive rehabilitation* (CR) aims at overcoming specific practical difficulties related to cognitive decline encountered by individuals in everyday life. CR involves methods such as the learning of compensatory strategies for lost functions and the optimization of residual functions.

Like any classification, this one has its limitations as, for example, some overlap may exist between these three categories in practice. Nevertheless, we will use it in this review as it provides a useful theoretical framework for our purposes.

Through the enhancement of cognitive and functional abilities, the ultimate goal of CI is to contribute to quality of life and independent living. Consequently, a critical aspect of CI concerns transfer effects: the extent to which improvement in trained tasks will generalize to other domains of functioning (Willis and Schaie, 2009; Zelinski, 2009). Thus, various outcome measures are used to assess CI transfer effects: *Proximal* outcomes refer to the specific cognitive domain or ability targeted by the intervention (e.g., performances on training tasks from the first session are compared to those obtained in the last training session); *Primary or near transfer* outcomes refer to untrained tasks or processes that share some similar characteristics with the trained ones (e.g., in a CI focused on working memory, the training tasks involve the visual domain while the transfer outcome measures, also targeting working memory, involve the verbal domain); *Secondary or far transfer* outcomes refer to the assessment of performance in domains that are different from those initially targeted by the training (e.g., in a training program focused on general cognitive functioning the transfer outcome measures include functional abilities, quality of life, or neuropsychiatric symptoms).

The assessment of CI must also consider the durability of their effects (Rebok et al., 2007; Willis and Schaie, 2009). Thus, studies in this area usually involve pre-post test assessments and follow-up evaluations, ranging from one to 5 years after the end of the intervention. Moreover, some CI include booster training sessions that are delivered after completion of the program to help individuals maintain or reinforce positive effects for as long as possible. For this purpose, booster sessions use either the same material employed during the initial training phase or one that involves similar cognitive process.

4.4.1.1 CI for Older Adults and the Use of Computerized Methods

In the field of geriatrics the interest in CI has grown considerably over the past decades. Two main reasons may account for this: a) a large number of studies have confirmed that older adults, with normal cognition or with cognitive impairment, are capable of improving cognitive skills and of learning new ones through systematic practice (Brehmer et al., 2008; Gates and Valenzuela, 2010), and b) different longitudinal studies suggest that participating in cognitively stimulating activities contributes to prevent or at least slow down the rate of cognitive decline among the elderly (Fratiglioni and Wang, 2007; Hall et al., 2009; Karp et al., 2009; Katzman et al., 1988; Wilson et al., 2002, 2007). Indeed, considering that cognitive impairment due to dementia is one of the leading causes of institutionalization for the elderly (Luppa et al., 2009), finding alternative methods to prevent and deal with these conditions has become an area of interest for health professionals and policy makers.

Traditional methods to deliver CI usually involve face-to-face individual or group sessions conducted by a trained moderator (e.g., a psychologist or a speech therapist). Training material in traditional CI may include paper-and-pencil exercises and other activities that focus on cognitive skills. Nowadays, although most therapists still use traditional methods, computer-based approaches have gained momentum. Computer-Based Cognitive Interventions (CB-CI) comprise software applications, virtual reality techniques, brain fitness software packages, videogames, online programs, collaborative training methods, and videotape or audiotape technologies (Boot and Blakely, 2011; Zelinsky et al., 2011). With regard to specific CBCI material, Kueider et al., (2012) have distinguished among three types of computerized programs: classic cognitive training programs, used to provide guided practice on standardized tasks targeting particular cognitive domains; neuropsychological software programs, designed to provide training in multiple cognitive domains through a variety of tasks; and video games.

It is important to note that advances in information and communication technology, and a common concern for healthy aging, have encouraged the development of cognitive training tools, particularly commercial brain fitness products (Gates and Valenzuela, 2010). Aging demographics show that older adults constitute a rapidly expanding market segment (Branchik, 2010). As a result of this recent trend, elderly are increasingly targeted by commercial “brain-training” digital games (Papp et al., 2009). A few studies have investigated the effects of commercial applications on cognitive enhancement (Fuyuno, 2007; Ijsselsteijn et al., 2007; Nacke et al., 2009; Owen et al. 2010). Although they highlight the advantages of providing cognitive tasks in an enjoyable way, their effects on general cognitive function have yet to be proven. Thus, we should expect that future gaming technologies, developed in the framework of cognitive aging research, will have the potential to influence cognitive functioning everyday behavior, psychological well-being and quality of life in older adults.

Over traditional methods a number of advantages of CB-CI has been reported in the existing literature:

- CBCI represent a flexible and cost-effective solution to promote cognitive engagement in older adults. In fact, users can access and benefit from these programs at a time and place that best suit their needs. Besides, the Internet allows a large number of services to be provided at lower costs than personal or group sessions.
- Immediate, accurate performance feedback can be provided to the user, a factor that helps to encourage motivation and compliance with the training program (Bherer et al., 2005).
- The possibilities of electronic data sharing offered by computerized methods enable health professionals to have a better understanding of the evolution of

participants' cognitive performance over time, particularly when CI are provided in a clinical context.

- CBCI are easier to combine with neuroimaging techniques for research and follow-up purposes. Indeed, various parameters related to cognitive tasks can be controlled more precisely (e.g., stimulus presentation, user input methods) in order to better isolate the neural correlates of specific cognitive processes (Bohil et al., 2011).

The increasing number of studies conducted on CB-CI for older adults, with or without cognitive impairment, is clear evidence of the interest given to these novel approaches. Many of these works have been included in literature reviews focused on clinical subgroups of elderly populations and/or on specific approaches (Acevedo and Loewenstein, 2007; Buschert et al., 2010; Clare et al., 2003; Grandmaison and Simard, 2003; Kueider et al.,2012; Lustig et al. 2009; Mahendra et al., 2005; Papp et al., 2009; Rebok et al., 2007; Sitzer et al., 2006; Zelinsky et al., 2011). Overall, these reviews suggest that CB-CI have the same potential to positively influence cognitive functioning as paper-and-pencil methods.

However, despite the interest that these novel approaches generate, several aspects merit further consideration. First, the identification of the general cognitive domains that have been successfully targeted by CBCI would help to better orient future research. Second, for clinical purposes, comparing the effects of these interventions on different subgroups of older adults (according to sensory capacities, cognitive status, age group…) would be useful to identify who benefits the most from the "computerization" of CI. Third, it is important to review specific factors related to the material itself (e.g., how CI take advantage of the possibilities offered by computer-based systems, the role this friendliness of the interfaces, usability issues) with the purpose of identifying which are the advantages of using this kind of material compared to pen-and-pencil material. Finally, several issues regarding the implementation of CBCI at home or in ordinary clinical settings, such as acceptability and compliance must be taken into consideration for CBCI to fulfill their potential as actual, everyday therapy tools.

Consequently, the aim of this paper is to present a review of main studies published in the past decade concerning CBCI for older adults, either cognitively healthy, with MCI or with AD. We attempt a) to summarize the effects of these interventions by cognitive domain and by population, b) to identify which intervention features are associated both with the improvement and the maintenance of cognitive functioning by emphasizing transfer outcomes when available, and c) to examine how the implementation issues mentioned earlier have been addressed. For these purposes, we report findings from the literature, discuss their implications and identify major limitations. Then, we propose recommendations to improve the quality of future studies in this field and infer a set of guidelines for the design of novel and more engaging interventions.

4.4.2 Materials and Methods

4.4.2.1 Literature Search

A literature search was carried out using the following computerized databases: Medline, PsychINFO, ISI Web of science, ISI Web of knowledge, and the Cochrane Library, for articles published between January 2000 and December 2010. Titles and abstracts were searched using the following terms: 'cognitive' OR 'memory' OR 'executive function' OR 'attention', and 'intervention' OR 'program' OR 'rehabilitation' OR 'stimulation' OR 'training'; and 'elderly' OR 'healthy' OR 'dementia' OR 'Alzheimer' OR 'cognitive impairment' OR 'MCI'; and 'computer' OR 'computerized' OR 'video game' OR 'virtual'. Reference lists were also hand-searched for additional studies meeting the inclusion criteria.

4.4.2.2 Inclusion and exclusion criteria

The studies selected for inclusion in this review met the following criteria: They were: (a) experimental studies involving CB-CI carried out with older adults (healthy subjects, suffering from MCI or AD), (b) studies that included any computer-based application (e.g., computer, software, video game, video/audio recording, virtual reality), (c) studies published in English, and (d) studies that reported standardized cognitive outcome measures for the CB-CI. The main studies excluded from this review were: (a) publications that were systematic reviews and not journal articles, (b) those in which participant's performance was not recorded at least at two points in time (pre/post test design), and (c) those in which participants, in the older adults group, were not 60 years or older.

4.4.3 Results

Twenty-four studies were included in this review. A summary of studies included can be found in Table 50. Selected studies were analyzed according to the following variables: type of intervention, modality, target-population, number of subjects (*N*), age, cognitive status, study design, duration, assessments, and training related outcomes. The studies were grouped according to the sub-population addressed.

Table 50 Summary of CB-CI for elderly adults

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
Ball et al., (2002) Willis et al., (2006)*	Multimodal intervention involving a computer-based speed of processing training	**1. HOA** *N*= 2802 M age 73.6 MMSE 27.3	RCT 1. TG (n=3): - Memory - Reasoning - Speed of processing 2. NCCG	10 sessions 60-75 min 5-6 weeks 4 booster training sessions 11 months later (60% sample)	- Baseline - Post-training - 1 year - 2 years * 5 years	- Improvement in proximal outcomes (memory, reasoning and speed of processing) for the 3 TG durable to 2 years (P >.001) - Most significant improvement for participants in the Speed TG (87%), followed by Reasoning (74%) and Memory (26%) - Booster sessions positive effect on memory and reasoning training - No functional transfer detected at 2 years evaluated through everyday problem solving tasks (self-reported and naturalistic tasks) * Functional transfer detected at 5 years (self-reported IADLs)
Mahncke et al., (2006)	Computer-based speed and accuracy of auditory information training (software Posit Science)	**1. HOA** *N*= 155 M age 70.9 MMSE ≥24	RCT 1.TG 2. ACG 3. NCCG	40 sessions 60 min 8-10 weeks	- Baseline - Post-training - 3 months	- Improvement in proximal outcomes (speed and accuracy of auditory information) - Transfer of benefits to nonrelated neuropsychological measures of memory (RBANS) durable to 3 months
Smith et al., (2009)	Computer-based speed and accuracy of auditory information training (software Posit Science)	**1. HOA** *N*= 487 TG, ACG M age TG 75.6 M age ACG 75.0 MMSE TG 29.1 MMSE ACG 29.2	RCT 1. TG 2. ACG	40 sessions 60 min 8 weeks	- Baseline - Post-training - 3 months	- Improvement in proximal outcomes (speed and accuracy of auditory information) - Improvement in non-trained measures of attention and memory using a composite score of subtasks from the RAVLT, RBMT and WMS-III - Far transfer: improvement in the PRO measure (perceptions of cognitive abilities) assessed by the CSRQ-25

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
Basak et al. (2008)	Real-time strategy video game "Rise of Nations" (Microsoft)	**1. HOA** *N*=24 TG, NCCG M age TG 68.8 M age NCGG 69.8 mMMSE TG 55.8 mMMSE NCCG 55.7	RCT 1. TG 2. NCCG	15 sessions 90 minutes 4/5 weeks	- Baseline - Post-training	- Improvement on game performances - Positive near transfer effects on executive control tasks: task switching, VSTM, focus or object switching in the n-back task, reasoning abilities (Raven's Advanced Progressive Matrices) and to untrained mental rotation task
Buschkuehl et al. (2008)	Computer-based working memory training	**1. HOA** N= 32 M age 80.1 MMSE n/a	CT 1.TG 2. ACG	23 sessions 45 min 12 weeks	- Baseline - Post-training - 1 year	- Improvement on proximal outcomes - Positive near transfer effects on untrained visual working memory task (block-span task) - No group differences found 1 year later
Dahlin et al. (2008a,b*)	Computer-based updating function training *fMRI	**1. HOA** N=29 TG, NCCG M age TG 68.3 M age 68.2, MMSE TG 28.6 MMSE NCCG 28.8 **2. YA** N=26, TG, NCCG M age TG 23.6 M age 24.0, MMSE TG 29 MMSE NCCG 29.1	RCT 1. OA TG 2. OA NCCG 3. YA TG 4. YA NCCG	15 sessions 45 min 5 weeks	- Baseline - Post-training - 18 months	- Improvement on trained tasks for young and older adults in the TG - No transfer effects in the OA TG - Near transfer effects in the YATG - Training effects for TG both groups and near transfer effects for YA durable to 18 months (n-back task)

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
Li et al. (2008)	Computer-based spatial working memory training	1. **HOA** N= 41 TG, NCCG M age TG 74.5, M age NCCG 73.3 MMSE n/a **2. YA** N=46 TG, NCCG M age TG 25.3 M age NCCG 26.4 MMSE n/a	CT 1. OA TG 2. OA NCCG 3. YA TG 4. YA NCCG	45 sessions 15 min 45 days	- Baseline - Post-training - 3 months	- Improvement on trained tasks for both TG - Near transfer effects to untrained n-back tasks for both TG - No far transfer effects in either age group
Bherer et al. (2005)	Computer-based dual-task training (auditory and visual identification)	**1. HOA** N= 36 M age 70 mMMSE 56 2. YA N=36 M age 20 mMMSE n/a	RCT 1. OA TG 2. OA CG 3. YA TG 4. YA CG	5 sessions 1 hour 2/3 weeks	- Baseline - Post-training	- Improvement on trained tasks for both TG - Near transfer effects to untrained discrimination tasks in both TG
Erikson et al. (2007)	Computer-based dual-task training, MRI/fMRI	**1. HOA** *N*= 26 M age 66.11 mMMSE >51 2. YA *N*= 31 age range= 19-32 mMMSE n/a	RCT 1. OA TG 2. OA CG 3. YA TG 4. YA CG	5 sessions 1 hour 2/3 weeks	- Baseline - Post-training	- Significant improvement on trained tasks for both TG - Near transfer effects in untrained dual-task paradigms for both TG - Increased hemispheric asymmetry for both age groups - Reduction in age differences in ventral and dorsal prefrontal activation

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
Mozolic et al. (2009)	Selective attention training, LCD monitor, and computer	**1. HOA** *N*= 66 TG, ACG M age TG 69.4 M age ACG 69.4 MMSE TG 28.3 MMSE ACG 28.5	RCT 1. TG 2. ACG	8 sessions 60 min 8 weeks	- Baseline - Post-training	- Significant reduction in interference from cross-modal distractors but not from within-modality distractors in the TG - Far transfer effect observed in the TG in non-trained domains (processing speed and dual-task completion)
Cassavaugh & Kramer (2009)	Computer-based multidomain cognitive training and driving simulator	**1. HOA** *N*=21 M age 71.7 MMSE dementia sreening test > 52	1. TG No CG	4 driving sessions 8 training sessions 12 days	- Baseline (2 driving sessions) - Post- training (2 driving sessions)	- Significant improvement in performances on the single and dual trained tasks. - Near transfer effects on post-training simulated driving performance
Schmiedek et al., (2010)	Computer-based cognitive training (working memory, episodic memory and perceptual speed)	**1. HOA** TG, NCCG *N* TG= 103 *N* NCCG= 39 M age TG 71.3 M age NCCG 70,6 mMMSE n/a 2. YA TG, NCCG *N TG*= 101 *N* NCCG= 44 M age TG 25.6 M age NCCG 25.2 mMMSE n/a	RCT 1. OA TG 2. OA NCCG 3. YA TG 4. YA NCCG	100 training sessions (average)	- Baseline - Post training assessment with near and far transfer tasks	- Significant improvement on the trained tasks for both training groups, except for a word list episodic memory task for the OA TG - Far transfer effects: generalization to cognitive abilities represented as latent factors

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
Gunther et al. (2003)	Computer-based multidomain cognitive training	**1. MCI** *N*= 19 age range= 75-91 MMSE n/a	1. TG No CG	14 sessions 45 min 14 weeks	- Baseline - Post-training - 5 months	- Significant improvement in the majority of practiced cognitive functions - Verbal learning ability and resistance to the interference improvement was maintained up to 5 months
Cipriani et al. (2006)	Computer-based multidomain cognitive training (software NPT)	**1. MCI** *N*=10 M age= 70.6 MMSE=28.0 **2. AD** *N*=10 M age= 74.1 MMSE= 23.9 **3. MSA** *N*=3 mean age= 69.0 MMSE= 26.7	1. TG No CG	Two blocks of: 16 sessions 13-45 min 4 weeks 4-8 weeks break	- Baseline - 3 months	- In the MCI group results showed a significant improvement in the majority of practiced cognitive functions and transfer effects only to the area of behavioral memory (RBMT) - In the AD group there was a significant improvement in MMSE score, verbal fluency (phonemic fluency) and executive functions (TMT B)
Rozzini et al. (2007)	Computer-based multidomain cognitive training (software NPT)	**1. MCI** *N*= 59 age range= 63- 78 TG, ChEIs, NCCG MMSE TG 26.8 MMSE ChEIs 26.4 MMSE NCCG 26	RCT 1.TG (ChEIs + TNP) 2. ChEIs 3. NCCG	Two blocks of: 20 sessions 60 min 4 weeks 2-months break	- Baseline - 3 months - 1 year	- Significant improvement in the TG on episodic memory (short story task) abstract reasoning (Raven's colored matrices) and depression, anxiety, apathy (GDS, NPI) observed 1 year after the training
Talassi et al. (2007)	Computer-based multidomain cognitive training (software NPT)	**1. MCI** *N*=37 TG, ACG M age TG 76.2 M age ACG 76.1 MMSE TG 27.5	CT 1. TG 2. ACG	12 sessions 45 min 3 weeks	- Baseline - Post-training	- In the MCI group results showed a significant improvement in post-training assessment in constructive apraxia (Figure Rey copy), long-term visuo-spatial memory, (Figure Rey recall) and in functional and affective status depression and anxiety (PPT, GDS) - In the AD group there was a significant improvement in global cognitive status (MMSE), and in affective status, depression and anxiety (GDS)

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
		MMSE ACG 26.9 **2. AD** *N*=29 TG, ACG M age TG 75.9 M age ACG 81.0 MMSE TG 20.8 MMSE ACG 18.4				
Belleville et al. (2006)	Multifactorial cognitive intervention focused on episodic memory. Computer-based attentional training	**1. MCI** TG, CG *N*= 28 M age TG 62.3 M age CG 69.3 MMSE TG 28.9 MMSE CG 28.2 **2. HOA** TG, CG N= 17 M age TG 65.9 M age CG 69.5 MMSE TG 29.0 MMSE CG 28.7	CT 1. TG 2. CG	8 sessions 120 min 8 weeks	- Baseline - Post-intervention	- In the MCI TG there was a significant improvement on two of the primary outcome measures of episodic memory (delayed list recall and face-name association). - A significant effect was also found on measures of subjective memory (QAM) and well being - No transfer effects in cognitive measures not addressed by the intervention. - There was no improvement in attentional skills addressed by the computer application
Barnes et al. (2009)	Computer-based speed and accuracy of auditory information training (software Posit Science)	**1. MCI** *N*=47 TG, ACG M age TG 74.1 M age ACG 74.8 MMSE n/a	RCT 1.TG Speed, accuracy of auditory information 2. ACG	30 sessions 100 min 6 weeks	- Baseline - Post-training	- No significant improvement on global cognitive function (RBANS) - Positive trend of improvement in measures of verbal learning and memory in favour of the intervention

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
Hofmann et al. (2003)	Interactive computer-based cognitive training (ICT), virtual reality.	**1. AD** *N*= 9 M age= 68.1 MMSE= 19.6 **2. Depressive OA** *N*= 9 M age 67.3 MMSE 25.4 3. Healthy OA *N*= 10 M age 69.3 MMSE 28.1	1. TG - AD - Depressive OA - Healthy OA (control group)	12 sessions 4 weeks	- Baseline - Post- training - Week 7	- Improvement on trained tasks and a significant reduction of mistakes in the use of the computer programme in the AD group - No significant differences between baseline and post- training cognitive assessment in neither group (CDR, MMSE, TMT A)
Galante et al. (2007)	Computer-based multidomain cognitive training (software NPT)	**1. AD** *N*= 11 TG, ACG M age 76.0 MMSE TG 22.9 MMSE ACG 23.1	RCT 1.TG 2. ACG	12 sessions 60 min 4 weeks	- Baseline - Post-training - 3 months - 9 months (MMSE)	- Results showed no significant improvement in the TG on general cognitive function. However, MMSE score in the TG remain stable over different assessments
Tarraga et al. (2006)	Interactive Multimedia internet-based system (IMIS) for cognitive training (Smartbrain)	**1. AD** TG, IPP, NCCG *N* TG=15 *N IPP*= 16 *N NCCG*= 12 M age TG 75.8 M age IPP 77.4 M age NCCG 76.9 MMSE TG 20.6 MMSE IPP 22.5	RCT 1. TG (IMIS+ IPP) 2. IPP (Integrated psychostimulation program) 3. NCCG	72 sessions 15-25 min 24 weeks	- Baseline - Week 12 - Week 24	- Participants in the TG (IMIS+ IPP) and in the IPP group had improved outcome scores on the ADAS-Cog and MMSE, maintained through 24 weeks of follow-up. - IMIS associated to IPP provided an improvement above and beyond that seen with IPP alone - Participants in the NCCG had their ADAS-Cog and MMSE decline, as expected

Study	Modality	Sample	Study design	Duration	Assessment	Main training-related outcomes
		MMSE NCCG 22.8				
Mate-Kole et al. (2007)	Interactive cognitive training (Mind Aerobics), and Adaptive Computerized Cognitive Training (ACCT)	**1. AD** *N*= 6 Age range= 64-93 MMSE n/a	1. TG - AD (*N*=4) - Vascular dementia (*N*=1) - Mixed dementia (*N*=1) No CG	18 sessions of Mind Aerobics 24 sessions of ACCT 6 weeks	- Baseline - Post- training - Week 10	- Improvement on global cognitive function assessed by the RQCST Global in the whole sample, on ADAS-Cog measures (n=5), and on visual-spatial abilities, psychomotor speed and executive function (TMT) (n=4) - Improvement on functional measures, especially in individual behavioural changes (FAQ, CFQ and caregiver reports)

Note. RCT Randomized Controlled Trial, CT Controlled Trial, OA Older Adults, HOA Healthy Older Adults, YA Young Adults, TG Treatment Group, CG Control Group, ACG Active Control Group, NCG No-contact Control Group, M age Mean age, MMSE Mini Mental State Examination, mMMSE modified Mini Mental State Examination, ADAS-Cog Alzheimer's Disease Assessment Scale-Cognitive, CDR Clinical Dementia Rating, CFQ Cognitive Failures Questionnaire, CSRQ-25 Cognitive Self-Report Questionnaire FAQ Functional Activities Questionnaire, GDS Geriatric Depression Scale, NPI Neuropsychiatric Inventory, PPT Physical Performance Test, QAM Questionnaire d'Autoévaluation de la Mémoire, RAVLT Rey Auditory Verbal Learning Test, RBANS Repeatable Battery for the Assessment of Neuropsychological Status, RBMT Rivermead Behavioral Memory Test, RQCST revised Quick Cognitive Screening Test, TMT(A, B) Trail-Making Test, VSTM visual short-term memory, WMS-III Wechsler Memory Scale, n/a non available

4.4.3.1 CI for Healthy Older Adults

In the ACTIVE study, the largest randomized controlled trial with older adults to date, Ball et al. (2002) evaluated the effect on functional abilities of three types of cognition-focused interventions: (a) memory training, (b) reasoning training, and (c) speed of processing training. A non-contact control group, that did not receive any intervention, was included. The computer-based program was only used for speed processing training whereas memory and reasoning training were delivered through a pen-and-paper activity. Task difficulty on the computerized program was automatically adjusted to the participant's performance. Participants in the three intervention groups showed a significant improved performance in the targeted ability that was maintained up to five years after the end of the intervention. The most significant results were found in the speed of processing-training group. Although there was no evidence of transfer effects at two years, a functional transfer effect was observed at five years follow-up, using a self- reported measure of IADLs (Instrumental Activities of Daily Living) (Willis et al., 2006).

Two randomized studies were carried out with healthy older adults in the context of the IMPACT project (Improvement in Memory with Plasticity-based Adaptive Cognitive Training) (Mahncke et al., 2006; Smith et al., 2009). These studies aimed to evaluate the benefits of a training program using a software application designed to improve the speed and accuracy of auditory information processing. Computerized tasks included exercises of speed of processing, spatial syllable match memory, syllable identification, forward word recognition span, working memory, and narrative Memory. Tasks were tailored to progress in difficulty as user's abilities improved.

In the study by Mahncke et al., (2006), participants were randomized into three groups: (a) treatment group, (b) active control group (watching and listening to educational lectures and other computerized programs), and (c) no-contact control group. In the study by Smith and colleagues (2009), participants were randomized into two groups: (a) treatment group and (b) active control group. Both studies showed a significant improvement in directly trained functions and in non-related standardized neuropsychological measures of memory in the experimental group. A generalization of the benefits to neuropsychological measures of attention and to subjective assessment of own cognitive abilities was also observed for individuals in the treatment group (Smith et al., 2009).

Basak et al., (2008) carried out a randomized study with healthy elderly using a strategy video game. The training program focused on the improvement of executive control capacity. A non-contact control group was included. The video game required frequent priority shifts among task components and provided individualized feedback. Participants in the training group significantly improved their game performance. A transfer of the training effects to non-related standardized neuropsychological measures of executive control functioning was also observed for this group. An interesting finding in this study was the correlation between individual differences in game performance and the performance on some of the executive control tasks. The authors suggested that the improvement in learning a complex primary task, such as this strategy video-game, would yield greater transfer effects.

Other studies have focused on the impact of computerized training of working memory in the healthy elderly. Buschkuehl et al. (2008) conducted a controlled trial with older adults to study the effects of participating in a working memory-training program. Participants in the experimental group took part in 23 sessions of training in three visual working memory tasks and two speeds of processing tasks. The level of difficulty in the training software was automatically adjusted to the participant's performance. Participants in the training group also received feedback after each trial. Older adults in the control group took part in a physical training activity. The experimental group showed a significant improvement in all the trained tasks. Near transfer effects were found in a block-span task that involved a short- term storage process and the visual domain, just as the training tasks. These differences were no longer observed at one-year follow-up.

The updating function, one executive component of working memory, has also been targeted as the principal objective of CI for healthy elderly (Dahlin et al., 2008a). The aim of this study was to evaluate the immediate and transfer effects of updating training in young and old adults. The design included four subgroups: (a) older adults training group, (b) young adults training group, (c) older adults control group, and (d) young adults control group. An updating letter memory task was used as a criterion task and a battery of cognitive test was used to assess the potential transfer effects. Task difficulty was adjusted to performance on the training program. Participants in both experimental groups improved in the updating task after attending 15 training sessions. Intervention effects were maintained up to18 months. No transfer effects to untrained tasks were observed in the older adults group, but in the younger adults group a transfer effect to a similar working memory task (*n*-back task) was found. This finding supported the hypothesis that transfer occurs if training and transfer tasks engage similar cognitive processes and if an overlap in neural circuit activation does exist.

For the same intervention, functional neuroimaging data were obtained before and after the training to examine practice-related neural changes in both age groups (Dahlin et al., 2008b). In the young adults group, fMRI showed pre-training joint activation in fronto-parietal area and in the left striatum for the updating task (letter memory task) and for the near transfer task (*n*-back task). For this group a transfer effect for the *n*-back task was found after the training. In the older adults group, the pretraining fronto-parietal activation was also found but the striatum showed no significant activation. Moreover, no transfer effect was observed in this group. Dahlin et al. (2008b) concluded that age-related changes in striatal function could explain the lack of transfer in the older adults group since striatum appeared to play a critical role in mediating transfer of learning after following updating task training.

Li et al. (2008) tested a computer-based spatial working memory training program with young and older adults to study age differences, immediate and transfer effects and maintenance of training effects. Participants in the training groups received feedback about their performance, but task difficulty was not automatically adjusted to performance. After completing 45 daily sessions of training in two spatial *n*-back tasks, younger and older participants in the experimental groups showed improved performances on the trained tasks, compared to young and older adults in the control groups. Near transfer effects were also found for both training groups for two untrained tasks (spatial *n*-back and numerical *n*–back), but there was no evidence of far transfer in either age group. Training gains were maintained in both groups over 3 months. Li et al. (2008) compared these results to those obtained in the study by Dahlin et al. (2008), and explained that the differences between the two studies concerning the transfer effects with older adults might have been related to the duration and frequency of the training program and to the nature of the working memory task employed.

Two related studies (Bherer et al., 2005; Erickson et al., 2007) investigated the effects of dual task training in healthy young and older adults. Erikson et al. (2007) evaluated behavioral effects and age-related cortical changes of computerized dual-task training. Structural and functional neuroimaging was undertaken before and after the five-session intervention. Participants were randomly assigned to a treatment group or a to a no-contact control group. The computer-based program focused on attention and executive control and provided continuous and adaptive performance feedback. Young and older adults in the training groups showed significant improvement in the practiced dual-tasks. Near transfer effects were found to other untrained dual-task paradigms in both age groups. Neuroimaging data showed a correlation between performance improvement and increased hemispheric asymmetry for both age groups. After the training, the differences between young and older adults, concerning ventral and dorsal prefrontal activation, were reduced. Authors conclude that this data indicates that young and older responded in a comparable way to dual-task training and it provides evidence for brain plasticity in older adults.

In the study by Bherer et al. (2005), training tasks included an auditory and a visual identification task, performed both independently and simultaneously. Both tasks required manual responses and performance feedback was provided all along the sessions. After the training period, younger and older adults showed equivalent improvement in reaction times, although the older adults showed larger improvement in accuracy related to the training. Near transfer effects were observed to other untrained discrimination tasks for participants in the two training groups.

Another randomized controlled trial examined the effects of visual and auditory selective attention training in healthy older adults (Mozolic et al., 2011). The aim of this CI was to improve participant's ability to process relevant information. Participants in the training group trained for eight sessions had the ability to suppress task-irrelevant auditory or visual stimuli in two conditions: (1) cross-modal distraction and (2) within-modality distraction. Task difficulty was adapted to the user's performance and verbal feedback was provided. In the control group, participants had an educational lecture program. Participants in the treatment group showed a significant reduction in interference from cross-modal distractors but not from within-modality distractors during the visual task. Post-training assessment showed near transfer effects in the treatment group to untrained domains such as processing speed and dual-task completion.

Cassavaugh and Kramer (2009) investigated whether computerized cognitive training would yield transfer effects to simulated driving performance in healthy older adults. The program consisted of two driving sessions in a driving simulator (baseline assessment), followed by eight computer-based cognitive training sessions, and two last driving sessions (post-training assessment). The computer-based cognitive training included single and dual tasks of manual control, visual attention and working memory. These tasks were chosen because of their relation to driving skills. The baseline and post-training tasks included car-following, visual memory and monitoring tasks, and their combination in dual-task conditions. Results showed a significant improvement in performances on the trained tasks (single and dual conditions) and in the simulated driving session at post-test.

In the context of the project COGITO, Schmiedek et al. (2010) assessed the effects of following a computerized cognitive training program focused on different cognitive abilities: working memory, perceptual speed and episodic memory. A group of young adults and another of healthy older adults received over a hundred daily 1-hour sessions in which difficulty was adjusted to performance. Two non-contact control groups, including young and older adults respectively were also selected. A number of near and far transfer tasks were used to evaluate the intervention effects on general cognitive abilities. Participants also completed pre and post-training assessment with computerized and paper-and-pencil tasks. Immediate training gains were found in all practiced tasks for both groups except for an episodic memory task. In both age groups significant effects were found in the post training session for individual tests and for cognitive abilities represented as latent factors. This study demonstrated that intensive and long-term cognitive training in healthy older and younger adults leads to positive near and far transfer effects. Moreover, this kind of intervention resulted in a significant improvement of cognitive abilities on a general level.

4.4.3.2 CB-CI for Persons with MCI

Numerous studies have demonstrated the feasibility and the benefits of delivering computer-based cognitive training to patients with MCI. Gunther et al. (2003), have evaluated a computerized cognitive training program with elderly patients with MCI living in nursing homes. The study did not include any control group. The training program consisted of 14 sessions, which included tasks designed to train attention, visual-motor skills, reaction time, vigilance, memory, verbal and general knowledge. An improvement was observed in the majority of the assessed cognitive functions. Improvement on verbal learning ability and resistance to the interference was maintained up to five-months after the training.

The effectiveness of the computer-based “Neuropsychological Training” (NPT) has been evaluated in older adults with MCI in three studies described below. The software includes different kinds of cognitive tasks (memory, attention, language, abstract reasoning and visuo-spatial abilities), and allows to adapt their difficulty, length, and input/output modalities, to the user’s capacities.

Cipriani et al. (2006) evaluated the impact of the NPT software in patients with MCI, AD and Multi-System Atrophy (MSA). The authors did not include a control group. Patients attended a program of four sessions over four weeks. Cognitive, affective, and functional assessments were conducted at the baseline and at the end of the second training program. MCI participants improved their general performance on the NPT software. Compared to AD participants, MCI subjects showed significant improvement in neuropsychological tests measuring working memory and psychomotor learning. For this group a transfer effect was confirmed for behavioral memory.

Rozzini et al. (2007) conducted a one-year longitudinal study to assess the effectiveness of the NPT program in older adults with MCI. Participants were randomized into three groups as follows: (1) treatment with cholinesterase inhibitors (ChEIs) associated with computer program, (2) treatment with ChEIs alone, (3) no treatment control group. Individuals participated in three blocks of training consisting of 20 individual sessions during four weeks, and spaced out by a two-month break. For the participants in the training group, task difficulty and exposure duration was individualized. Results showed that the group treated with NPT and ChEIs resulted in a significant improvement of episodic memory, abstract reasoning and in behavioral disturbances (depression, apathy and anxiety).

Talassi et al. (2007) evaluated the effectiveness of two types of interventions, one of them including the NPT software, among ambulatory patients suffering from MCI and mild AD. Participants in the experimental group used the NPT software for cognitive training whereas participants in the control group received physical rehabilitation. The occupational and behavioral therapy was identical in both interventions. MCI patients in the experimental group showed a significant improvement in constructive apraxia, visuospatial memory, functional and affective status, compared to the control group.

Belleville et al. (2006) evaluated the effects of a multifactorial intervention for older adults with MCI on episodic memory. The 8-session program involved training in attention and episodic memory (computer-based), different mnemonic strategies and their application to daily life, and stress management techniques. A number of homework exercises were formulated to practice the learned strategies in ecological settings. A group of older adults with MCI and another, of healthy elderly, took part in the study. Participants were assigned either to a treatment group or to a waiting-list control group. After the training, MCI participants showed a significant improvement in two of the three primary outcome measures of episodic memory (delayed list recall and face-name association). There was no improvement in attention skills targeted by the computer application. Results suggest that the intervention had a positive impact on the subjective assessment of memory and the feelings of well being in the MCI treatment group.

Barnes et al. (2009) examined in a randomized controlled trial the effects of computer-based speed and accuracy of auditory information training (Posit Science software) in elderly with MCI. Participants in the control group performed three types of computer-based activities: listening to audio books, reading online newspapers and playing a computer game. After six weeks of training with the Posit software, participants in the treatment group did not show any significant improvement in general cognitive function (primary outcome). For the secondary outcomes (specific measures of memory and other cognitive processes) the authors observed a pattern in which effect sizes for verbal learning and memory measures tended to benefit the treatment group, but the differences between the intervention and control groups were not statistically significant. One possible explanation for these results, besides the small size of the sample, was that the activities offered in the control group might have been as stimulating, as those included in the training program.

4.4.3.3 CB-CI for persons with Alzheimer's Disease

Hofmann et al. (2003) carried out a study that investigated the benefits of a computer-based cognitive training program in a group of patients with AD. The authors compared the AD group with a group of patients with a major depressive episode and a healthy control group. The interactive program consisted in a virtual environment simulating a shopping route where the subject had to resolve some social competence tasks and some orientation and memory tasks. At the beginning of each session a three-item shopping list had to be learned and later recalled. A set of multiple-choice questions related to the context or to everyday tasks in the virtual environment had to be answered as well. After twelve training sessions there was no significant improvement in any of the cognitive measures for neither of the groups. Concerning the training variables (mistakes, latency, multiple-choice questions, repeat of instructions), participants in the AD improved their general performances and had their number of mistakes significantly reduced. Nevertheless, they performed significantly worse than the other two groups in all four training variables.

In the study by Cipriani et al. (2006), previously described, the group of ten older adults with AD participating in the CI showed a significant improvement in MMSE (Mini-Mental State Examination) score and on tests of verbal fluency and executive functions. Similarly, participants with AD in the experimental group of the study conducted by Talassi et al. (2007), also cited, have significantly improved global cognitive functioning (MMSE) and a significant reduction of depression and anxiety symptoms.

Galante et al. (2007) conducted a single-blind controlled study with eleven older adults with mild AD and MCI, treated with ChEIs. In the treatment group, older adults participated in twelve individual training sessions with the NPT software, described above. Older adults in the control group participated in semi-structured interviews in which they were interrogated about their current life and relevant past events. Neuropsychological assessment was performed at baseline, at the end of the treatment, and three months after. The MMSE was performed at a 9 months follow-up assessment. Results provided no evidence for any improvement in general cognitive functioning following the treatment. However, MMSE scores remained stable among older adults in the experimental group, while it declined significantly in the control group.

Tarraga et al. (2006) conducted a single-blind randomized study to evaluate an interactive multimedia internet-based system (IMIS) for cognitive training in patients with AD, in addition to ChEI treatment and classic psychostimulation. Participants were assigned to three groups: (1) experimental group, in which participants received the computer-based cognitive training and the integrated psychostimulation program (IPP), (2) IPP control group, in which only the psychostimulation program was offered, and (3) ChEI control group, in which participants continued to receive just the standard ChEI treatment. The IMIS offers the possibility of training different cognitive domains through a set of exercises adjusting automatically their difficulty level. After the 24-week intervention, participants in the experimental group (IMIS, IPP and ChEI), and participants in the IPP control group (IPP and ChEI) showed a significant improvement on the ADAS-cog (Alzheimer's Disease Assessment Scale-Cognitive) and MMSE scores, which was maintained at 24-weeks follow-up. ADAS-Cog and MMSE scores declined in participants in the ChEI control group, as expected. Patients in the IPP control group had better scores than those in the ChEI control group at 12-week assessment but these effects were attenuated after 24 weeks. No functional improvement was observed among the three groups.

A preliminary study was reported by Mate-Kole et al. (2007) on the effects of a combined CI with patients suffering from moderate to severe dementia (AD, vascular and mixed dementia). The combined CI consisted of an interactive cognitive training program delivered in group sessions (Mind Aerobics), and an Adaptive Computerized Cognitive Training (ACCT), delivered in individual sessions. The ACCT offered multiple cognitive training tasks (attention training, visual-spatial and motor skills, problem solving, memory and visual discrimination, etc.). Difficulty level was automatically adjusted. After six weeks of intensive training (between three and four sessions per week), results showed a significant improvement in general cognitive functioning in the whole sample and improvement in ADAS-Cog measures and enhanced visual-motor coordination and speed for some participants. An improvement in functional abilities was also observed, particularly in behavioral changes reported by the caregiver.

4.4.4 Discussion

Training and near transfer effects were observed in most of these studies corroborating that CB-CI have the potential to influence cognitive functioning. These findings confirm that older adult brain exhibits neural plasticity that can be exploited to prevent or improve cognitive functioning (Jessberger and Gage, 2008; Lövdén et al., 2010). Taken together, results are in agreement with epidemiological studies, which have demonstrated that participating in cognitively stimulating activities (education, professional career, social networks and leisure activities) may slow the rate of cognitive decline among the elderly (Fratiglioni et al., 2004; Karp et al., 2009; Katzman et al., 1988; Wilson et al., 2007).

However, far transfer of skills, from the original training paradigm (task and stimuli) to a different one (e.g., everyday functioning), was less frequently observed. In addition, the majority of authors who have studied CB-CI have also pointed out a number of limitations in the existing research. In this section we will discuss the main issues addressed by these studies and present some key considerations for future research.

4.4.4.1 Level of Outcomes Assessed

Effects at the proximal outcome level or training effects

The majority of studies reported an improvement in proximal outcomes targeted by the training in older adults who took part in CB-CI, regardless of their cognitive status. This finding could be partially explained by the fact that a number of tasks used in these interventions involved the processing of perceptual stimuli and basic psychomotor skills, within the framework of a regular practice. These factors are related to skill learning and perceptual priming effects. Skill learning refers to the gradual acquisition of lasting performance improvement on a specific task as a function of repeated practice. Perceptual priming describes performance gains in processing a stimulus that has been previously experienced, even after long time intervals. It benefits also from the number of repetitions (Hauptmann and Karni, 2002). Indeed, skill learning and perceptual priming are both known for being preserved in healthy elderly and in individuals with MCI and early AD (Merbah et al., 2010). At this outcome level CB-CI have proven to influence positively performances on directly trained tasks.

Effects at the primary outcome level or near transfer effects

Implemented alone or combined with other approaches, CB-CI have shown to have beneficial effects on the participant’s performance when transfer assessment tasks tapped similar cognitive processes to those targeted by the training tasks. For instance, Buschkuehl et al., (2008) showed that healthy older adults who followed a working memory-training program improved their performance not only in directly trained tasks (e.g. repeating a sequence of colored squares previously presented) but also in a block-span task that was not included in the original training program. This is considered a near transfer effect because, although different, training and transfer tasks concerned a short- term storage process and the visual domain.

Near transfer effects were also found in studies that used non-specific cognitive training material. For instance, in the study conducted by Basak et al., (2008), healthy older adults who participated in 15 training sessions on a real-time strategy video game improved not only their performances on the game, but also in tasks of executive control that were not explicitly presented in the video game. The study of simulated driving in older adults conducted by Cassavaugh and Kramer (2009) also showed that training in driving related aspects such as manual control, visual attention and working memory resulted in improvements in near tasks involved in simulated driving.

However, near transfer effects were not observed in all studies. Different factors that limited transfer effects, or the possibility of measuring them, were highlighted, including: (a) The high specificity of training strategies (Belleville et al., 2006), (b) Motivational factors (Barnes et al., 2009; Cassavaugh & Kramer, 2009; Hofman et al., 2003; Li et al., 2008), (c) Using a small sample size (Barnes et al., 2009; Belleville et al., 2006; Buschkuehl et al., 2008; Cipriani et al., 2006; Galante et al., 2007; Hofman et al., 2003; Mate-Kole et al., 2007), (d) The lack of a control group (Cassavaugh & Kramer, 2009; Cipriani et al., 2006; Gunther et al., 2003; Mate-Kole et al., 2007) or the comparison with an active control group that provides a high cognitive stimulating activity (Barnes et al., 2009; Galante et al., 2007; Li et al., 2008; Sitzer et al., 2006; Tarraga et al., 2006).

Effects at the secondary outcome level or far transfer effects

Finally, only a few authors showed that the intervention had an effect on *secondary outcomes* or far transfer effects. This aspect was evaluated taking into account practice-related improvement in general cognitive abilities, functional capacities, behavioral disturbances, or self-perception of cognitive capabilities. Overall results suggested that CB-CI that involve multiple cognitive domains, more complex and meaningful tasks, longer periods of training, and booster sessions had more possibilities of leading to positive far transfer effects. On the contrary cognitive skills trained in an isolated manner frequently failed to transfer to general cognitive abilities or functional application contexts.

Two methods were used for the assessment of far transfer effects in general cognitive abilities: (a) Neuropsychological screening using test batteries for general cognitive functioning such as the MMSE, or the ADAS-Cog when individuals with cognitive impairment were concerned. (2) The evaluation of intervention-related changes at the ability level and not only at the task level (Schmiedek et al., 2010). This was done by choosing training tasks that represent the targeted ability, at a latent level, and then by conducting a statistical factor analysis focusing on the common variance resulting from the chosen tasks.

Transfer effects on functional capacities were evaluated to a lesser extent using mostly self-assessment instruments (Ball et al., 2002; Belleville et al, 2006; Willis et al., 2006) or caregivers reports (Mate-Kole et al., 2007). The limited transfer effects observed to functional capacity resulted in the first place from the selection of highly domain-specific training and transfer tasks. Actually, most of the tasks included in these studies were very similar those employed in neuropsychological batteries (Green et Bavelier, 2008), in this sense, the majority of CB-CI that were reviewed engaged cognitive process in a rather isolated and unnatural manner (Acevedo & Loewenstein, 2007; Lustig et al., 2009, Mate-Kole et al., 2007). The fact that only a few studies used performance measures of everyday activities as outcome criteria, such as the one targeting simulated driving (Cassavaugh & Kramer, 2009), illustrates well this point.

4.4.4.2 Specificities of CB-CI

The use of computer systems has given a new dimension to CI by multiplying the possibilities offered by traditional methods. For instance, CB-CI facilitate customized training by automatically adjusting the difficulty level and by providing performance feedback. Both factors are strongly associated with larger training and transfer effects (Green and Bavelier, 2006). Automatic adjustment of difficulty level is important in order to select tasks that remain challenging and motivating after several practice sessions (Li et al., 2008; Schmiedek et al., 2010). Performance feedback is also considered an important factor in learning, although further research should clarify its impact on older adults performance (Green and Bavelier, 2006; Beckmann et al., 2009). Finally, in terms of performance measures, CB- CI ensure precise and rapid data processing.

Because of their flexibility in terms of geographic location and scheduling, CB- CI can reach larger audiences than traditional methods. In a clinical context, CB-CI can be part of a “home treatment” of older adults with cognitive impairment. Furthermore, they are a cost-effective solution to deliver CI to older adults. These programs can be accessed via the Internet through various electronic devices including computers, videogame consoles, cell phones or tablets.

Another particularity of CB-CI is the aesthetic component. In fact, videogames and novel software applications include advanced graphics and sound features that enable programmers to create interactive environments with a high level of realism. Via these tools, older adults could benefit from more ecological CI in a pleasant and engaging way. Recently, gaming technology has introduced user interfaces that make possible new forms of interaction without using a button or a controller (e.g., Sony Eye Toy, Nintendo Wii, Microsoft Kinect) (Skip et al., 2011). This is the case of *exergames* that combine game play and physical exercise using motion tracking. These tools are increasingly used in senior centers and retirement communities to improve depressive symptoms and quality of life among residents (Rosenberg et al., 2010). Thus, we should expect that future gaming technologies, developed in the framework of cognitive aging research, will have the potential to influence not only cognitive and functional capacities but also psychological well-being and quality of life in older adults.

4.4.4.3 Some Limitations and Future Directions

In the present review, the wide variability observed among studies concerning the frequency and duration of the training, targeted cognitive processes, control group condition, outcome measures, inclusion of boosters sessions, and setting conditions (e.g., home, laboratory) precluded statistical comparisons between studies. Hence, it seems necessary to conduct extensive research to determine more precisely how these factors contribute to the success of CB-CI.

The influence of individual differences (e.g., initial level of performance on cognitive measures, computer use, and socioeconomic and psychosocial factors) should also be addressed in order to know who benefits better from these treatments. Another factor that necessitates further examination is how the level of investment of participants, their expectations, and other motivational factors, modulate the effects of cognitive interventions. This point is critical because effective interventions are useless unless older people are willing to engage in them (Boot et al., 2012). Unfortunately, these variables have been overlooked, not clearly defined, or simply not addressed in most of the works conducted in this field. It is possible to conclude in this respect that research in this area has focused too much on the effectiveness of CB-CI, leaving some important questions unanswered, for instance, studying the attitudes and level of acceptance towards CB-CI among older adults.

Besides, considering that in the next few years CI could be provided as home treatment, studies must be conducted beyond the laboratory setting, in real-life conditions. Evaluating the level of adherence to this kind of intervention should be a priority research objective in this field. If far transfer effects from an intervention depend on extensive practice and increased intensity of cognitive engagement, a valid question for further reflection in this field might be: *How willing are people to be 'in training' indefinitely?* (Zelinski, 2012).

With regard to the software applications used in the studies presented in this review, we observed that despite the wide range of technological possibilities that exist nowadays only a small number of CI took advantage of them. A single study used a commercial videogame (Basak et al., 2008) and just two other studies used software including content related to real-life activities (Cassavaugh & Kramer, 2009; Hofmann et al., 2003). In that sense, we should expect in the next few years that CB-CI make a better use of the existing gaming and virtual and reality technologies for designing vivid environments with more ecological content. Indeed, there exists a strong argument for designing cognitive training tasks as natural as possible and for focusing on the users' areas of interest (i.e., personalized content) in order to improve motivation and compliance. With respect to this last point, training tasks should be integrated in a program that offers content related to daily life activities, such as cooking, shopping or managing household finances, to improve the possibilities of far transfer effects and the motivation of the participants

Surprisingly, only a few studies examined usability issues concerning the use of computer applications by older adults. One of them was the IMPACT study (Mahncke et al., 2006; Smith et al., 2009) in which research assistants installed the computer at participants' home, providing them with personalized training on the use of the computer system before starting the cognitive training program. Considering that older adults are, in general, less familiar and experienced with ICT, the pertinence of investigating usability requirements and training procedures aiming to introduce computer-based applications and Web browsing to inexperienced users, must be emphasized.

4.4.5 Conclusions

The object of this review was to summarize the main studies conducted in the past decade in the field CB- CI for older adults with different cognitive profiles. These interventions have proven to positively influence a range of cognitive skills, and in some cases, functional abilities and psychological health. However, ecological validity and other methodological issues should be addressed in future studies for research and clinical practice. Results confirmed the importance of focusing on training tasks that represent cognitive abilities involved in everyday functioning and on reliable assessment methods. In regard to this matter, neuroimaging techniques constitute a valuable resource to support understanding of neurophysiologic mechanisms underlying CI and to guide their design Computer applications offer a potentially cost-effective and flexible method for widespread application of CI. Still, forthcoming research should take a larger advantage of computer applications currently available. Finally, attention must be paid to user-system interactions if the aim is to create in-home technologies that will be perceived by older adults as easy-to-use, utile and enjoyable.

4.4.6 References

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4.5 Ethical Issues at Stake in the Design and Use of Assistive Technology for Older Adults with Cognitive Impairment

4.5.1 Introduction

Although the use of technologies for providing care and support to older adults is a relatively recent practice, it is rapidly growing. The primary goal of assistive technology (AT), telemedicine, and in situ monitoring technologies is to promote aging in place and independent living (Brittain, Corner, Robinson, & Bond, 2010; Charness, Demiris, & Krupinski, 2011; Kang et al., 2010). The interest given to these technological applications can also be explained in terms of the improvement of the quality of care, the reduction of healthcare costs, their possibilities of use in institutional and domestic settings, the improvement of caregiver burden, and their contribution to the understanding of aging and age-related conditions (Beech & Roberts, 2008). Healthcare technologies are particularly used in geriatric settings to meet the needs of people with chronic illness (Botsis & Hartvigsen, 2008; May, Finch, Mair, & Mort, 2005; Nugent, 2007), and with cognitive impairment, such as mild cognitive impairment (MCI), Alzheimer's disease (AD) or other forms of dementia (Carrillo, Dishman, & Plowman, 2009; Dishman & Carrillo, 2007; Lauriks et al., 2007).

People with dementia may benefit from AT[21] products and services if these are designed to meet their needs and capacities and respect their preferences and values (Spector & Orrell, 2010; Hoe & Thompson, 2010; MacDonald, Grand, & Caspar, 2011). User-Centered Design (UCD) methodologies, which place user's needs and requirements at the center of the design process, might be adopted to respond to these aims and objectives. Indeed, an increasing number of studies on AT for older adults and dementia care have opted for these design strategies and there is general agreement about their advantages (Davies et al., 2009; de Joode, van Heugten, Verhey, & van Boxtel, 2010; Galbraith, Mulvenna, Martin, & McGloin, 2008; Pino et al., 2012).

From a more general perspective, UCD methods have received increased attention in recent years from companies, public organizations, and all the partners involved in the design

[21] Throughout this chapter the term AT will be used to refer to the wide range of technology-based products and services, including low-level to high-tech assistive devices, internet-based technologies, and telehealth applications, that can be employed for health and social care purposes.

of ICT products and services. In addition, the *living lab* approach has emerged with the aim of reuniting end-users and different stakeholders to discuss needs and priorities and conceive innovative solutions in a co-creation process that takes place in real life settings. One of the areas of research in which living labs are increasingly used is the development of technological applications for healthcare and social participation that target older adults (e.g., MIT Age Lab, Healthy Aging and Independent Living Lab, from the Mayo Clinic).

However, as with any decision regarding the care of persons with AD the use of AT in this context raises several ethical and societal questions that should be considered throughout the entire design and development process and in all stages of their implementation (Alzheimer Europe, 2010; Baldwin, 2005; Bjorneby, Topo & Holthe, 1999; Brittain, Corner, Robinson, & Bond, 2010; McCreadie & Tinker, 2005).

In this chapter we will present some of the main ethical issues that have been identified in these contexts. This analysis is based on the projects conducted at the laboratory LUSAGE; a recently created living lab specialized in the design and assessment of technology-based solutions for older adults with cognitive impairment (Pino et al., 2012). First, we describe the main characteristics of the living lab approach and explain why such methodology promotes the assessment of ethical issues. Then we review some of the ethical principles that may be considered in the design process of AT products and services and in their implementation.

4.5.2 How does the living lab promotes ethical analysis in the process of design and development of AT?

Advances in Information and Communication Technology have allowed users to be better informed about their health choices giving them a more active role in the decision-making process concerning prevention strategies, medical treatments, and psychosocial support. As a consequence, AT designers have changed their focus from an approach that mainly addressed healthcare providers' needs and requirements to patient-centered applications (Demiris et al., 2007). This new approach encompasses diverse *User-Centered Design* methods that emphasize placing the user at the center of the design process with the purpose of creating usable, acceptable, and effective products and services (Rubin & Chisnell, 2008).

Living labs have emerged with the aim of creating real partnerships between users and all the stakeholders concerned by the development of technological solutions. The living lab concept is a complex one, because it can refer at the same time to an environment, a methodology, and a system, as has been pointed out by Bergvall-Kareborn, Hoist & Stahlbrost (2009). Each of these perspectives allows the consideration of different issues, for example, the constitution of technological platforms and user communities (environment), the application of user-centered practices (methodology), and the relationships between the partners involved and the living lab, a system that works as a whole (system). McPhee, Westerlund & Leminінen (2012, p.3) provided the following definition of living labs:

> *"Physical regions or virtual realities, or interaction spaces, in which stakeholders form public-private-people partnerships (4Ps) of companies, public agencies, universities, users, and other stakeholders, all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts"*

The success of the process of design and implementation of AT for older adults with cognitive impairment depends to a great extent on the involvement of primary end-users into the project (Alm & Newell, 2008; Hawkey et al., 2005; Newell et al., 2011). Consequently, the focus that living labs make on co-creation seems appropriate for these kinds of projects (Schumacher & Feurstein, 2007; Kusiak, 2007).

The living lab promotes the respect of the user's autonomy, the evaluation of technologies according to principle of beneficence and non-maleficence, the application of accessibility criteria to the design, and the identification of risks related to the implementation of a new product or service. Thus, ethical analysis is conducted throughout the different phases of product design including: user profile definition, assessment of users' needs and requirements, evaluation of technology acceptance, usability inspection, and final product assessment (Rubin & Chisnell, 2008). Within a living lab perspective, the identification of ethical issues is a transversal process (Figure 58). Several techniques may be used for this task, such as guideline reviews, focus groups, interviews, questionnaires and direct observations.

The living lab, as an environment, provides an ecological setting for the observation and analysis of user's behavior in a secure and non-intrusive way. The assessment of early versions of the prototypes usually takes place under controlled and safe conditions, while advanced prototypes can be tested in real conditions (e.g., hospital, day care center, home, public space). Finally, three principal features of the living lab approach encourage the consideration of ethical issues in the design practice: openness, cooperation for the development of innovative work of the highest quality, and multidisciplinarity.

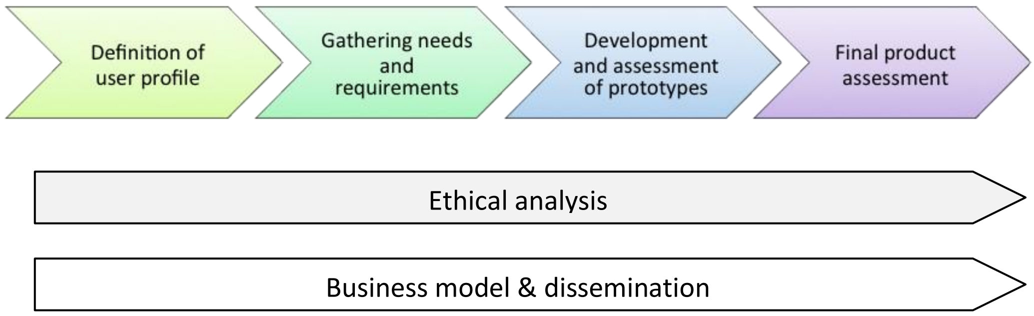

Figure 58 Phases of product design lifecycle in a living lab

4.5.3 Ethical Principles and the Design and use of AT in AD

This section presents the main ethical issues raised by the design and use of AT for health and social care in AD. This analysis is based on the four ethical principles proposed by Beauchamp and Childress (2001) in the field of biomedical ethics: autonomy, beneficence, non-maleficence, and justice. The recommendations resulting from the evaluation of care practices in AD provided by different organizations were also used for this reflection (Alzheimer Europe, 2010; WHO 2012).

4.5.3.1 The Principle of Autonomy

As far as persons with cognitive impairment are concerned, the question of autonomy, which is the ability to act according to one's beliefs and personal choices, is a major issue. On the one hand, persons with cognitive impairment have a diminished capacity for judgment, affecting their ability to make informed choices. On the other hand, the presence of cognitive impairment should not justify the presumption that the person is not capable of any decision regarding his/her life choices (Mozley et al, 1999). Indeed, for people who have become dependent, autonomy can be expressed through attempts to adapt to new conditions of life, for example the introduction of new AT (Alzheimer Europe, 2010).

Meeting the Needs and Expectations of the User

When designing or prescribing an AT solution, one common mistake is to rely exclusively on the advice of a third party (relative or professional) to define the needs of the end-user (McCreadie & Tinker, 2005). Following only such an external indication may jeopardize the user's autonomy and freedom of action. Evaluating the end-user's needs and expectations is crucial throughout the whole design and development process because needs and expectations might evolve over time. Once the AT solution has been implemented it is necessary to assess its effects on the life of the person. This assessment should cover usability, acceptability, usefulness, and the degree to which the solution has met the needs of the person.

In the Lusage laboratory, we have carried out different focus groups to explore the needs and expectations of end-users regarding new technologies and have often found a difference of opinion between caregivers and persons with AD. For example, a caregiver may find reassuring the use of a robot at the care recipient's home because it will allow him/her to *"monitor the person, see if he/she feels well, and react if something happened to him/her"*. In contrast, the person with cognitive impairment can express his reluctance: *"Right now I do not feel concerned by this type of assistance, maybe later when I get older or sicker".* In this context, the acknowledgment that the person makes of his own needs is a prerequisite to the appropriation of these tools (McCreadi, Tinker, 2005). Therefore, a fundamental step in the design and prescription of technology is to collect the 'felt' needs and expectations of potential users.

Respect for the Choice of the Person with AD

Autonomy is also linked with the capacity to give informed consent. The freedom of the person with AD either to participate in a research experience within the framework of a living lab project, or to accept or refuse the use of the proposed device must be respected. In this context, the issue of informed consent is a central point, especially when the severity of cognitive impairment is likely to affect the judgment of individuals with dementia.

Although involving a third party in decision-making concerning the participation of persons with dementia in AT design projects is needed in some cases, the project team should present the information related to the design project in an appropriate manner and involve these individuals in decision-making. When prescribing an AT solution physicians should make sure as well to present information to the person with dementia regarding his/her treatment in an appropriate manner and involve him/her in decision-making. It is also essential to be able to regularly collect the person's consent, as it may change over time. Accordingly, the use of technology must be stopped if required by the person.

Balancing Autonomy and Beneficence

Despite the benefits of technology in supporting persons with AD, some authors have noted the possible restriction of autonomy related to their use (Landau & Werner, 2012; Niemeijer et al., 2010). For example, geolocalization systems can be viewed by some persons as a reassuring aid, and by others as an obstacle to freedom. For the latter, the so-called supporting tool may become an instrument of restraint that would meet the needs of control and security of caregivers rather than their own needs. A detailed analysis of advantages and disadvantages of the intervention that takes into account the opinions of the patient is therefore essential when prescribing AT.

4.5.3.2 The Protection of Dignity

A fear commonly expressed in focus groups by potential users is that AT (e.g., assistive robots) acts in place of the person and thus might deprive the person of his/her remaining autonomy. Valkila et al. (2010) have explained that for older adults accepting to use supporting services can be experienced as a crisis because it is associated to the loss of autonomy. One proposed solution is to allow users to actively participate in the implementation of the technological devices in order to provide assistance only for the tasks for which external assistance is mandatory. If the person is confident that he/she can control the system, he/she will have the feeling that the technology improves his/her self –esteem and positively impacts his/her dignity.

The representations of technological devices in older adults should also be considered. Sometimes the solutions provided can be perceived as stigmatizing and infantilizing and so have a negative impact on the person’s dignity. This pertains to both, the appearance of the product and its modes of interaction. It is therefore important to consider these representations in order to set up uses, technical devices, and functionalities that might contribute to build a positive image of the person.

4.5.3.3 The Respect of Personal Privacy

The adoption of AT also raises the issue of privacy. Indeed, most medical remote monitoring systems automatically record users’ activity or physiological parameters. This is beneficial since it can quickly provide reliable data to health professionals who can assess changes in users’ health status and act in emergency situations. However, a user’s right to privacy could be violated if the procedures for processing such data were not clearly defined upstream or if details about their use were not clearly given to the person. The automatic collection of information (presence or activity sensors) can also become a problem if the usual end-user interacts with other individuals whose activity is recorded at the same time and whose consent has not been previously obtained. The treatment of sensitive data must obviously respect the laws concerning the protection of persons. A reflection on the potential ethical dilemmas that can result from medical informatics (treatment, storage and data communication) should therefore be conducted prior to the implementation of these systems.

4.5.3.4 The Principle of Beneficence and Non-Maleficence

The principles of beneficence and non-maleficence respectively refer to the need to act for the welfare of others and not to harm as a result of an intervention. The use of AT has many benefits for persons with AD but might potentially be harmful in some circumstances.

The advantages of technologies are mainly due to their flexibility in terms of accessibility, location, and media (computer, consoles, mobile phones, etc.). These methods also allow precise targeting of the caring goals and appropriate monitoring of the patient's follow-up. Moreover, the implementation of these devices in the ecologic environment of a person with AD can prolong his/her ability to live at home and reduce the burden on formal and informal caregivers.

Nevertheless, as noted earlier, an evaluation of the medical or medico-social benefits of most of these technologies is still needed. Indeed, after the first phase of technology evaluation performed in research laboratories, it is now mandatory to evaluate the benefit of these technologies in ecological conditions at home in randomized controlled trials. To avoid potential conflicts of interest, these evaluations will require the involvement of independent "verification" agencies operating on the model of medical device evaluation with the introduction of quality insurance processes and vigilance.

Assessing Potential Risks and Benefits

When a professional caregiver prescribes an AT solution to a person with AD, he/she must encourage decisions that will promote the person's well-being and comfort. However, determining what is good for a person with dementia is not an easy task. For example, technical assistance may be beneficial from a medical point of view but have negative consequences on other aspects. In other cases, despite the discomfort that the use of technology can cause, the failure to use it could jeopardize the person's safety. For this reason the potential benefit of a technology must be balanced against the risk incurred by its use.

However, it is important to note that the majority of AT services and applications provided are currently still in development. Therefore, the scientific literature in this field mainly concerns the assessment of laboratory prototypes or exploratory studies involving a small number of subjects and few authors so far have assessed the medical benefit provided by these technologies.

4.5.3.5 The Principle of Justice

In the field of healthcare the principle of justice refers to the recognition and respect of fundamental human rights, including equal access to resources and care for all members of society. The principle of justice should also be taken into account in the policies, plans and laws that govern access to assistive technology for individuals suffering from AD. At the individual level, this principle implies equal access to information about services and opportunities of accompanying technologies available and a provision of ergonomically tailored products.

Towards Accessible Technology

One of the factors that affect the acceptability of technologies by older adults is usability. This criterion refers to the conditions necessary to develop technologies associated with an effective, easy and satisfactory use. According to several studies in the literature, and our experience in the laboratory LUSAGE, older adults with cognitive impairment are able to learn to use new technologies and enjoy them as long as they provide clear benefits and display ergonomics tailored to their needs. It is important, therefore, that the choices made in the design of these technologies do not make demands of users that exceed their abilities. For the development of AT devices, we use, a co-creation approach that consists in an active collaboration between users (persons with AD, caregivers), engineers and designers. The process of successive iterations facilitates the development of interfaces and content tailored to users' abilities.

The Criterion of Equity in the Access to Technologies

The test of fairness implies equal access to support services for persons with AD and their families, in terms of availability, cost and monitoring. The increasing use of technology could promote a wide dissemination of these interventions, which were only available for a minority in the past. For instance, regarding psycho-educational programs for caregivers, traditional approaches used to be constrained by the availability of such training in the local environment, the need to go to the location of the intervention or to comply with fixed schedules, which is especially difficult for people who must take almost constant care of someone with AD. The use of the Internet to disseminate these programs will minimize these difficulties and ensure more equal access to interventions. However, although Internet use has increased among seniors, it is still limited compared to other age groups. In France, currently only 16.9% of people aged over 75 and 40% of people aged 55-64 have a computer at home. Furthermore, only 18% of people over 65 say they use the Internet (CAS, 2011). Consequently, there's a reflection to be conducted on ways to improve the engagement of older people into digital technologies.

Distributive justice also relates to the financing of these services. Currently the development and use of AT products for these users is not a widespread practice, which keeps their costs are relatively high. Therefore, persons with AD with limited resources may not be able to benefit from these offers. In the long run, the issue of funding for these technologies, a factor that ensures fairness, depends on their large-scale industrialization and the existence of a regulatory framework for support schemes and group insurance for health and autonomy.

4.5.4 Conclusion

AD care is a domain in which the incorporation of AT has the potential to provide a real benefit for older adults with AD and their caregivers. Living lab methodologies promote the ethical analysis as a transversal process in the design and development of products and services. Once AT products are released the choice of using them requires careful consideration of ethical aspects related to their use. However, decision process is not an easy task especially when the therapeutic goals of an intervention for the person with dementia are opposed to the principles of autonomy or dignity. In this context, the ethical principles should be interpreted with flexibility, depending on the person and context. In addition, training regarding ethical decision-making should be an essential element of capacity building for the professionals involved in the provision of care, including policy makers, professionals and families.

An AT product should not be understood just as a technical tool since its use will have repercussions on many levels (individual, social, economic, political) and actors (patient, environment, professionals, community). On the side of users, the attitudes and opinions towards these systems are conditioned by their representations and the self-image induced by their use. These opinions must be heard and respected. The widespread use of new technologies for monitoring health, promoting autonomy and social participation will also depend on the availability of these tools and the conception of training strategies to allow prospective users to get familiar with them.

5 GENERAL DISCUSSION

In this section we summarize the main findings and limitations of the studies conducted within this thesis and suggest a set of recommendations to address the theoretical and methodological challenges identified throughout this work. Special considerations for involving older adults with cognitive impairment in HF/E research are emphasized. Then, the topic of AT modeling systems is addressed followed by the proposition of an extension of the Comprehensive Assistive Technology (CAT) model, originally formulated by Hersh & Johnson (2008), for its use in the context of dementia care. Finally, a short discussion of the relationship between the models of disability, dementia care, AT, and the choice of design approach is given.

5.1 Summary of Findings and Limitations

The studies included in the present work have illustrated the different stages of the cycle of design and development of AT (Figure 59). Each study has provided new theoretical and methodological insights for specific areas of AT design for older adults with cognitive impairment, such as social assistive robots, software applications for cognitive training, and online support services for older adults (Table 51).

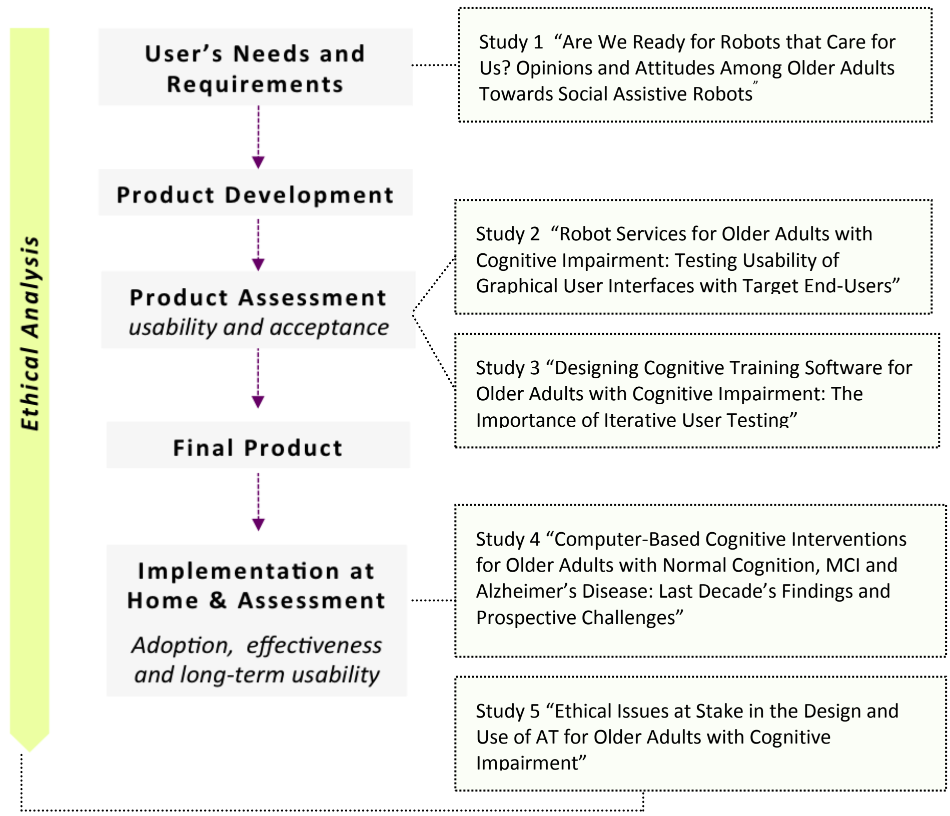

Figure 59 Studies conducted in this thesis and relevant AT design and development phase

Table 51 Summary of findings, limitations, and methodological implications from reported studies

Study	Design phase & study description	Main findings	Limitations	Methodological implications
1	*Gathering user needs and requirements* Exploration of the attitudes and opinions of older adults (individuals with MCI, caregivers of persons with AD, healthy older adults) towards social assistive robots (SAR) and the influence of individual factors on the definition of potential-users' profile	- Older adults acknowledge the potential benefits of SAR for supporting everyday functioning, safety at home, and social participation - Needs, opinions, and perceived usefulness of SAR appeared to be dependent on individual and group factors (patients with MCI, AD caregivers, healthy older adults) - Participants agreed that personalization of SAR is required to meet their particular needs - There was a significant difference between current and future acceptance in all groups	- Small sample size (*N* = 25) - A group of people with dementia was not included - No direct interaction with the robot was proposed - Changes in attitudes towards SAR over time were not studied	- Importance of the assessment of individual and contextual factors in user profile definition for the design of tailored SAR solutions - Importance of the identification of subjective representations of people as AT prospective users - Examining caregiver and care recipient needs and attitudes towards AT seems fundamental for providing solutions tailored to each specific situation - Needs, requirements, and technology acceptance assessment over time is suggested
2	*Product assessment* Usability testing of two software applications (agenda and online grocery shopping list) for an assistive robot intended for older adults with cognitive impairment	- A number of usability problems in the interfaces were discovered allowing the definition of a set of recommendations for design improvement - It was confirmed that cognitive status, age, and technology experience had an influence on technology use - Users with little technology experience and/or cognitive impairment need environmental support to reduce cognitive workload when using software applications	- Small sample size (*N* = 22) - No repeated usability assessments were conducted, therefore usability over time was not studied - No alternative designs were assessed - Acceptance issues were not addressed - Factor analysis could not be performed to determine the weight of cognitive status, age, or computer experience on task performance	- Design guidelines and scientific data on cognitive aging are useful for the development of AT solutions but considering individual and contextual factors in usability testing is equally important - Usability assessment of AT applications over time is suggested - AT design should consider training needs - Involving caregivers in usability testing is recommended when persons with cognitive impairment require supervision to use AT devices
3	*Iterative product development and assessment* Design and usability testing of two versions of PRIMO, a software application for cognitive training for older adults with	- A number of usability problems in the interfaces were discovered allowing the definition of a set of recommendations for design improvement - Persons with AD experienced several difficulties using the	- Small sample size (*N* = 26) - No alternative GUI designs were presented - Factor analysis could not be performed to determine the	- Iterative design has proven effective to develop usable AT applications - Design guidelines and scientific data on cognitive aging are useful for the development of AT solutions but considering

Study	Design phase & study description	Main findings	Limitations	Methodological implications
	cognitive impairment	software autonomously, however, task performance improved in this group across the sessions - It was confirmed that cognitive status, age, and technology experience had an influence on technology use - Users with little technology experience and/or cognitive impairment need environmental support to reduce cognitive workload when using software applications	weight of cognitive status, age, or computer experience on task performance - Acceptance issues were not addressed in the second usability study	individual and contextual factors in usability testing is equally important - Usability assessment of AT applications across different sessions has proven useful to understand technology use over time - AT design should consider training needs - Involving caregivers in usability testing is recommended when persons with cognitive impairment require supervision to use AT devices
4	*Final product assessment* Literature review on the effectiveness of computer-based cognitive interventions for older adults (healthy elderly individuals, persons with MCI, persons with AD)	- Positive training and near transfer effects were found in most of these studies confirming that computer-based interventions have the potential of improving cognitive functioning - Only a few studies examined and reported far transfer of cognitive training to everyday functioning and quality of life	- Differences in experimental methodology preclude direct comparison of current studies - Most of the studies were conducted in laboratory settings, thus, little is known about long-term adherence to cognitive training programs - Most of the studies reviewed did not examine usability or acceptance issues	- Importance of considering individual and contextual factors in the assessment of cognitive training effects - One of the challenges in this field is the design of cognitive training programs with contents related to everyday life
5	*Ethical analysis process* Analysis of ethical issues related to the design and use of assistive technology for older adults with cognitive impairment and the advantages of living lab methodologies in this context	- Ethical issues raised by the design process, provision, and usage of AT applications for older adults with cognitive impairment were identified concerning the respect of autonomy, dignity, personal privacy, the principle of beneficence and non-maleficence, and justice - Main advantages of the use of living lab methodologies for the design and assessment of AT applications were pointed out	- No systematic procedure was used for the examination of ethical issues in the field - Only main ethical issues were addressed by the analysis	- A solid methodology is required in this field to identify ethical issues at stake in the design and use of AT and to inform decision making - Ethical analysis should be conducted iteratively over time

Overall results from these studies have allowed us to confirm that classical methods of HF/E provide a good basis for structuring the design process of AT for older adults with AD. Nevertheless, some adjustments are required to properly design effective and acceptable assistive products in this context, and more particularly, to address the specificities of the AD situation (e.g., role of individual and contextual factors, the caregiving situation, intra-individual changes, training needs).

Also, it is worth noting that some limitations encountered in these studies resulted from the fragmentation of the design process into different phases rather than viewing it as a continuum. For example, in the two usability studies the use of a systematic procedure to collect and analyze task performance data allowed the identification of usability flaws and accessibility barriers in the interface; these findings were used to provide a list of design recommendations. However, the analysis did not go any further and other issues, such as technology acceptance and intention of use, were not addressed. The study on the opinions and attitudes of older adults towards SAR allowed us to examine how individual and group factors influenced the acceptance and expectations that participants had of these systems. But again, a very specific level of analysis was used, and we did not explore how users' opinions could change over time, after having direct interactions with robots. Finally, the literature review on computer-based cognitive interventions for older adults provides another example of this "high specificity" problem because the studies reviewed focused primarily on the effectiveness of computerized cognitive training programs but most of them did not address usability, acceptance, or compliance issues.

Each phase of the design process has its own objectives (e.g., requirements gathering, usability testing, incremental development, clinical assessment), and although the benefits of user-centered practices and iterative procedures are increasingly recognized in AT design, attention must be paid to the tendency to over-fragment the design process or to stay at a very broad level. The studies conducted in this thesis were part of bigger collaborative projects in which design tasks were planned in a sequential manner. This factor explains why we have investigated different user-research aspects in a rather isolated way.

Findings and limitations encountered in these studies motivated us to investigate more precisely how AT design differs from traditional product design, and then, to examine the potential use of AT models in the context of dementia. Taking into account the aforementioned factors two points that emerged from this thesis are discussed in the following sections:

(1) How to develop innovative and ethical strategies for successfully involving individuals with dementia, and their caregivers, throughout the different stages of the design process of AT solutions?

(2) How the use of AT models could contribute to the design, provision, and use of AT solutions for AD care by taking into account the most important features of the dementia situation (e.g., progression over time, fluctuating symptoms, caregiver roles)?

5.2 Involving Older Adults with Cognitive Impairment in User Research

With the growing interest in the use of technology to support older adults with cognitive impairment, the question of how to involve these users in HF/E research has received increased attention (Alm & Newell, 2008; Astell, Alm, Gowans, Ellis, Dye, & Vaughan, 2008; Newell et al., 2011; Charness & Holley, 2001; Hawkey, Inkpen, Rockwood, McAllister, & Slonim, 2005; Eisma et al., 2004; Robinson, Brittain, Lindsay, Jackson, & Olivier, 2009; Savitch, Zaphiris, Smith, Litherland, Aggarwal, & Potier, 2006). In general, the studies carried out within this thesis agree with works conducted in this area on three key issues:

(a) In order to develop usable, useful, and acceptable AT products and services for people with cognitive impairment (MCI, AD), and their caregivers, scientific data is a good starting point, but not where design documentation should end. Users must participate actively in the design process.

Although guidelines and user modeling have proven to be useful methods when designing for people with no disabilities, it is more difficult to define a single user profile characterizing elderly people with cognitive impairment (LoPresti et al., 2008). Indeed, there is a wide inter- and intra-variability among individuals with disabilities concerning physical, cognitive and sensory capacities (Newell et al., 2011); fluctuating symptoms observed in patients with dementia is a good illustration of intra-variability (Bradshaw, 2004). Also, an important heterogeneity is observed among people with dementia with respect to their needs, wants, and contextual factors (e.g., housing, social network, caregiving situation).

Thus, on the one hand it is recommended to use the existing data from the scientific literature on age-related changes in cognitive and physical capabilities to define general specifications of AT devices, user interfaces, and training programs for these users (Fisk et al., 2009; Pak & McLaughlin, 2011). On the other hand, the successful design of assistive products requires an understanding of these users' needs in a given context, for which direct observation and interaction are the best methods (Rogers & Fisk, 2010). This explains the importance of including an end-user group, not only in the user-testing phase, but also at each stage of the product design lifecycle, from planning to data collection and analysis.

(b) Involving people with dementia in HF/E research can be challenging for several reasons; however, when the collaboration between these users and design teams is done ethically it benefits both of them.

Different challenging issues related to the participation of people with dementia in the design of AT have been identified. Some of them concern the recruitment of participants. For instance, Newell et al. (2011) emphasized the difficulty of finding and recruiting a "truly representative user group" of individuals with disabilities. In fact, many elderly individuals with cognitive impairment have a relatively isolated life and remain at home most of the time. This makes recruitment a lengthy and laborious endeavor (Eisma et al., 2004). Moreover, "representative" implies homogeneity, whereas in reality characteristics and functionality vary widely in these populations. Some ethical issues can arise as well in the recruitment phase, for instance, the difficulty to obtain informed consent from some users and legal competence status (Gregor et al., 2002; Newell, Carmichael, Gregor, Alm, & Waller, 2009). Hawkey et al. (2005) also observed that some formal and informal caregivers who refuse the participation of the person with AD in a HF/E research project had the perception that the experience could be overwhelming or traumatic for the person with AD.

Other challenging issues associated with the involvement of users with dementia in the development of AT solutions include: the restrictions imposed on designers by clinical staff to work directly with people with dementia (Newell et al., 2011), communication difficulties with users who may not be able to articulate their opinions (Newell et al., 2009), and the presence of cognitive and physical limitations that affect the accuracy of self-reported evaluations and the length of attention span, making it necessary to considerably reduce the duration of working sessions (Eisma et al., 2004).

However, when appropriate logistics are provided (i.e., suitable physical and ethical conditions), people with mild to moderate dementia have proven to be capable of providing valuable feedback in HF/E projects (Alm & Newell, 2008; Hawkey et al., 2005; Robinson et al., 2006). Eisma et al. (2004) have found as well that involving these users in the design process can have a positive effect for their self-esteem when their opinions are listened to and considered. These authors have also reported that people with dementia perceived their involvement in an AT design project as an opportunity to interact with other people and learn about new topics.

(c) Traditional methods of HF/E must be adapted and modified in order to constitute an effective methodology for this population.

Challenges faced by design teams when working with people with dementia have motivated the conception of innovative and more flexible HF/E methodologies that better suit the needs and capacities of these users; two examples are provided here:

Alm & Newell (2008) conceived three different requirement-gathering methods adapted to individuals with dementia: (a) *Regular participant observation*. A volunteer from a day center for patients with AD was included in the design team to carry-out a permanent participant observation at the center, while he accomplished his daily tasks with elderly clients as a volunteer. The main difference between this technique and classic ethnographic methods is that in this experiment the observer acted as a volunteer/researcher and not as a researcher/researcher. This method was found useful to provide in-depth insights about the needs of people living with dementia in their daily context. (b) *Facilitated focus groups.* In a focus group with individuals with dementia each participant was assigned a facilitator, expert in the use of AAC (Augmentative and Alternative Communication) techniques, to support and assist the participant when he/she wanted to make a contribution. All contributions were written down on flip charts and the discussion was stopped regularly to read the new contributions; and (c) *Using actors and wizard of Oz techniques to help people with dementia articulate their needs and opinions towards AT*. This sort of interactive theater helped to illustrate the impact of assistive AT in everyday life for individuals with dementia who can experience some difficulties imagining the possibilities of these novel applications and to elicit discussion among them.

Some recommendations for conducting usability testing with people with dementia have been suggested by our research team (Pino, Boulay, Faucounau, Wu, & Rigaud, 2010):

- Defining the number and the length of sessions as well as the timing for tasks according to users' capacities. Most usability tests only include one testing session but we have found useful to schedule more than one session for persons with AD in order to compensate for cognitive deficits and reduce the fatigue of participants.

- Conducting a brief cognitive assessment of the participant before testing to determine his/her global level of cognitive functioning. This information can be useful to examine mental workload and task demands resulting from the use of a system.
- Providing a familiar and welcoming atmosphere. Usability testing can be conducted either in natural contexts (e.g., day care center for people with AD), or in a living lab that reproduces a typical living room.
- Carrying out exploratory sessions to familiarize participants with the system assessed and the procedures and gestures required to complete tasks.
- Providing clear instructions for each step of the task and avoiding dual-task situations that may confuse the participant.
- Waiting longer before prompting and giving participants the possibility to ask for help.
- Encouraging participants to find their own way to use a system as long as it works for them. For example, in a usability study we observed that some participants with AD felt more comfortable employing both hands to use a computer mouse or a touch-pad, even if a single hand is normally used.
- Impairment of judgment abilities is frequent in individuals with AD. Therefore, it may be difficult to obtain and interpret self-reported preference scores from these users. Taking into account non-verbal behavior (e.g., facial expressions, body language) can help to better assess participants' feelings and attitudes towards the product.
- Involving the caregiver in usability inspection when the product is intended to be used by the person with AD and the caregiver, or under his/her supervision.

5.2.1 A Short Recommendation Summary

Based on the findings and limitations of the studies presented in this thesis, we provide a set of recommendations for the development of design projects of AT for older adults with cognitive impairment.

1. Setting Up the Project Plan

The project plan is the foundation for the entire product development. It includes the composition of the project team, whose members should be preferably from multidisciplinary fields to get a rich understanding of the problem (e.g., HF/E, neuropsychology, healthcare, engineering, design, occupational therapy, and sociology). The project plan comprises as well the choice of a design approach and study design (e.g., phase of the product-design lifecycle that the project will cover, outcomes expected for each phase, and HF/E methodologies that will be used). A central point in this phase is the identification of primary, secondary and tertiary stakeholders and the definition of the way they will be involved. The strategies that will be put in place to monitor and evaluate each working task should also be reviewed at this stage.

⋆ *The Choice of Design Approach*

It is desirable to explicitly choose the design approach that will be used (e.g., Product-Centered, User-Centered, Universal, or User-Sensitive Inclusive Design). Discussing this issue within the project team can help to identify the advantages and limitations of each alternative. This is an appropriate occasion to discuss as well concepts and beliefs with respect to disability and dementia care, and the underlying philosophies and ideologies that support them. For example, if a medical approach prevails, AT solutions will probably emphasize the compensation of impairments and performance enhancement. On the other hand, if the project team uses a more social or biopsychosocial approach, other outcomes will consequently be targeted by AT products and services (e.g., social inclusion, quality of life).

It is assumed that AT solutions that take psychosocial factors into account, rather than just deficits and impairments, will generate more acceptance and positive interest among prospective users. Similarly, User-Centered approaches and iterative methods should be preferred over Product-Centered approaches and waterfall design cycles, the former being more convenient to create usable, efficient, acceptable, and successful AT products than the latter. With this respect User-Sensitive Inclusive Design practices have a great potential to bring a unique solution for each particular problem, which is an optimal strategy in the context of dementia, whereas Product-Centered Design methods have the risk of creating solutions devoid of any differentiation, thus completely incompatible with the user's needs (i.e., product myopia). The importance of issues at stake deserves the discussion!

⋆ *The Identification of Stakeholders*

The value of an AT product results from a co-creation process in which users, caregivers, health professionals, manufacturers, and suppliers all have their part. Stakeholder identification is a critical success factor because each design phase involves multiple and important choices: the people who will be affected by them and have the knowledge to make the right decisions should be the ones who make them. Characterizing stakeholders is also the best way to understand their interests, roles, and responsibilities in the project. Major stakeholders in an AT design project include:

- **Primary end-users**: the persons who will actually be using an AT product or service (i.e., elderly persons with cognitive impairment). This group directly benefits from AT by increased autonomy and quality of life.
- **Secondary end-users**: persons or organizations being in direct contact with primary end-users, such as formal and informal caregivers, family members, friends, neighbors, healthcare organizations and their representatives. This group benefits from AT directly when using AT products and services (at a primary end-user's home or from a distance) and indirectly when AT is used as a complement or substitute to formal human care.
- **Tertiary end-users** are institutions and private or public organizations that are not in direct contact with AT products and services, but who contribute in organizing, financing or prescribing them. This group includes public sector service organizers, social security systems, and insurance companies. Their benefit from AT comes from increased efficiency and effectiveness.

2. Defining the Legal and Ethical Framework

Ethical and legal guidelines that will govern the project should be defined in parallel with the project plan. The ethical analysis consists in identifying ethical issues that may arise from the involvement of persons with cognitive impairment in the design process, and the evaluation and use of AT solutions. All the procedures required to obtain ethical approval from the relevant ethics committees should be reviewed as well. Moreover, the ethical framework should be practical enough to help AT developers find appropriate solutions that fit within it.

Defining ethical guidelines for projects in this area is a challenging task because it entails finding a balance between sometimes conflicting principles and interests. In any case, a key factor for ethical analysis in this context is to take into account the perspectives of primary users (i.e. people with MCI, AD) and caregivers. Cognitive disability can make it impossible to obtain a valid informed consent from the person with dementia; in these cases surrogates (e.g., spouse, children) should be able to make decisions about research participation. However, the use of surrogate consent for participation in a project does not replace the obligation of providing information concerning the study to potential participants with AD and ensuring that the information given has been understood. Local organizations that support people living with AD and their family members can provide information and advice on ethical and legal matters.

Finally, ethical guidelines should be revised throughout the duration of the project. In other words, prototypes and methodologies should be adjusted when necessary to ensure consistency with the ethical framework defined. Inversely, ethical guidelines should be updated and adjusted to take into consideration additional ethical issues that will result from user research. Some of the following questions, among others, should be addressed: What ethical issues or risks are mostly seen/expected in the solution provided? What functionality/aspect is expected to be the most problematic from an ethical and societal perspective? How can the design and services be improved? What ethical safeguards does the project team need to build in?

3. Recruiting End-Users

Once the project plan has been completed and agreed upon, the first step for involving elderly users in the design process is to contact and recruit them. When the project requires the participation of elderly people with MCI or AD some recruitment sources can be healthcare professional networks (memory clinics, nursing homes), patient organizations and senior centers. The support for the project provided by these institutions and associations has the advantage of giving confidence to participants. This is one of the benefits of public/private partnerships established within the framework of the living lab approach for healthcare innovation.

4. The Importance of Language

"The choice of words is not neutral, but rather it involves naming or wording the natural world ideologically, shaping them for particular purposes and interests" (Liu, 2008). Indeed, the choice of words impacts the way AT design projects are oriented and perceived. Terms and expressions used to refer to cognitive impairment, disability and AT have an influence both on the way designers structure a problem and create a solution and on the perceptions end-users have of AT products and services. In accordance, it is recommended to use an inclusive and

positive language that promotes dignity and conveys a positive representation of prospective users.

5. Providing Clear and Complete Information on the Project

A fundamental point for successful user involvement is to explain to potential participants the aim and the extent of the project in simple and understandable terms, particularly when working with people with MCI or AD. At each stage of the process participants must be given the time to ask questions and take in the information. Moreover, it is important, from the beginning, to inform users about their role in the project and the amount of time required to participate in the different activities.

6. Establishing Primary End-User Profiles

The definition of end-user profiles should cover a range of aspects: (a) cognitive and functional characteristics, that can be informed by a neuropsychological assessment which provides a comprehensive overview of the user's abilities and limitations; (b) possible physical or sensory limitations; (c) everyday needs and requirements; (d) perspectives toward AT solutions (e.g., attitudes, expectations); (e) living situation of the person (e.g., housing, social network, availability of support services); and (f) lifestyle and preferences. Covering all these individual and sociodemographic variables may be useful to examine the factors that influence not only user performance when interacting with AT products, but also user acceptance and willingness to use them.

7. Ensuring the Participation of Informal Caregivers

Involving informal caregivers in the design process of AT for elderly people with cognitive impairment is important for several purposes: to learn more about the primary end-user and corroborate his/her needs; to understand the caregiving situation of the primary end-user and define the role that AT could play in the current distribution of care-related duties; and to specify the caregivers' user profile because caregivers can directly benefit from AT, and in many cases, they will be required to learn to use and personalize the AT device at home.

8. Adapting Methodologies

User research is about understanding end-users. For an optimal involvement of older adults with cognitive impairment in AT design, traditional HF/E techniques should be adapted not only to their needs and capacities but also to their interests and lifestyle characteristics. To this end, project teams must emphasize creativity and flexibility to encourage proactive and playful ways of interacting with end-users. Requirement-gathering practices, observations, interviews, usability tests, and the assessment of final products can considerably benefit from informal settings, social activities, design games, and different methods that make users feel at ease.

9. Learning From End-Users

A key point to remember is that in a collaborative project, users are asked to participate as partners or co-designers and not as research subjects. Members of the project team must have a genuine interest in listening to what the end-users have to say and make participants understand that their advice is highly relevant for the project. Accordingly, empathy must be a quality of the members of the research team.

Older adults' involvement in an AT design project depends to a great extent on the value they perceive in it, either for them, their families, or future generations. In fact, a feeling of solidarity and the desire of making a contribution to society motivate many older adults that take part in these projects. Finally, if participants do not receive a monetary compensation for their participation, a good way to compensate them for their time and effort is to conceive user-research activities that are meaningful and rewarding to them (e.g., an opportunity for meeting other people, learning new things, having a good time, etc.).

A good starting point to getting to know the user is to set aside preconceptions and stereotypes about elderly people and dementia, and see situations anew. End-users' needs, requirements and opinions regarding AT solutions should be elicited on a regular basis throughout the entire design and development process because these may change over time; particularly after interacting directly with prototypes and early versions of the products.

10. Going Beyond Functionality: A Wider Perspective on AT

AT refers to a wide range of products and services aimed at supporting healthcare, autonomy, psychological well-being and social participation. Unfortunately, most of these projects have a health-based focus. Supporting cognitive or functional abilities in individuals with AD is important; but a more comprehensive perspective of AT is necessary to promote users' enrichment and satisfaction. This means, thinking of AT as a way of helping users to reorganize their living situation in a more comfortable, safe, and pleasant manner. Consequently, efforts must be made to explore other individual and social dimensions that can be addressed by AT, in particular, those related to social relationships, self-expression, and emotions.

11. Keeping the Contact After the End of the Project

One common shortcoming of design projects on AT involving end-users is that there is no reciprocal compromise on behalf of the project team to provide information to participants and their families after the project is finished. Creating a more equalitarian relationship with end-users in a project based on the co-creation of AT solutions implies giving them feedback about the evolution and results of the project once the conception phase is over. It can also be quite rewarding for older adults to know that their contribution to the project was meaningful.

Maintaining and nurturing contact with healthcare institutions and seniors associations that helped with the recruitment of persons is not only encouraged but is also a condition to establish long-term partnerships which can benefit both, organizations, because they can increase the offer of activities to older adults, and design teams because future collaborations can be fostered.

5.3 Application of AT Models in Dementia Care

AT models have been proposed to guide the systematic description and implementation of AT solutions. A key feature of AT models is that they acknowledge the heterogeneity of situations experienced by potential users of AT and support the development of personalized solutions. Many methodological implications identified in the studies conducted within this thesis could be addressed by the use of AT models because these tools allow a careful examination of the relationship between factors related to the person with dementia, the activities he/she desires to carry out, social factors, and AT applications.

However, to date, AT models have not been used in the field of dementia. One reason that could explain this fact is that AT modeling is a rather recent field of study and main applications of AT models have concerned assistive products for educational or work purposes and persons with motor and sensory disabilities (Cook & Hussey, 2002; Hersh & Johnson, 2008a, 2008b). Besides, because of the relative novelty of AT for dementia care, the majority of design and development projects in this area have used traditional product design approaches. In our case, limitations in the studies here presented, which could not be addressed by traditional design practices, lead us to examine AT modeling frameworks.

In Chapter 3 we have described two AT models, the Human Activity Assistive Technology (HAAT) model (Cook & Hussey, 2002) (Figure 60) and the Comprehensive Assistive Technology (CAT) model (Hersh & Johnson, 2008a, 2008b) (Figure 61). Although the HAAT and the CAT models share a similar structure we consider that the CAT model could better fit any particular situation of individuals living with dementia for several reasons. First, the CAT model provides a very detailed description of each one of its components (person, activity, context, and AT), a more flexible framework for the design and implementation of AT solutions, and the possibility of adding a temporal dimension for the repeated assessment of AT over time. This is a very encouraging point as, despite the presence of core clinical features in AD, the substantial clinical heterogeneity that exists among persons with dementia, regarding cognitive, functional, psycho-behavioral characteristics, and disease progression over time, is widely acknowledged (Cummings, 2000).

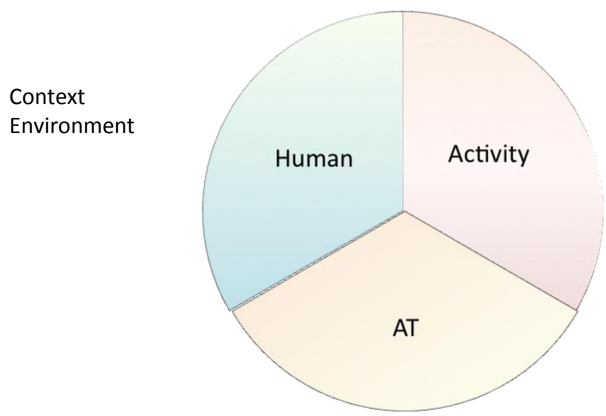

Figure 60 HAAT model (Cook & Hussey, 2002)

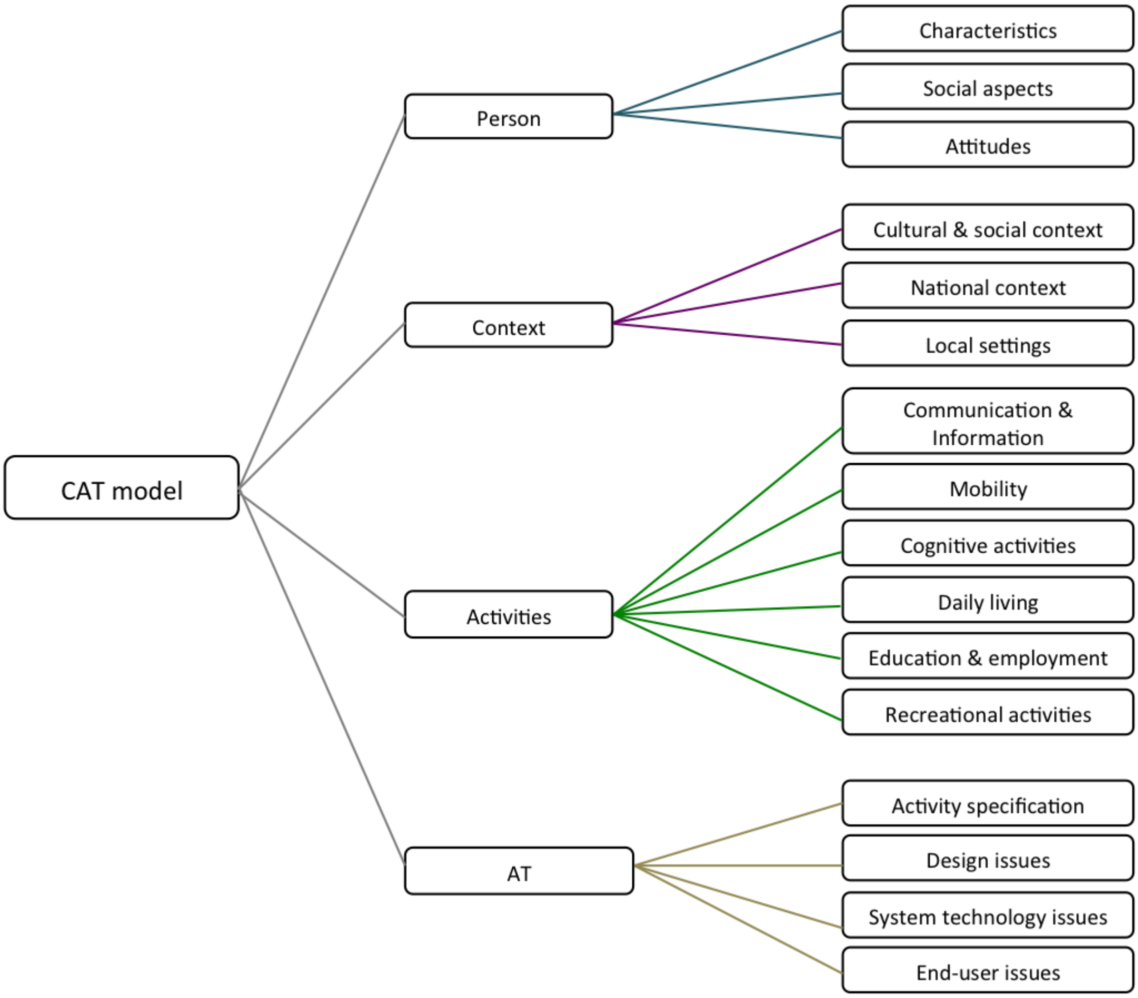

Figure 61 CAT model (Hersh & Johnson, 2008a)

Another advantage of using the CAT model for dementia care is that the consideration of a wide range of context and activity factors broadens the purpose of AT products and services. Because it adopts a social perspective on disability, the aim of AT in the CAT model is not only the enhancement of users performance in a particular task, but more globally, helping them to overcome the infrastructural, attitudinal and socio-economical barriers that prevent their participation in society (Hersh & Johnson, 2008b). This position is in line with the view of Charness & Holly (2001) about the use of HF/E approaches in AD care. These authors argued that increased efficiency is not likely to be the most important outcome for individuals with AD, whereas providing them with effective environmental solutions and adapted training could contribute to maximize their comfort, safety, and most of all, their well-being. Accordingly, the CAT model covers a wide range of AT solutions with a varying degree of complexity and allows the combination of low and high technologies in order to promote autonomy and social participation.

Finally, the CAT model covers some factors that have been found to influence the acceptance and use of technology among elderly users, such as technology experience, attitudes towards technology, usability issues, and training needs (Czaja, Sharit, Ownby, Roth, & Nair, 2001; Brajnik, Yesilada, & Harper, 2011; Fisk et al., 2009; Wagner, Hassanein, & Head, 2010). The assessment of these factors suggested by the CAT model could certainly contribute to the design of personalized AT solutions that closely match end-user requirements.

However, although the CAT model appears to be a valuable tool to guide the design and implementation of AT for dementia care, it is worth discussing how it could be better adapted to be used in this context. Our proposition consists in adding four factors that we have identified in our studies as being critical in the design process of AT for people with dementia: (a) caregiving situation, (b) fluctuating symptoms, (c) preserved abilities, and (d) care strategies (Figure 62).

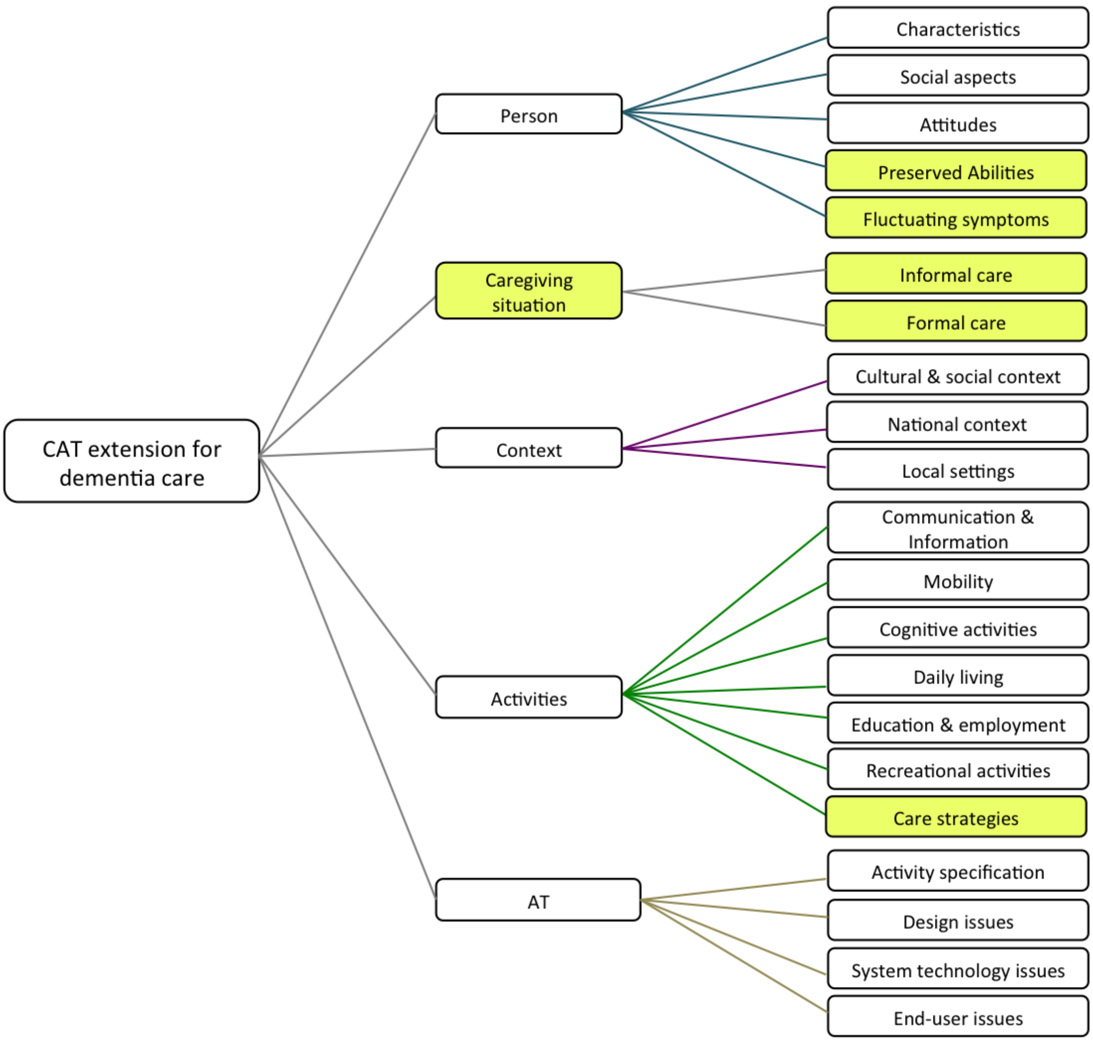

Figure 62 Modified version of the CAT model suggested for its use in AD care

5.3.1 AT and the Caregiving Situation

The implementation of AT solutions for individuals with disabilities usually involves a caregiver (i.e., individual who provides care and interacts with the person on a daily or very frequent basis) (Kintsch & DePaula, 2002). This issue of critical importance in the context of AD, because as the disease progresses people with AD require increasing assistance with daily tasks. The majority of individuals with AD receive care from their spouse or from adult children, the typical scenario being that of a single person providing most of the care, which typically results in caregiver burden (Schulz & Martire, 2004). Hence, one of the goals of AT in dementia care is to mitigate caregiver burden through different means: by offering caregivers concrete solutions to deal with some challenging behaviors of the patient (e.g., wandering, repetitive questioning, apathy); by providing the care recipient with cognitive assistance for everyday functioning, task that otherwise would be assumed by caregivers (e.g., reminding events, monitoring activities, ensuring safe use of domestic appliances); and overall, by allowing caregivers to take a break from their caregiving duties in order to take care of themselves (Carrillo et al., 2011).

In addition, the participation of caregivers is critical for successful implementation of AT for individuals with dementia because these individuals may need support, not only for decision-making concerning the use of AT, but also to use it. Also, the caregiver must be willing to learn to use and personalize the AT device, to accept the changes in the interpersonal dynamic that could result from the use of AT, and to understand that AT solutions must be readjusted over time (Kintsch & DePaula, 2002).

In the original CAT model the caregiving factor is not explicitly included but suggested as “the availability of support and friendship from the local community” (Hersh & Johnson, 2008a) under the social aspects related to the ‘person’ component. We find that this conceptualization does not reflect the importance of the caregiving dimension in the context of dementia. We consider that in any dementia caregiving situation an allocation of tasks, previously performed by the person with AD to the caregiver(s), takes place at different levels. Hence, when AT solutions are provided, they should be integrated within this pre-existing system, even for those who do not have an identifiable caregiver. As a result, a reallocation of functions occurs again. For this reason we suggest adding a ‘caregiving situation’ factor to the model and to place it at the first level in the hierarchy tree, with the ‘AT’, ‘Person’, and ‘Activity’ components (Figure 63).

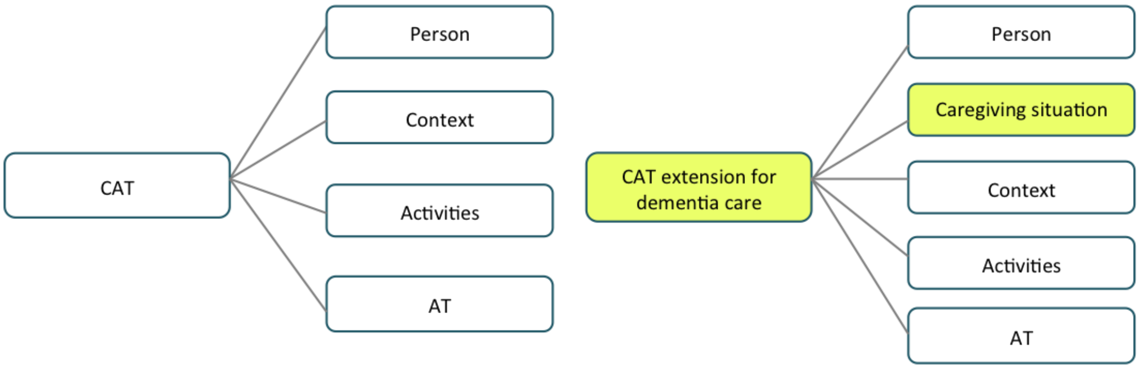

Figure 63 Original CAT model and modified version for its use in dementia care

In a similar line of reasoning, Topo (2008, p.6) argued that AT is best understood as an extension of aids and the provision of adaptations "beyond static pieces of equipment" (as cited by Marshall, 1995). Accordingly, just as informal and formal caregivers may be either substitutes or complements in dementia care (Bolin, Lindgren & Lundborg, 2007), AT and caregiving (formal and informal) could also be either substitutes or complements, depending on each particular situation (e.g., goals, everyday needs), sociodemographic, and medical factors (e.g. availability of formal and informal care, degree of cognitive and psychological impairment, economic resources).

Nevertheless, although the redistribution of caregiving duties through AT brings several opportunities for improved care management and quality of life in care recipients and caregivers, it merits further research. To date only a few works have examined the use of AT to substitute personal assistance among older adults with disabilities. These studies have found that if, in general, the use of AT among older disabled elderly is associated with fewer hours of help, older adults with severe cognitive impairment are less likely to substitute AT with either type of personal care than those with physical limitations, primarily because some AT applications may be too difficult to be used by cognitively impaired people (Agree, Freedman, Cornman, Wolf, & Marcotte, 2005; Hoenig, Taylor Jr & Sloan, 2003). Also, the majority of AT items reported in these studies concerned mobility, bathing, or toileting equipment such as canes, bath seats, walkers, bath rails, and wheelchairs. Further studies should focus on the substitution potential or other kinds of AT products and services, for example, those targeting cognition, social functioning, and entertainment and leisure activities.

5.3.2 Factors Related to the Person Component

Fluctuating symptoms and preserved capacities in individuals with AD were discussed in Chapter 2. *Fluctuating symptoms* refer to day-to-day changes observed in many individuals with AD in terms of cognitive functioning, behavior, and arousal. Persons with AD may exhibit periods of confusion, which are characterized by memory failure (e.g., repetitiveness in conversation or forgetfulness), episodes of illogical or disorganized thinking, drowsiness or lethargy, and moments of staring into space for long periods, alternating with episodes of lucidity and capable task performance (Bradshaw, 2004; Escandon, Al-Hammadi, & Galvin, 2010; NIA, 2011).

When modeling AT systems for people with dementia it seems important to evaluate this intra-individual variability in cognitive and functional capacities. Only by doing so can AT solutions be designed to be flexible enough to respond, not only to the great heterogeneity that exists among individuals with dementia, but also to the changes observed in each individual from moment to moment or day to day. One of the implications of fluctuating symptoms for AT design is that the degree of assistance provided should be automatically tailored to the current needs of the user. To this end, artificial intelligence and context-aware technologies have the potential to recognize the user's context and provide him/her with an appropriate assistance (Pollack, 2005). In this regard, LoPresti, Mihailidis, & Kirsch (2004) have highlighted that an inflexible AT device may be source of task errors resulting in user frustration.

Finally, considering that fluctuating behavior in AD is often related to the demands that a task or a particular situation places upon the user (Bradshaw, 2004), a practical application of the CAT model extension for dementia care could be the identification of environmental demands that usually trigger cognitive or behavioral changes in the person with dementia. This information could be used afterwards to design effective solutions, either to reduce these demands or to help the user better cope with them.

The other person-related factor that appears to be relevant for the modeling of AT systems in the context of dementia is the identification of the *preserved capacities* of the person. Chapter 2 provided an overview of some cognitive and psychological skills and capacities that individuals with dementia retain throughout the course of the disease (e.g., learning new skills through the use of procedural memory strategies, emotion processing, non-verbal communication, life-long habits, values, preferences, life experiences). Effectively, if AT solutions for dementia care are implemented within a psychosocial approach, they should be designed based upon the strengths of the person with dementia, as primary building components, and not upon deficits and impairments (Dröes, van Mierlo, van der Roest & Meiland, 2010).

Furthermore, because of the progressive nature of AD, AT solutions that focus exclusively on cognitive or functional deficits would only have short-term efficacy. On the contrary, AT solutions that focus on the preserved capacities could contribute to the autonomy and well-being of people with dementia on a long-term basis. The original CAT model includes skills and capacities as 'characteristics' of the person. Nevertheless, we consider that this factor should be evaluated separately because to assist people with dementia with what they are no longer able to do requires to focus first on what they can do and enjoy doing. Consequently, we suggest including both factors, 'Fluctuating symptoms' and 'Preserved abilities', as 'Person' attributes for the use of the CAT model in AD care (Figure 63).

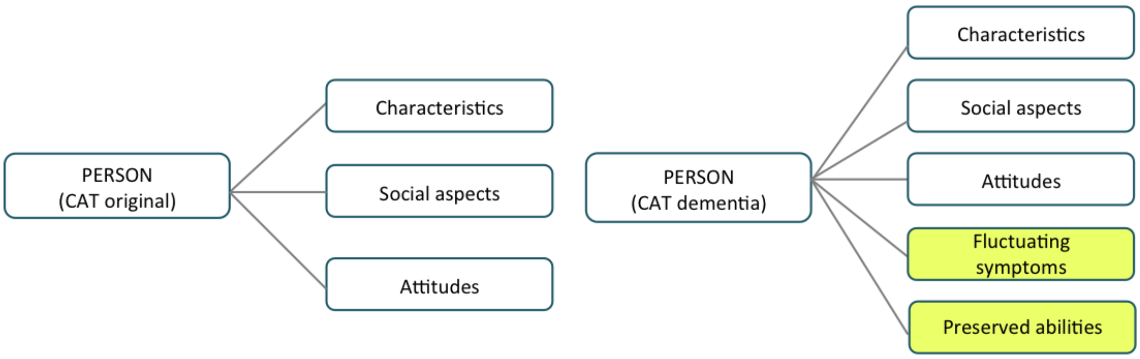

Figure 64 Original CAT model and modified version for its use in dementia care at the person level

5.3.3 Factors Related to the Activities Component

The 'Activities' component in the CAT model refers to major social and domestic activities in which persons may require support from AT applications (Hersh & Johnson, 2008a). The original model includes six activities grouped in:

(a) *Fundamental activities* such as of mobility, communication and access to information, and cognitive activities.

(b) *Major contextual activities* of daily living, education and employment, and recreational activities.

For its use in the context of dementia care we suggest adding a 'care strategies' component to the CAT model (Figure 64) at the 'Activities' level, referring to the health and social care plan that has been agreed between the care recipient and his/her care professional and social services (e.g., goals, diet, exercise plan, medical treatments, and support services). Making explicit this component in the model could be helpful to identify care-related situations for which persons with dementia could benefit from AT support. The care plan should be reviewed over time with the aim to assess whether the current care strategies, including AT provision, meet the care recipient's needs or if an adjustment is required.

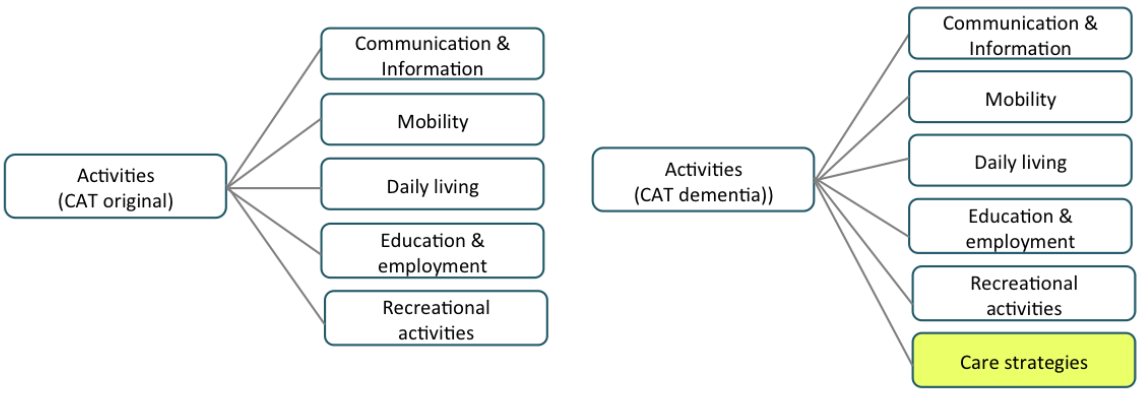

Figure 65 Original CAT model and modified version for its use in dementia care at the activities level

5.4 Connecting Things or the "Big Picture"

One of the objectives of this thesis was to investigate the underlying theoretical assumptions of AT usage in the context of dementia care and their implications for the design and assessment of AT solutions. With this purpose, we have examined medical, social, and biopsychosocial perspectives on disability, dementia, dementia care, AT, and different design approaches such as product-centered, universal, and user-centered design. To conclude this work we propose a conceptual network to analyze the relationship existing between these concepts and different approaches for AT design in the context of dementia (Figure 66).

This exercise of "connecting things" has the merit of illustrating that some conceptual agreement exists between the way of understanding disability and dementia, the role given to AT, and specific approaches for designing AT solutions, when adopting either a medical, a social, or a biopsychosocial perspective. We acknowledge that this analysis is just theoretical and provides an oversimplified view of the situation. In real life the boundaries between these perspectives are less clear and the relationships more complex, for instance, the same assistive product could be designed and provided from one perspective or another (Table 52). It is rather the combination of disability and dementia concepts, AT purpose, the person on whom AT choices depend, and the degree of user involvement on the process, that will help to determine which theoretical perspective is dominating However, we believe that having a deeper understanding of the underlying assumptions of each of these perspectives might be helpful to bring coherence to research and development projects in the field of AT for dementia care, inform design choices and support AT provision.

The conceptual network presented in Figure 66 can be summarized as follows:

(a) Medical perspective: The medical model of disability considers disability as the result of any loss or abnormality of psychological, physiological or anatomical structure or function. Consequently, dementia is understood as a biological neurodegenerative process that causes cognitive and functional impairment and leads to disability. Pharmacological treatment is emphasized in this perspective, and assistive products are meant to help the diagnosis or treat symptoms (e.g., compensate for impairments). Users' needs are objectively - or professionally- defined based on a set of recognized clinical criteria, and other individual, social, and contextual factors are hardly taken into account. In this sense *AT models cannot be clearly associated to the medical perspective*. In the design process, the provider shapes the product and the involvement of end users is very limited or nonexistent, which corresponds to a Product-Centered design approach. Finally, AT outcomes focus on performance improvement, and little or no consideration is given to contextual and psychosocial factors, The role of the individual with dementia is rather passive in this approach: it does not promote empowerment, defined as "A social process of recognizing, promoting, and enhancing people's abilities to meet their needs, solve their problems and mobilize necessary resources to take control of their lives" (Jones & Meleis, 1993).

(b) Social perspective: In this perspective disability is considered as a socially created problem, resulting from the way disability is defined, social attitudes and organization. Therefore, sociopolitical measures that promote the inclusion of persons with disabilities in society are favored over pharmacological treatments or rehabilitation approaches. The individual plays an active role in the social perspective because his/her concerns and own experiences allow the identification of physical, environmental or social barriers, which are subsequently addressed by laws and regulations. In this sense, the social perspective is empowering for individuals with disabilities. In this perspective the term of "Accessible Technology" is preferred over "Assistive Technology" because the former emphasizes the role of technology in making human activities more accessible rather than the need of assistance, (Ladner, 2010). The CAT model (Hersh & Johnson, 2008a) was developed within this theoretical framework; consequently, one of its goals is to identify the barriers encountered by people with disabilities when carrying out a wide range of social and domestic activities and to provide them with solutions that allow them to accomplish these activities when the community environment is not designed for disabled people. The concept of Universal Design also arises from a social approach because it considers that systems and environments should be conceived, to the greatest extent possible, to be usable by all.

(c) Biopsychosocial perspective: Disability from a biopsychosocial perspective refers to impairments in physical or psychological functions or structures, to activity limitations when performing a task or and action, and to participation restrictions in everyday life situations; it is understood as the result of physiological and psychosocial factors. Psychosocial models of dementia take into account the role of physiological, psychological, social and environmental factors in the experiences of people with dementia in order to provide interventions that meet each individual's situation. Although psychosocial interventions are emphasized in this approach, the possibilities of pharmacological treatment are also recognized; the primary goal being to find a solution that best suits the needs of the person. AT within this perspective is understood as a tool that not only contributes to the autonomy of the individual but also to social participation and quality of life. The user's needs are at the center of AT choices; consequently this is an empowering perspective. Social and environmental factors are also taken into account. In a general way, AT models are compatible with a biopsychosocial perspective, since personal, contextual, and activity-related dimensions are taken into account for the description and implementation of assistive products. The extension of the CAT model proposed in this work fits within this approach because we consider that the design of AT solutions for people with dementia requires an analysis at both levels, physiological and contextual. Finally, User-Centered design approaches, and in particular User-Sensitive Inclusive Design methods, are in agreement with the biopsychosocial perspective because they take into account the analysis of inter- and intra-variability and encourage personalized solutions.

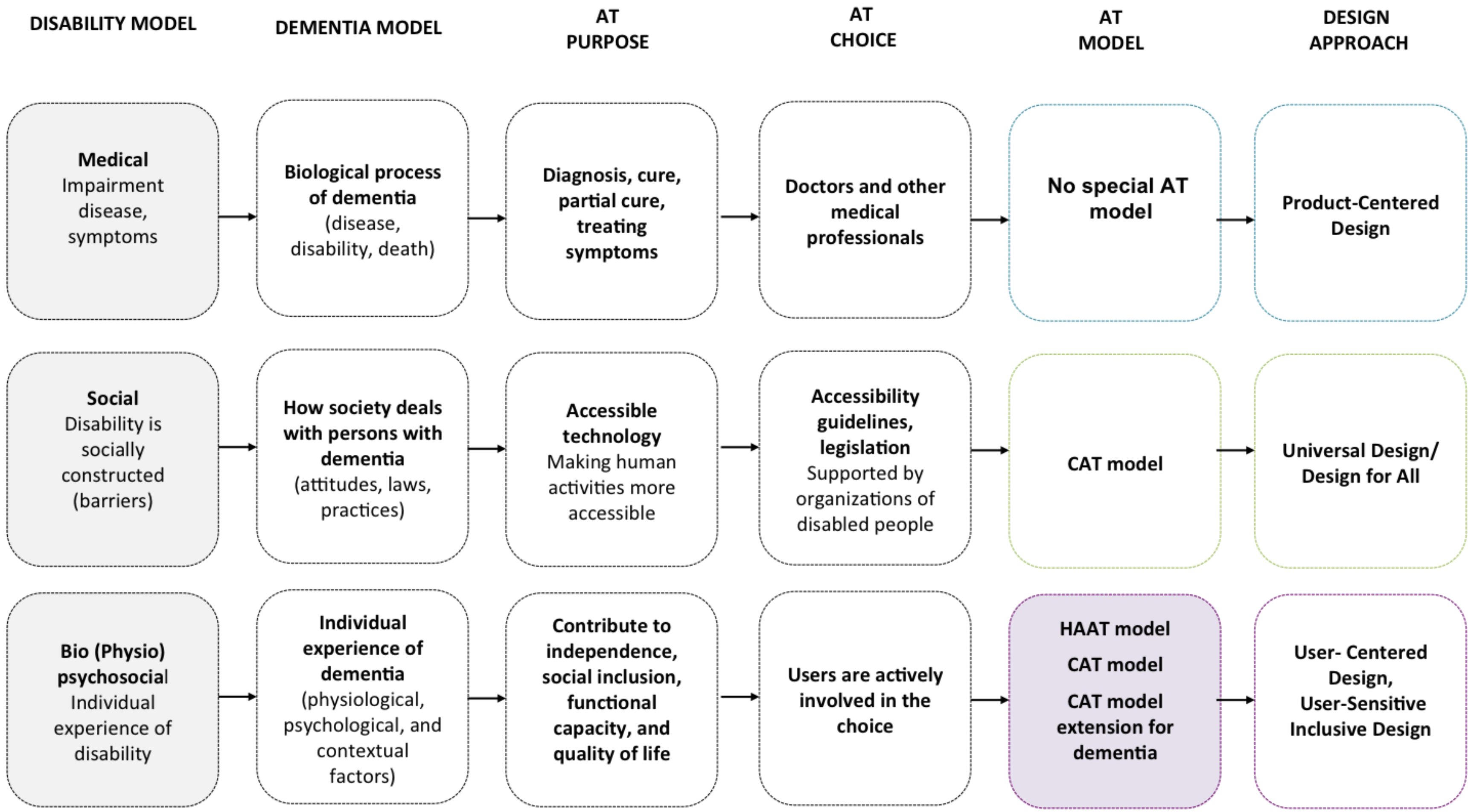

Figure 66 Relation between disability, dementia care, AT models, and design approach

Table 52 Examples of AT applications for people with AD, intended end-user group, and compatible theoretical approaches

Domain	AT device	End-user group		Compatible approach		
		Person with AD	**Caregiver Informal/ formal**	**Medical**	**Social**	**Bio psycho-social**
TELECARE	Monitoring devices for physiological data (temperature, heart rate, blood oxygen level)		✓	×		×
	Activity monitoring (pedometer, accelerometer)		✓	×		×
	Gait monitor		✓	×		×
SAFETY	"Wandering" technologies to locate or notify a person	✓	✓	×		×
	Alarms to alert caregivers		✓	×		×
	Fall detectors	✓	✓	×	×	×
	Temperature/heat sensor	✓	✓		×	×
	Door and window sensor	✓	✓		×	×
	Gas, carbon monoxide, smoke	✓	✓		×	×
	Automatic lighting	✓	✓		×	×
	Electrical usage sensors	✓	✓		×	×
COGNITIVE FUNCTIONING	Cognitive-memory aid	✓		×		×
	Cognitive-aphasia	✓		×		×
	Cognitive-navigational tools	✓		×		×
	Cognitive games	✓		×		×
FUNCTIONAL CAPACITIES	Task guiding	✓		×		×
	Item locator devices	✓		×		×
	Medication reminders and dispensers	✓		×		×
	Signs, notices and other environmental aids	✓			×	×
	Smart Homes	✓	✓	×	×	×
	Assistive robotics	✓	✓	×		×
	Accessible everyday technologies (domestic appliances)	✓			×	×
SOCIAL FUNCTIONING	Intercoms	✓	✓		×	×
	Telephones	✓	✓		×	×
	Communication aids	✓	✓		×	×
	Accessible computers and software	✓			×	×
	Accessible TV remote controls, radios and music players	✓			×	×
	Electronic games	✓			×	×
	Websites and online social networks for people with AD	✓			×	×
	Social assistive robots	✓				×
PSYCHO BEHAVIORAL SYMPTOMS	Agitation sensors	✓		×		
	Light therapy	✓				×
	Multi sensory therapy	✓				×
	Music therapy	✓				×
	Physical design that supports well-being	✓			×	×

6 CONCLUSIONS

The goal of this thesis was the examination of the design and development cycle of AT intended to support cognition, functional capacity, and social interaction in older adults with MCI or Alzheimer's disease using a HF/E framework and a psychosocial perspective. Therefore, this dissertation has covered different topics related to the design, development, and use of AT products including requirement-gathering practices, usability testing, assessment of the effectiveness of AT applications, and ethical analysis of the issues raised by the design and use of AT.

This final section summarizes three key issues that emerged from the analysis of the design process of AT carried out within this work, the contributions and limitations of the studies presented in this thesis, and suggests future research directions.

(1) Implicitly or explicitly, concepts about disability and dementia underlie the process of design and development of AT products and services for older adults living with Alzheimer's disease

> *"The problem of design rests not on theoretical notions of how we define disability, but on ensuring the needs of the person are translated into appropriate design that should be empowering to the user"*
> Dewsbury et al. (2004, p. 155)

This question could be considered as purely theoretical but actually has many practical implications. The design of AT products or services follows a methodology for idea generation and implementation that, most of the times implicitly, makes assumptions about the goals of AT and primary end-users. One of the contributions of this thesis was to provide insight into how medical, social, or biopsychosocial perspectives on disability and dementia care may lead to the definition of different goals for AT products and services. For instance, if a medical model guides the project, AT solutions will probably emphasize the compensation of impairments, the restoration of lost function, and performance enhancement; if the project team uses a more social approach, other outcomes will normally be targeted (e.g., social inclusion, quality of life).

Each of these perspectives can also be connected, theoretically, to different design approaches (e.g., Product-Centered, Universal, or User-Centered design) and consequently, determine the degree of user involvement in the design process. Medically oriented projects are more likely to use Product-Centered methods and waterfall design cycles in which users' needs and requirements tend to be preconceived and "fixed" before the beginning of the development phase. In contrast, social oriented projects tend to employ User-Centered methods and iterative and incremental design cycles in which users' needs and requirements are assessed on an ongoing basis and in a more dynamic and flexible way.

Nevertheless, these theoretical issues are rarely discussed in the design teams and many decisions are often taken *ad hoc.* For this reason, one of the recommendations given in this work is to make an explicit choice of design approach, and to discuss beliefs and concepts about disability, dementia, and the role of AT within the design project teams. Certainly, the definition of a conceptual and methodological framework is just a step that could bring coherence to the project and not an end in itself; theory should lead to action.

AT models are helpful in this respect, because they provide a powerful and simple tool to examine the relationships between user, activity, context, and AT solution. However, to date, these models have not been used in the context of dementia. One of the reasons that could explain the lack of work on the modeling of AT for individuals with dementia is the relative novelty of both fields (i.e., AT modeling, use of AT in dementia care). The gap existing between designers and developers of AT, and between clinicians and providers could also account for this.

In this regard, another original contribution of this work is the suggestion of an extension of the Comprehensive Assistive Technology (CAT) model proposed by Hersh & Johnson (2008a) for its use in the field of AD. In this adapted version four factors, considered critical for the design and implementation of AT solutions for individuals with AD, were added to the current configuration of the model: the *caregiving situation*, *fluctuating symptoms* and *preserved capacities* of the person with AD, and *care strategies*. These factors were selected in the first place to respond to the need of modeling a more dynamic process and to reflect the ever-changing needs of individuals with AD and their caregivers. Also, these new elements emphasize the consideration of individual characteristics and the need for personalized AT solutions in the context of AD.

Further work will be required to examine the descriptive and analytical power of the CAT model in the context of AD case in order to determine if the factors currently covered by the model, and those that were suggested in this work, are convenient: first, for the definition of AT profiles of persons with AD; second, to match AT solutions to particular end-users with dementia; finally, to effectively measure the resulting outcomes.

(2) The analysis of users' characteristics and of system features conducted at each phase of the product development cycle is important, but so is keeping the process as a whole in sight

> *"Effective cognitive interventions are useless unless older people are willing to engage in them"*
>
> D. Boot

Each phase of the product development cycle, from the definition of users' profiles to the final product assessment, has its own objectives. However, when the different phases of AT design (e.g., needs and requirements, technology acceptance, usability, compliance, effectiveness) are carried out in a very isolated way there is a risk of loosing sight of the process as a whole.

Usability studies are necessary in this field to define general design guidelines of accessibility that reflect the cognitive and physical abilities of older adults with cognitive impairment. Also, *defining users profiles* is essential for the development of acceptable and personalized solutions tailored to a particular end-user group. Assessing the *clinical benefits* of AT solutions is fundamental as well because ineffective solutions will have no value to the user. However, studying each one of these aspects independently from the others is a major shortcoming for two reasons: (a) beyond usability, functionality, or effectiveness, more complex factors influence the acceptance and use of AT among older adults, for example motivational aspects, individual and social identities, current and future self-image, perceived enjoyment, and perceived opportunities for social interaction, and (b) user requirements are not static; they evolve over time, particularly after interaction with prototypes and products that provide new technical capabilities.

Future research in this field should take this problem into account to conceive new methodologies that allow keeping a broad perspective of the whole process while focusing on the specific objectives of each design phase and understanding the relationship between the part and the whole. For example, the identification of users' needs and system requirements should be carried on an ongoing basis, at each phase of the design cycle and not be limited to a single formal assessment.

(3) Greater expectations of AT

"Each client wants a bit of magic and something that 'fits' them"
D. Norman

"I'm so sentimental and sensitive that I would like the robot to recite poetry to me, to play some music for me, the concerts that I love…and that it wears a knitted cape"

Woman with MCI, 83 years old

Cognitive and functional impairment in older adults brings many challenges concerning social and health care, but also many opportunities. AT is one of the tools that we have at our disposal to fulfill the needs of older adults regarding physical and mental health. AT has the potential to reduce dependence in those with AD by delaying functional decline, increasing the extent to which they engage in everyday activities, and in some cases reducing the need for personal assistance.

However, considering that the unique purpose of AT should be to compensate for a particular impairment or enhance users' performance in a very specific domain is too narrow a view, as our work has shown. Still, for example, the majority of AT products for older adults with AD focuses exclusively on prompting and reminding. In some way, this is symptomatic of a rather stereotyped view of people living with AD: a population characterized by cognitive decline, in particular memory loss. It does not mean that the consequences of memory impairment on the life of persons with AD are not serious, because they are. And it is very positive that AT offers a potential solution for the support of memory function. The drawback is that by focusing exclusively on cognitive and functional outcomes we may be leaving out a large number of possibilities of providing entertainment, fun, aesthetic and emotional experiences, and social opportunities to persons living with AD.

To a certain extent AT solutions that over-emphasize functionality ignore the one thing that is central in human performance models: the human. It is understandable that this perspective was dominant decades ago, when the medical models was the only reference to conceptualize disability, dementia, and dementia treatment, and when technology offered very limited possibilities to meet the various needs of older adults. But paradigms have changed and other perspectives about aging, disability, and technology have emerged. In addition, older adults often ask for services and applications that make them feel good, alive, part of something, and not just to remind them of medication, meals, or appointments, or to alert someone in case of emergency. Older adults have greater expectations of AT than has been thought until now and this is a need to which we must respond urgently as technology will soon have to compensate for the lack of human resources for the care of older adults, in particular those living with dementia.

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General Web Sites

EUROSTAT (Statistical office of the European Union)

http://ec.europa.eu/eurostat