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Information Technology for Active Ageing: A Review of Theory and Practice

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Active Ageing (AA) aims to foster a physically, mentally and socially active lifestyle as a person ages. It is a complex, multi-faceted problem that involves a variety of different actors, such as policy makers, doctors, care givers, family members, friends and, of course, older adults. This survey aims to understand the role of a new actor, which increasingly plays the role of enabler and facilitator, i.e., that of the *technology provider*. The survey specifically focuses on *Information Technology* (IT), with a particular emphasis on software applications, and on how IT can *prevent* decline, *compensate* for lost capabilities, aid *care*, and *enhance* existing capabilities. The analysis confirms the crucial role of IT in AA, shows that AA requires a multi-disciplinary approach, and identifies the need for better integration of hardware, software, the environment and the involved actors.

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1. INTRODUCTION

“Running is my life. I will keep running to inspire the masses” says Fauja Singh in a recent interview after announcing his retirement from running marathons[1] The sur-

[1]http://news.discovery.com/human/life/101-year-old-marathoner-retire-130124.htm

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prising aspect of his statement is not so much the intention to quit running competitions but rather his age: Fauja is 102 years old and known as the oldest marathon runner of the world[2].

What Fauja is teaching us is that life does not end after retirement and that the right exercise, diet, determination and opportunities have the power to keep or even improve quality of life also when facing the burdens of age. Fauja is not only an extraordinary sportsman, he is also representative of a more general phenomenon of today's ageing society (admittedly, an exceptional one): increasingly, people do not just live longer and generally healthier, but they also keep practicing physical activities (e.g., dancing, hiking or swimming), reading to stay informed or writing themselves to inform others, engage in social relationships (also over long distances), or travelling, even in advanced age. That is, older adults are increasingly active and want to take part of society and to contribute to it.

Enabling this active participation as we grow old has become one of society's most important modern challenges. And this is a challenge with many sides. First, prevention of age-associated physical function decline and disabilities has gained importance and it has been pointed out that it should be the focus of societys attention [Guralnik et al. 1996; Ferrucci et al. 2004]. When older adults lose their ability to move within their environments without needing assistance they are less likely to remain active in the community. Second, as we age, our health is naturally challenged and older adults face higher rates of morbidity, mortality, health care utilization and cost, next to a poorer quality of life [Guralnik et al. 1994; Guralnik et al. 1995; Hardy et al. 2011]. Finally, with people living increasingly longer, our society is slowly changing its composition, adding to the complexity of the problem: the World Health Organization (WHO) estimates that "by 2025 there will be approximately 1.2 billion people worldwide over the age of 60, reaching 2.0 billion people by 2050, with 80% of them living in developing countries" [WHO 2002].

Addressing these issues involves perspectives as different as health sciences, economics and politics. In healthcare, the focus is usually set on increasing the amount of years of good health as the means for extending independence and quality of life as long as possible [Silveira et al. 2013]. Healthy ageing is characterized by the avoidance of disease and disability, the maintenance of high physical and cognitive function, and sustained engagement in social and productive activities [de Bruin 2012]. These three components together define successful ageing [Rowe and Kahn 1997]. The challenge we are facing today is how to support public health policies that would help elderly in achieving the goals of prevention with the aim to remain independent. An extended life should ideally also involve preservation of the capacity to live independently and to function well [Katz et al. 1983]. That is, we need to understand how to provide effective answers to the need for specifically tailored physical activities, how to provide intellectual stimuli that keep older individuals mentally active, or how to help elderly keep socially integrated; e.g. in touch with their family and peers. Here is where politics and public policy makers become important [Satariano et al. 2012], who must recognize these needs and work toward an environment, a society and an infrastructure that facilitate life to elderly. Large support for public health policy can in this context also be allocated to technology in terms of advanced instruments for healthcare and in terms of support it can provide to the everyday activities of individuals. Technology is already permeating our everyday lives, e.g., smartphones and the Internet. Yet, many of the solutions are still targeting tech-savvy people and do not specifically focus on elderly users and their families or communities.

[2] http://en.wikipedia.org/wiki/Fauja_Singh

With this survey, our aim is to shed light on the role information technology (IT) might play in supporting elderly to age actively. Our goal is to understand how IT can better support an active ageing (AA), where we define AA as a physically, mentally and socially active lifestyle as a person ages. The survey is based on the analysis of literature collected during two years of research and practice in designing IT solutions specifically tailored to the needs of elderly and includes contributions coming from Computer Science disciplines as varied as eHealth, Mobile Computing, Social Computing, Ubiquitous and Ambient Computing, Persuasive Technologies, and Human Computer Interaction. We provide the following contributions:

— A review of the concept of Active Ageing in light of its different definitions in literature, followed by a discussion of the challenges and design issues of IT for the elderly.
— A systematic evaluation framework that brings together the different determinants that affect quality of life during the ageing process with the support IT can bring to modulate these determinants.
— A review of literature including exemplary IT services and applications that provide support for AA, using our evaluation framework analyze contributions and describe their characteristics.
— A discussion of the different aspects of the state of the art and an outlook of what we believe will be the challenges and opportunities of the IT solutions for AA to come.

The remainder of this article is structured as follows: Next, we discuss the effects of age and the meaning of AA. Then, in Section 3, we analyze what contributions IT in general can bring to ageing and which are the core development challenges in doing so. In Section 4, we introduce our evaluation framework. In Sections 5, 6, 7, and 8, we present the core overview of IT services and applications we have evaluated, offering also a discussion at the end of each of these sections. We conclude the paper with a brief report on similar surveys that precede our own (Section 9) and a conclusion, summarizing the discussions we present in each section and an outlook of challenges and opportunities of IT for AA (Section 10).

2. WHAT IS AGEING?

Ageing is a process we all undergo from the moment of our birth. At the beginning, ageing means growing, getting stronger, and differentiating ourselves while we build our identities, gain experience and knowledge. Around the age of 20, our physical, sensory, and cognitive capabilities peak and stabilize until we reach our 50s/60s. While our life experiences and our knowledge (and perhaps our wisdom) will continue to grow, our capabilities start to decline depending on factors like our genetics, lifestyle, and social environment. The exact reason of this decline is not yet entirely understood. Some theories speak of a natural and programmed process that takes place in our bodies, while others explain decline as the result of damage accumulated over time [Goldsmith 2012]. Independently of the reasons that determine decline, ageing unavoidably affects functioning as a complex interaction of genetics, chemistry, physiology, and behavior/lifestyle [Stibich 2009].

Ageing often comes with augmented risk of adverse health conditions that may affect physical functioning. Some of the most common age-related health problems are mobility related. Sometimes the changes in physical capabilities come as a result of diseases. Non-communicable chronic diseases increase in most societies [K.G. 1988] and negatively effect on physical functioning. Examples of non-communicable diseases are diabetes, cancer, and hypertension. Most of the health problems in old age are chronic non-communicable diseases [WHO 2002], which require constant monitoring and care. Although research has shown that many of these conditions have their origins in early childhood, it is well known that behavioral factors; e.g., tobacco or alcohol consumption, a sedentary lifestyle, etc. considerably increase the risk of developing or aggravating non-communicable diseases.

Independently of health, there are three macro-areas of manifestations of age that group different phenomena that affect quality of life and that allow us to structure our analysis: *physical capacity*, i.e., the capacity to perform physical activities; *sensory capacity*, i.e., the capacity to capture and interpret information; and *cognitive capacity*, i.e., the capacity to process, reason on, and produce information. Common cardiovascular, neuromuscular, physiological, sensorimotor, and cognitive changes associated with ageing are summarized in the literature [Concannon et al. 2012; Li and Lindenberger 2002; Morrison and Baxter 2012].

Research has also shown yet another key aspect of ageing, one that it is sometimes disregarded or not mentioned when discussing the phenomena: our ability to still grow in happiness. In fact, there seems to be an increase on self-reported subjective wellbeing once we pass our 50s [Stone et al. 2010]. This duality of ageing, where we can grow in some aspects (i.e., experience, wisdom, happiness) and yet face also decline in others (i.e., physical, sensory and cognitive abilities) is what takes us to the concept of **Active Ageing**, which we discuss and define in the following section.

2.1. What is Active Ageing?

Ideas around AA have taken many different names and forms within the field of Gerontology. In the mid 1990s, one of the first attempts to sum up these ideas into a term was the definition of *successful ageing* as having a "low probability of disease and disease related disability, high cognitive and physical functional capacity, and active engagement with life" [Rowe and Kahn 1997]. Terms such as healthy or productive ageing and ageing well followed later in the same line of describing desirable ideals about the ageing process [Mandin 2004]. According to Tesch-Roemer [2012], these definitions represented an idealization of ageing and were not inclusive enough. The Organisation for Economic Co-operation and Development (OECD) defined AA as "the capacity of people to lead productive lives in society and economy" [OECD 2000], focusing the concept on the occupational dimension. The WHO popularized AA by publishing a policy framework for enabling AA. WHOs definition emphasized opportunities within the process of ageing with AA being the "process of optimizing opportunities for **health**, **participation** and **security** in order to enhance quality of life as people age" [WHO 2002].

This focus on opportunities represented a shift in how the concept was understood and the definitions that followed took the same approach, differing only on which aspects or dimensions of quality of life were emphasized other than health, security and participation. Along with the emphasis on opportunities, the point of view of these definitions was almost always that of policy makers trying to enable AA through society's institutions.

The United Nations through its Economic Commissions for Europe (UNECE), for example, emphasize that the promotion of *social integration* and *active involvement* in community are the key elements of AA [UNECE 2002] while *autonomy*, *self-determination* and *choices* are the core dimensions according to [Mandin 2004]. The Institute for Prospective Technological Studies of the European Union (IPTS) emphasize the need for policies around *independence* and *autonomy* [Malanowski et al. 2008] defining *AA policies* as those that "enable people, as they grow older, to lead independent lives (socially and economically), making their own choices about how to shape their lives in all its spheres".

In 2012 the European Union (EU) promoted the **European Year for Active Ageing** (http://europa.eu/ey2012/) updating the definition of AA to "growing old in good

health and as a **full member of society**, feeling more fulfilled in our jobs, more **independent** in our daily lives and more **involved** as citizens". The EU takes then a more lifestyle oriented definition, which is summarized in a particularly inspiring phrase from their website: "No matter how old we are, we can still play our part in society and enjoy a better quality of life". *Employment*, *Participation* and *Independence* are the key dimensions in this definition.

Other definitions of AA use phrases such as "engaged in life", "live life as fully as possible" (http://www.icaa.cc/about_us/philosophy.htm) or "having as much as possible of *independence*, *autonomy* and *social inclusion*" [Dalli et al. 2011]. One of the latest term definitions says that AA is a "*process* that leads to both objective and subjective quality of life in old age in the domains of *health*, *social integration*, and *participation*" [Tesch-Roemer 2012].

In summary, the general idea is that it does not matter how old you are, there will still be a role to play in society to enjoy a better quality of life. Whether we define it from a policy-making perspective or from a lifestyle point of view, AA improves well-being in the dimensions of health, participation, security, employment, independence, autonomy and integration. All these dimensions can be argued to be included within those proposed by the WHO, leading to the definition we used in this survey, where we put together both policy makers and the lifestyle perspectives.

Definition 2.1. ***Active ageing (AA)*** is having a physically, mentally and socially active lifestyle as we age, with optimized opportunities of quality of life in the domains of *health*, *participation*, and *security*.

"***Health*** is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" [WHO et al. 1948]. ***Participation*** is the ability of a person to engage in socio-economic and cultural activities, making a productive contribution to society as they age (e.g. attending cultural activities, volunteering, being part of local communities, interacting with family and friends). ***Security*** is having adequate protection and care when assistance is required while maintaining as much as possible of autonomy and independence (e.g. receiving quick response to emergencies such as falling, or having the possibility to make our own choices). Altogether, these are the three ***main aspects of AA*** and they influence each other in multiple ways [Motel-Klingebiel et al. 2004; Walker and Lowenstein 2009]. Health is often seen as a precondition for participation and security, however, it is also well know that more social participation can improve health, while at the same time security can enhance people's opportunities for participation [Tesch-Roemer 2012].

2.2. Determinants of Active Ageing

How well both individuals and populations age is determined by a set of enabling factors (and the interplay between them) called the **determinants of AA**, each affecting one or more of the three main aspects of AA we presented before.

Definition 2.2. ***Determinants of AA*** are influences that surround individuals and which the process of AA depends on.

Based on the report by the WHO [WHO 2002] and other inputs from the literature we have cited in the previous section, there are 17 determinants that are key for enabling AA, organized in six main categories. Building upon WHO's definitions, each of these categories is explained in the following paragraphs. A description of each specific determinant is included in Appendix A.

Health services are public or private health services to which a person has access, including health promotion, disease prevention, curative and mental health services. Part of this is the equitable access to primary healthcare and long-term care by informal caregivers and/or healthcare professionals. ***Behavioural determinants*** are the behaviours a person regularly follows. Behaviours like healthy nutrition, active participation in ones own care, not smoking nor using alcohol and engaging in regular physical activity can all have a positive impact on AA. ***Personal determinants*** are the set of characteristics of a persons biology, genetic and physical limitations, including psychological factors like ones own intelligence, cognitive capacity, self-efficacy and self-esteem.

Environmental determinants are the conditions of a person's physical surroundings which can help people age better. Transportation means, safe housing, clean water, air and safe food are all environmental determinants of AA. ***Social determinants*** are the conditions that define a person's social environment, including how much support a person receives from its social networks, how many opportunities for education and lifelong learning the person has access to and how much risk of violence and abuse the person is subjected to. Finally, ***economical determinants*** are the set of different aspects of an individual's economic environment like level of income, access to work and to social pension (also referred to as social protection) services.

Altogether, determinants influence the process of AA by improving or deteriorating the opportunities for Health, Participation and Security. They can be seen as the general categories of problems that must be solved in order to enable AA. The role that IT can play is that of attacking the problems that are hidden under each of these categories, so that in the end, opportunities for *health*, *participation*, and *security* are improved.

3. IT FOR THE ELDERLY

IT can help to maintain health and independence increase participation and enhance security as we grow old. To do so effectively, it cannot overlook the changes that ageing brings to people's lives. This section therefore explains the four approaches with which IT can enable AA.

3.1. Objectives of IT for elderly

The four approaches in which IT can enable AA come from the literature of Gerontechnology, an interdisciplinary field devoted to "the study and design of technology and environments for independent living and quality of life of older adults"[3]. These four approaches are summarized as *Gerontechnology goals* [Harrington and Harrington 2000]. Figure 1 shows our representation of each of these approaches in terms of how they positively impact in some aspects of our life. In each figure, the dashed curve represents how would our life course be by following these approaches. A definition of each goal follows the figure.

— ***Prevention.*** Is the first and foremost goal of Gerontechnology. Successful prevention can make the other three goals redundant. In addition to enabling AA, prevention implementation success may also lead to economics savings that can be redirected to other societal needs [Harrington and Harrington 2000]. As we age, prevention helps us to avoid injuries and slow down physical, mental and social decline (Figure 1a). Using a machine to stay fit and keep walking, following a physical training plan using videos on YouTube, improving our nutrition with a tool that helps us log and monitor what we eat or stimulating our brain with computer games are examples of IT enabling AA through prevention.
— ***Compensation.*** When an impairment or disability can no longer be prevented or cured, *compensation* comes into place to either reduce the impact of the declined

[3]http://gerontechnology.info/index.php/journal/pages/view/isghome

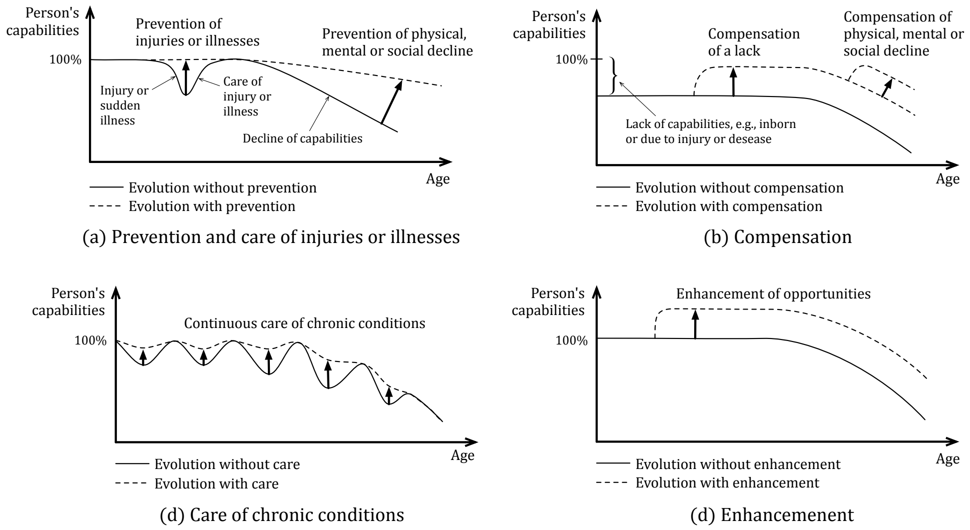

Fig. 1: Gerontechnology Goals

capability, or to partially and artificially replace a not available capability (inborn or due to injuries or illnesses; Figure 1b). Compensation is applied either on the environmental or on the personal level [Harrington and Harrington 2000]. (Geron)technology can be used for these purposes, making up for impairments that people face as they age.

— ***Care.*** When we cannot prevent nor compensate a problem, and/or we need assistance to recover from an incident or to reduce the impact of a chronic condition, *care* is needed (Figures 1a and 1c). (Geron)technology for care acts to facilitate the work of the caregivers. The caregiver can either be a formal caregiver (e.g., nurse, physician) or an informal caregiver (e.g., family member, friend).
— ***Enhancement.*** (Geron)technology can help to create new opportunities and extent existing capabilities, and help people gain new capabilities (Figure 1d). Using IT to keep updated with our interests, to learn new things, to find interesting activities to join, to augment experiences in which we are already involved, to enable real time access to information or to discover new experiences or work opportunities that we can commit to are examples of IT for enhancement.

4. EVALUATION FRAMEWORK

The goal of this survey is to understand how IT can aid AA, that is, which IT *solutions* may help address which of the *problems* of AA. We therefore developed a conceptual evaluation framework that brings together the two perspectives introduced above. The structure of the framework is illustrated in Figure 2: On the top, we find our *definition* of AA, with its three major *dimensions* (health, participation, security). In order to understand how IT may modulate these dimensions, we then show which *determinant categories* (and their specific determinants described in Appendix A) can be used as levers. From the bottom, we structure the solution space first into the four *goals* (we could call them also application domains) technology may pursue, in order to make life better; then, we show which *types of applications* may serve which of these goals.

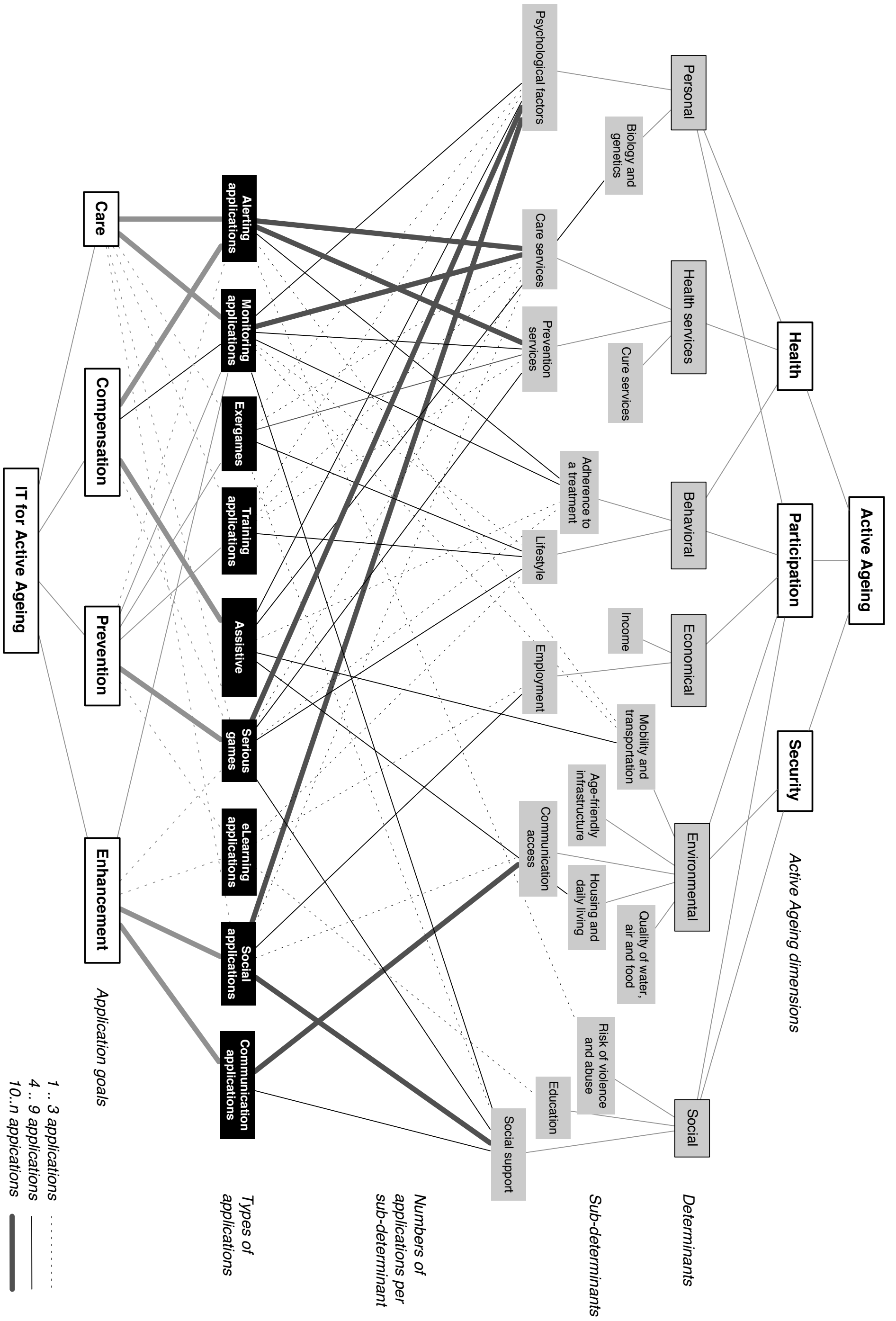

Fig. 2: ICT for Active Ageing: evaluation framework.

The types of applications are a bottom-up result of our analysis; in Appendix D we describe the body of works considered and the criteria we followed for their selection. The application types stem from a careful clustering of all considered applications into groups of applications serving similar purposes; clusters were considered only for groups with at least three members. Applications of the same type share common features, such as monitoring physical activities, gaming, alerting about medication, and similar. Given the versatility of applications and the different uses one may make of them, one application may fit into one or more different types. However, in order to assign each application to exactly one type of application when multiple options were available, we opted for the type in which most the features of the application were focused. For example, *alerting applications* generally include the features of *monitoring applications* (e.g., tracking some metric of measure), in that they add additional functionality to their features (e.g., rules that fire if a measure exceeds a given threshold and notify a caregiver or family member).

The ***types of applications*** we identified are:

— ***Monitoring applications*** are systems that keep track of the state of something or someone (e.g., activity sensors like wearable step counters or pedometers).
— ***Alerting applications*** are systems that notify about the occurrence of an event (e.g., medication reminders).
— ***Assistive applications*** are systems that help users in the realization of an activity by suggesting how to perform the activity (e.g., interactive mobility guides).
— ***Training applications*** are systems that guide someone to improve a particular skill over a period of time (e.g., nutritional virtual coaches).
— ***Exergames*** are serious games that have physical exercise as a primary purpose (e.g., Nintendo Wii fitness games).
— ***Serious games*** are games whose primary purpose is solving a problem, not pure entertainment (e.g., cognitive stimulation games).
— ***Communication applications*** are systems that enable remote peers to communicate (e.g., person-to-place texting services).
— ***Social applications*** are systems that enable social interaction and networking (e.g., social networking services).
— ***eLearning applications*** are systems for electronically supported learning and teaching (e.g., Web knowledge and wisdom sharing sites).

As illustrated in the framework picture, the role of application types is not merely that of classifying applications, but, more importantly, that of *connecting* the determinants of AA with the four gerontechnology goals and of *explaining* which type of application may be used to act on the determinants and to implement which goal.

In order to facilitate the comprehension of what characterizes applications for AA, we identify seven major dimensions to further analyze each application:

— ***Stakeholders:*** These are the people who interact with the application. We distinguish three types of stakeholders: the *beneficiary*; the *family*, including informal caregivers and friends; and the *healthcare professional*, which includes formal caregivers (e.g., doctors) and generic healthcare experts (e.g., physiotherapists).
— ***Beneficiary:*** This is the most important stakeholder, typically the older adult, that benefits from the application. Examples of beneficiaries are *independently living* or *community-dwelling* elderly, older adults *following a treatment*, under *informal* or *formal healthcare*, with *physical* or *cognitive impairments*, and similar.
— ***Intrusiveness:*** This refers to how much an application represents an uncomfortable obstacle to the normal life of the beneficiary. Examples of potentially intrusive

elements are *storage of private information*, *frequent requests* to interact with the system, *reminders or alerts*, the need to *wear or carry* a device or sensor, and similar.

— ***Risks:*** These refer to the potential harmful consequences or damages in the case the application or device does not function properly. Examples of risks are *physical injuries*, negative *emotional impact*, or *leak of sensible information*, and similar. The higher these risks, the lower the potential adoption.
— ***Collected data:*** These refer to the information that is captured, processed and/or stored. Typical examples of collected data are: a person's *performance* in a physical or cognitive activity, *medication prescriptions*, *adherence* to a treatment, etc.
— ***Persuasion techniques:*** The are the techniques that aim to keep the motivation to use the application high. Examples are: *gamification*, *competition*, *collaboration*. The full list of persuasion techniques we consider is provided by Fogg [2002].
— ***Infrastructure requirements:*** These include the hardware, software and infrastructure requirements of the application, such as: *PC* (e.g., desktop computer, laptop), *game consoles* (e.g., Nintendo Wii, MS Kinect), *touch/gesture devices* (e.g., tablets and tabletops), and *custom-made devices* (e.g., medication dispensers, vests), and similar.

We use these dimensions in the following analysis, which we structure into four sections, one for each of prevention, compensation, care, and enhancement.

5. IT FOR PREVENTION

We start our review of IT applications and services for AA with those that help people to prevent (or delay as much as possible) age related physical and cognitive decline.

5.1. Applications for Prevention

The first approach to prevention from the IT perspective is the use of ***exergames*** to motivate people to participate in positive and healthy activities. Most exergames are designed to prevent physical decline by helping and motivating elderly to engage in physical activities, maintaining and even improving physical abilities such as muscle strength and balance. Gaming consoles that allow players to control games with their movement favour the development of these systems. For example, many of the games available for the Nintendo Wii console have been tested with seniors in several studies [Koay et al. 2010; Lawrence et al. 2010], almost always with positive results in terms of acceptance of the technology and increase of physical activity. There are also efforts to improve the design of these games to make them even more suitable [Gerling et al. 2010]. In this line, SilverPromenade [Gerling et al. 2011] is an exergame specifically designed to motivate institutionalized frail elderly (e.g., living in assisted living facilities), into taking virtual walks by easily stepping in and out of the Nintendo Wii's balance board (i.e., a board similar to a weight scale that serves as a game controll for the Wii). In this way, the games can facilitate *prevention services* focused on maintaining good levels of physical activity which in turns influence positively the *lifestyle* determinants. To a lesser extent, also Microsoft's XBox 360 Kinect console which does not need a remote sensor but instead uses a 2D camera, has been tested with success to, for example, stimulate visual performance of institutionalized elderly with wheelchairs [Chiang et al. 2012]. According to Jung et al. [2009], exergames in groups can also enable AA by improving *psychological factors* like self-esteem and affect.

Other than game consoles, physical training often demand for custom-built devices and sensors. For example, de Morais and Wickstrom [2011] have used a custom-built device with a camera and body sensor to record the movement of the elderly in order to monitor and guide the senior elderly to exercise Tai Chi. By learning Tai Chi, the beneficiary will also improve physical abilities, positively affecting the *lifestyle* determinant. Similarly, a custom-built walk-board is used by Kim et al. [2012] to encourage elderly to walk more by detecting when they are walking over it and giving incentives to do it again. The incentive is implemented by using the metaphor of a “virtual sheep” that they have to take care of within an animated farm, displayed in a PC. The more they walk, the better the situation of the sheep. Also for walking, Hansen [2011] developed a custom-built robot that plays a ball game with the elderly in which a ball is exchanged between both of them while the robot is moving. The elder has to hand the ball back to the robot, which push him or her to walk. Walking more, in these examples, results in a positive impact on the *lifestyle* determinant.

Mobile devices have also been leveraged for exergames. This is the case of “Walk 2 Win” [Mubin et al. 2008], a mobile game that elderly can play in group or individually and in which to progress, they need to walk in a closed environment and discover hidden artifacts. The application uses a smartphone and local Wi-Fi to detect the user’s geographical location and a central server to synchronize and moderate the game. By simply playing, people increase their walking and socialize at the same time, positively affecting *lifestyle* and *social support* determinants.

Similar to exergames, the second approach to prevention involves the use of ***serious games*** that require the user to do a serious task while playing a game. Most serious games follow the goal of stimulating cognitive functioning skills (i.e., vigilance, visual-spacial attention, selective attention, focused attention, divided attention, hand-eye coordination, memory, etc.), positively affecting *psychological factors* determinants. One example of such games is the simplified version of Stepmania[4] for iPads [Far et al. 2012] designed specifically for elderly to play with and improve their divided attention abilities. Stepmania is a musical game in which a group of floating symbols falls through the screen, synchronized with a background music. The goal of the game is to catch the symbols just when they overlap with their corresponding button on the screen, by tapping on the buttons. Because the game requires concentrating on multiple moving object at the same time it can improve divided attention in the long run. Cogniplus [Schuhfried 2007] is another example with the same goals and wider range of cognitive training programs, deployed on a custom-built computer for animated cognitive games known as the Vienna Test System (http://www.schuhfried.com/vienna-test-system-vts). Cogniplus is used by psychologist in formal therapeutic environments, hence potentially improving health *prevention services*.

Also in the line of improving *prevention services* and *psychological factors*, tabletop devices (situated touch displays on a table) are also a popular platform to deploy serious games for seniors. Two examples are the HERMES Maze [Buiza et al. 2009], used for training memory and preventing the elderly from missing medical appointments; and an adaptation of the popular puzzle game Tangram [Zapirain et al. 2010], used to support psychomotor activity therapies. They both leverage on tabletop devices to offer a range of cognitive training games (e.g. puzzles, crosswords, mazes) that emulate the experience of playing a physical table board game, where seniors sit around a table and play together. The tabletop Tangram uses also a webcam to monitor game playing in order to detect mistakes and train the user in solving the puzzles, with the goal of improving short and long term memory.

More in the line of improving *lifestyle* determinants, mobile devices have also been used to deploy serious games. An example of this is OrderUp! [Grimes et al. 2010], a mobile game that runs on a smartphone and puts the user in the role of a server in a restaurant whose goal is to make meal recommendation as quickly and healthy as possible, in order to keep the job. The more healthy the choices, the more health points the user gains. Ultimately, the goal is to motivate people to consume healthy food. Since

[4]http://www.stepmania.com

a small social network is integrated in the system to discuss nutrition choices, there is also a positive impact in the *social support* determinant. Similarly, Derboven et al. [2012] designed a shopping game where elderly has to remember the shopping list and buy the products in a virtual reality shop. The family can connect with the elderly and assist them with the shopping. This practice improves memory skills, adding *psychological factors* to the list of determinants that are positively affected by this system.

The third approach to prevention is the use of ***training applications*** with the purpose of preventing decline or loss by training an ability or skill. These applications benefit from incorporating persuasion techniques but without making the training into a game like serious and exergames do. An example of this type of applications is ActiveLifestyle [Silveira et al. 2013], an iPad based training application that provides video-based training exercises to improve strength and balance. The application also incorporates persuasive strategies (i.e. positive and negative reinforcement, social interaction with public bulletin board and private mailing system, collaborative training, self-monitoring and reminders) in order to motivate the user into adhering to the training plan. Similarly, Flowie [Albaina et al. 2009] is a training application for motivating elderly to walk. Flowie keeps track of the daily step count of the person with a pedometer and displays progress using growing flower in a situated display placed in the home. A third example of the same type is Seniorcize (http://www.walkinglibrary.com/seniorsize.html), a tablet application that presents workout sessions and tips about physical exercises. By supporting and motivating physical exercises training, all these applications positively affect the *lifestyle* determinant.

In the same line, also affecting positively the *lifestyle* determinant, and leveraging the use of sensors, Steffen et al. [2011] designed an application to suggest physical exercises and monitor the user activity trough a wearable sensor, thereby coaching the user throughout the exercises. Other works have used robots as trainers, which is the case of "robot exercise instructor" [Fasola and Mataric 2010], a mobile robot that coaches the elderly user to perform seated exercises to improve physical strength. During the training, the robot performs the exercise activity and the trainee imitates the robot. Training applications addressing the *lifestyle* determinant are not only about physical activities. DanceAlong [Keyani et al. 2005], for example, is a training application for learning how to dance. Focused on nutrition, Autom [Breazeal 2011] is a small robot that help users to improve their nutrition and prevent health problems through a conversational system that engage elderly in a daily coaching dialog about nutrition.

Finally, one last example of training application is CleverMind (http://www.myclevermind.com), an iPad application with a nice and intuitive interface specifically designed for elderly with decreased cognitive ability that features cognitive assessment training, tracking and reporting integrated within all the other functions of the tablet like surfing the Internet or connecting with loved ones through facebook. The goal is to entertain users while at the same time strengthening their cognitive proficiency, positively affecting *psychological factors* and *social support*.

The fourth approach to prevention is the use of ***monitoring applications*** that monitor user's behaviors, sending this information to third party who can response to it in preventive manners. Most of these applications affect the *prevention services* and *care services* determinants, because they improve the connection of elderly with their caregivers. For example, the nutritional advisor system [Lázaro et al. 2010] allows nutritionists to create a menu and a diet schedule for an elderly patient, who can later report about his or her compliance with the diet, which can have a positive impact on the *lifestyle* determinant. Similarly, but focused on cognitive testing, Byun and Park [2011] designed a monitoring application that keep tracks of the elderly performance metrics (i.e. reaction-time, short-term memory, discernment) in three different cognitive games, informing about it to the beneficiary's doctor, who can use this information to assess the psychological wellbeing of the patient in order to plan interventions or adjust therapies. The same approach is proposed for Alzheimers interventions [Makedon et al. 2010] and for other services to asses cognitive state of elders [Jimison et al. 2004; Jimison et al. 2010] in order to support *prevention services*. Playing games within these applicaitons have also a the additional positive impact on the elder's *psychological factors*.

Another monitoring application to support *care and prevention services* that is mixed with a game consists of a system to monitor elderlys performance in following the instructions correctly when playing Dance-Dance-Revolution (a dancing game where a person receives dancing instructions and needs to move accordingly) [Smith et al. 2009]. The person's movements are monitored through a sensing carpet and a score is presented at the end of each music allowing caregivers to monitor dancing movements and assess patients physical conditions. This, in turn, is used to support training advices or to adjust the physical training program that serves the purpose of preventing physical decline, thereby also addressing the *lifestyle* determinant.

In some cases, a self-monitoring approach might be enough to improve *lifestyle*. For instance, Consolvo et al. [2009] provides a fitness device that allows the elderly to monitor their own physical activities and sends the data to their phone to support user self-awareness about his physical conditions. Another self-monitoring application worth mentioning is the Iom feedback hardware (http://www.wilddivine.com) consisting of a wearable sensor that measures "skin conduction level" as a measure of stress, and later guides the person, through a PC application, in how to control and reduce stress, addressing then the *psychological factors*.

To a smaller extent, prevention is also enabled by the means ***alerting and eLearning applications***. Alerting is used to inform the elder or a caregiver in a potentially harmful situation right away, trying to prevent them from happening. An example is the Ambient Trust Cube [Shankar et al. 2012] consisting of a custom-made light cube that visually alert elderly when they try to visit a risky website (using a definition of risky websites provided by the WebTrust - http://www.webtrust.org), thus preventing potential *risks of violence and abuse* that might result from these websites. On eLearning, Ali et al. [2012] designed an application that organizes nutritional knowledge in modules that are easy to use by elderly, helping them to gain awareness of their nutrition to prevent health problems, thereby addressing the *lifestyle* determinant and positively affecting also *education*.

5.2. Discussion

Prevention applications aim to prevent a decline. This can be physical (e.g. strength and balance), cognitive (e.g. memory, attention and vision) or even social (e.g. social isolation). Hence, accuracy (e.g. accuracy of collected data or functioning of the application or device) so important, since the lack of accuracy does not seriously hurt the beneficiary. This, along with the facts that games are motivating and simply fun, are strong reasons of why most of the applications in this section are ***exergames*** and ***serious games***. In this regard, Nintendo Wii and MS Kinect are frequently used as an instrument to deliver exergames for the elderly. However, most cognitive training games and applications use a cheaper device such as a personal computer or a tablet. Given that physical training games require the beneficiary to perform physical activities, exergames using Wii and Kinect can fulfil this requirement. Cognitive training games usually require an interface with controls (e.g. keyboard, mouse, touch interface) to supply the training program. Bearing in mind the lower demand for accuracy and the beneficiary of prevention application (which is considered as a healthy elder with limitation) games are a very good choice. Another reason for serious and exergames to be so popular in prevention is that they were very successful to increase the adherence of a preventive activity.

Monitoring applications are also widely used for the purpose of prevention because they are useful to keep the healthcare experts updated about the beneficiary's situation and eventually allow the experts to control the beneficiary's behavior. Monitoring applications often-times enable healthcare experts to take decisions about the beneficiarys healthcare and to prescribe a more accurate intervention based on the beneficiary health. Hence, most of these applications target more that one user category. It is usually the beneficiary itself and the healthcare experts or family that controls the monitoring part. Among these, fewer monitoring applications do not involve a third party and instead provide self-monitoring to the beneficiary.

Training applications incorporated with persuasion techniques are also very common, particularly in serious training scenarios, where professionals are behind the training programs that are facilitated by the systems. Gamification is also widely used in most of the training applications in addition with other persuasion strategies (e.g. positive and negative reinforcement, self-monitoring, and awards) to motivate the elderly to adhere to the training plan.

The rest of the applications (i.e., alerting applications and eLearning) are rarely used for the purpose of prevention. In prevention, alerting applications are acting similar to self-monitoring applications by reminding the beneficiary about potential risk or threat that might happen. It is notable that very few applications used eLearning in order to prevent a physical or cognitive decline by teaching the beneficiary exercises that changes their lifestyle to a more active one. Unlike the aforementioned applications, eLearning is using an indirect way to prevent the beneficiary from a wrong lifestyle or activity.

Based on our analysis, prevention applications are usually not too intrusive and tend to be cheap since they often-times do not require high accuracy and a complex custom-built system. Lack of accuracy in these systems however might hinder the user experience and lead to frustration with the technology. Intrusive characteristics might include in some cases the need of carrying or wearing a sensor (i.e., a pedometer to count steps). In general, natural user interfaces such as tablets and tabletops are very common, providing direct interaction with the objects on the interface.

Furthermore, prevention seems to be the most important area where game mechanics and persuasion technologies can find a successful application domain. In fact, they are already in use within many of the contributions for prevention we have included in this review, showing effectiveness in improving, for instance, adherence to training plans [Silveira et al. 2013; Albaina et al. 2009].

Figure 3 in Appendix B presents this summary visually, highlighting the connections between AA determinants and the types of applications that affect them along with their aggregated characteristics.

6. IT FOR COMPENSATION

When an impairment or limitation can no longer be prevented, IT enables AA by compensating the reduced ability. In this section, we describe IT contributions that fall under this category, including assistive, alerting, monitoring, serious games and social applications.

6.1. Applications for Compensation

The first way in which IT contributes to compensating the impact of a reduced or lost ability is by assisting people in activities where the affected ability is involved. We refer to this type of contributions as ***assistive applications***. A system that is exemplary of this approach is MAPS (Memory Aiding Prompting System) [Carmien and Fischer

2008], which helps to compensate memory limitations while performing daily life activities like taking a bus to reach home or shopping groceries for a meal, addressing thus determinants of *psychological factors*, *housing and daily living* and *mobility and transportation*. MAPS uses a PDA (i.e., personal digital assistant) to prompt a person what to do in order to complete an activity, one step at a time. The list of steps to follow (i.e., the assistance script) is previously prepared by caregivers, loaded in the PDA via wireless networks and triggered manually by the person who selects what activity to perform or automatically by the PDA which suggests what to do. MAPS can also integrate information from a public transportation system and GPS in order to provide a real time personal travel assistant. The guidance provided by MAPS has been found to be effective on increasing independence of its users, who were also able to follow instructions, although not always in a precise way [Carmien et al. 2005]. Addressing also *housing and daily living* and *mobility and transportation* but without focusing on *psychological factors*, the Information Bubbles system [Huertas et al. 2010] also provides assistance information in a PDA, only in this case the prompts are automatically displayed when the elder is inside a “bubble” (i.e., usually visited buildings like the town hall or the supermarket) and contain guiding information about that place (e.g., where specific products of the supermarket are). iGrocer [Shekar et al. 2003] is a smartphone assistive application that advises users what to buy, what to avoid and where to find products in the supermarket, based on a nutritional criteria that is previously established to respond to the user’s particular health conditions or needs, addressing the determinant of *housing and daily living*.

More focused on *mobility and transportation* and *psychological factors*, Fujitsu’s Smart Walking Stick (http://www.bbc.co.uk/news/technology-21620624) compensates forgetfulness by embedding an assistive application in an everyday common object used by elderly: their walking canes. The cane has a GPS sensor locate the person, a LED display mounted on top to show what direction should be taken, and it vibrates to indicate when a direction must be changed. Similarly, another embedded IT application is the GUIDE-Me AIS prototype [García-Vázquez et al. 2011], which mounts small displays in medication containers to indicate which pill must be taken, in what doses, at what time, addressing in this way the determinant of *adherence to a treatment*. The Cook’s Collage [Mynatt et al. 2004] also follows this line by embedding a situated display and a recording camera in the kitchen furniture in order to first record pictures of the steps necessary to cook a meal and subsequently display these pictures to aid the person remember the process, addressing then the determinants of *psychological factors* and *housing and daily living*. The BioAid iPhone hearing aid app (http://bioaid.org.uk/) is another assistive example, turning an iOS device into a hearing aid by processing sound from the microphone and then delivering it over headphones in real time, thereby compensating reduced hearing abilities in older adults and addressing *biology and genetics* factors.

IT systems can also act as facilitators of daily life activities, compensating for lack of mobility and strength. This is the case of the Gesture Pendant [Mynatt et al. 2004], a wearable necklace that interprets elderly hand gestures in order to perform home related tasks like opening a door, dim the lights, or close the blinds, addressing in this way the determinant of *housing and daily living*. Similarly, compensation through facilitation can also be achieved by designing user interfaces with a focus on specific limitations, like visual impairments (i.e., *biology and genetics* factors), which are not limited to elderly users, but can also benefit younger users also visually impaired in some way. For example, BigLauncher (http://biglauncher.com/) provides an Android launcher application (i.e., a UI theme) that uses fonts, icons and colors suitable for users with limited vision. Similarly, the No-Look-Notes is “an eyes-free system that uses multi-touch input and audio output” [Bonner et al. 2010] to guide a blind or visually impaired person while writing on a smartphone. Other auditory interfaces are the WebAnywhere browser [Bigham et al. 2008], which facilitates internet navigation using the voice and provides an audio output of the content in websites; and the PEN-PAL [V. et al. 2011], which is an electronic pen that scans and reads out loud any text document. In general, most of the IT applications for accessibility (e.g., screen readers like JAWS - http://www.freedomscientific.com/products/fs/jaws-product-page.asp) are suitable to compensate visual impairments that come with age.

In the same way that BigLauncher compensates visual impairments with a carefully designed user interface, the IDBlue special pen [Iglesias et al. 2009] compensates the lack of skills in using technology by offering a more natural interface to interact with a digital agenda system. Lack of skills with technology often leads to frustration and a decrease in self-esteem, which is part of the *psychological factors* determinant. The digital agenda organizes elderly daily activities and medical visits. The pen can read RFID tags that are attached to images on a special board. Like a remote control, each image represents a functionality of the agenda that runs on a PC. When the user taps an image with the pen, the associated tag is read and transmitted via Bluetooth to the computer, which interprets and executes the actions on the system. The digital agenda in itself is also an example of an assistive application for compensating declining memory.

A second way in which IT compensates age-related cognitive decline is via ***alerting applications***, the most typical example being medication intake reminder systems that alert the person when it is time to take a medicine, addressing the determinant of *adherence to a treatment*. The e-Pill medication dispenser family (http://www.epill.com/), EMMA (http://www.inrangesystems.com/) and RMAIS (RFID-based Medication Adherence Intelligence System) [McCall et al. 2012] are some examples of embedded reminders in medication dispensers (i.e., custom- made devices that organize and facilitate the retrieval of pills). Alerts can be auditive, visual or even phone calls that will only stop once the patient takes the pills from the dispenser. If missed, e-Pill dispensers will also send SMS or email alerts to caregivers. We mention only three in this paragraph, yet alternatives abound in the market and in literature [McCall et al. 2012]. Other examples of medication intake alerting applications are implemented as smartphone applications, which is the case of UbiMeds [Silva et al. 2009], Wedjat [Wang et al. 2009], AIS REMIND-Me [García-Vázquez et al. 2011] and the Medication Compliance System [Qudah et al. 2010].

Another interesting usage of alerting systems is for compensating visual impairments to address the determinant of *mobility and transportation* through the use of ultrasound detectors (i.e., like the sonar of submarines) integrated with walking canes to detect objects that are further away from the original cane length. Once the sonar detects a potential obstacle, the cane would start to vibrate to alert the person about the obstacle. Examples of this are the Ultracane (http://www.ultracane.com/), the K-Sonar (http://www.batforblind.co.nz/) and the Miniguide (http://www.gdp-research.com.au/minig_1.htm).

A third way of IT for compensation is the use of ***monitoring applications***, commonly part of alerting systems, that complement the task of compensating cognitive decline for addressing *adherence to a treatment*. As an example, radio frequency identification (RFID) technology has been used to add monitoring in medication dispensers [McCall et al. 2012][Ho et al. 2005]. RFID tags are attached to medication boxes. The medication dispenser uses an RFID reader to scan the medication box and read information about the treatment and the doses stored in the RFID tags. This information is compared with the measures of a scale that weighs the box after the pill is taken, to monitor how well the treatment is followed and inform the user. CARE-Me [García-Vázquez et al. 2011] is also a monitoring application for compensating cognitive decline and improving medication compliance. It uses a positive feedback metaphor in a digital photoframe to inform about compliance and make the patient aware of the progress. The metaphor is a tree that it is populated with parakeets. Each parakeet represents a week of the treatment and grows in size after every day in which the dose of the medicine was correctly taken. At the end of the week, the parakeet flies away and a new one appears [García-Vázquez et al. 2011]. This is one of the very few systems that integrates a persuasion technique to motivate the person in achieving a goal.

The Fujitsu smart stick (http://www.bbc.co.uk/news/technology-21620624) and the alerting mobile application proposed by Qudah et al. [2010] can be also listed as monitoring applications. The first uses 3G or Wi-Fi connectivity to send positioning data back to a host computer, where caregivers or relatives can monitor the person's position, along with other vital signals like the hearth rate, addressing mainly that person *mobility and transportation*. The second uses data-mining algorithms and bio sensors for analyzing patterns of medication intake in relation with vital signals (e.g., hearth rate), with the hope of better understanding medication effects, addressing then *adherence to a treatment*.

One last monitoring application that belongs to the domain of compensation is the memory aid Show me the Video proposed by the HERMES project [Buiza et al. 2009]. This application records a video stream of the elderly's house events, and then replays them in a tabletop device to help the beneficiary to remember the event, addressing *psychological factors* and compensating for age-related reduced memory.

The fourth way of IT for compensation is the use of ***serious games*** to compensate for reduced memory through the means of an entertaining game. In this line, MoviPill [De Oliveira et al. 2010] addresses the determinant of *adherence to a treatment*, improving medication compliance by persuading patients with a mobile phone game that fosters social competition. Each time the patient takes the medication, a score is calculated based on how close to the prescription time it was taken. At the end of each week, the game highlights the week's winner to all players and resets the game for the following week. A second Serious game that also help to compensate age-related reduced memory (i.e., *psychological factors*) is the HERMES Maze [Buiza et al. 2009], which is deployed in a tabletop device and challenges patients with a maze that has an appointment sheet as the reaching point. The patient has two starting points, one with "appointment clues" (e.g., medical visit) and the other with "time clues" (e.g., 11 a.m.). By playing the game, the elderly is aided to recall real life appointments with doctors or medication intake times. In terms of evaluation, only De Oliveira et al. [2010] include a study where the effectiveness of social competition was compared to the use of reminders, finding that social competition augmented compliance.

Finally, the field of Robotics has also contributed with ***social applications*** in the form of robots that provide companionship and sense of social connectedness to compensate loneliness and thereby address *psychological factors*. Generally, they are used by seniors who are under psychological therapy for dementia or depression. Two examples of this type of robots are the Huggable [Stiehl et al. 2006] and Paro [Wada and Shibata 2007]. Both Paro and the Huggable are therapeutic robotic companions with sensitive skins that react to touch to trigger some type of response of the robot. The Huggable serves also as a communication and monitoring medium, collecting information in the form of video and audio, which is later sent to a health professional, who can in turn monitor the progress of the patient and communicate directly with him if there is a need. A field trial of Paro shows both a psychological improvement and a physiological indication of stress reduction (via urinary tests) after interacting with the robot for a while [Wada and Shibata 2007].

6.2. Discussion

Compensation applications are mostly used by older adults independently, mostly because they are oriented to older adults that have either cognitive or physical impairments that need to be compensated (e.g., lack of memory, visual limitations, hands tremor, etc.). Compensating a cognitive and some physical decline (e.g., loss of sight or hearing) often requires to work on building physical artifacts or infrastructure (e.g., walking canes, motorized wheelchairs, hearing aid devices, ramps etc.). This is what is usually referred to as ***assistive technology*** and we have decided to draw a line on what we consider IT by including only applications that process and store information that people can consume or interact with. It is common that IT applications for compensation require then some form of custom-made hardware (e.g., medication dispensers). Mobile devices and wearable sensors, combined with home automation equipment, are other typical infrastructure requirements. Family and doctors are involved when monitoring applications are used to track medication compliance, allowing them to know when a person has not taken the medicine. In general, alerting applications for compensations are oriented to self-sufficient people, able to follow instructions. Monitoring applications for compensation aim at extending assistance in the form of additional control. Not including common assistive technology applications, IT for compensation mostly contributes to compensating cognitive decline related impairments.

Frequent reminders and access to personal health information (e.g., medication compliance, daily life activities and vital signals) are common elements of these applications that could potentially be perceived as intrusive, raising privacy concerns. Constantly wearing or carrying devices or sensors (e.g., the gestures pendant) can be perceived as physically obstrusive [Melenhorst et al. 2004], which is why this aspect needs to be designed carefully to render their benefits clearly in order to reduce this perception. When the benefit of technology is noticed clearly and they are seen as relevant, people are willing to make concessions about their privacy [Shankar et al. 2012]. More importantly, since people will rely on these applications for guidance, there is a risk of producing more harm than good if the guidance is not correct or appears in the wrong moment. Persuasion techniques (e.g., goal-setting, rewards, social competition) are used in this domain, mainly for addressing medication compliance by keeping people motivated to follow their treatments. This seems to be a promising direction that has not been thoroughly explored yet.

As final note, there is clear tendency toward more integration between physical artifacts and information and communication technologies (like in the case of the augmented canes). More and more, assistive hardware is merging with information and communication technologies, resulting in an emerging field of opportunities for new and innovative assistive services.

Figure 4 in Appendix B visually summarizes this discussion, showing the different types of applications, AA determinants they affect and their aggregated characteristics according to our evaluation framework.

7. IT FOR CARE SUPPORT

IT for Care comes into place when a problem can no longer be prevented nor compensated, and assistance is needed, either to facilitate recovery from an incident or to reduce the impact of a chronic condition.

7.1. Applications for Care

The first approach to care support is the use of ***alerting applications*** aimed at taking care of elderly by alerting someone about the occurrence of an event, with the goal of triggering response when falls, missed or due medications, lack of activity and other adverse situations put elderly at risk.

The major part of these applications are for detecting and alerting about falls. Thanks to these alerts, caregivers can immediately react and avoid or at least reduce the risk of more serious injuries. Most of these systems rely on wearable sensors that leverage on the use of tri-axial accelerometers to monitor body motion and detect falls [Sim et al. 2011; Tong et al. 2009; Bourke et al. 2008]. In addition to accelerometers, Doukas and Maglogiannis [2008] collect and monitor sound data, combining it with movement data in order to detect falls of patients. Chen and Lin [2010] introduce an RFID- based gait monitoring system to assist caregivers detect stumbles and falls. Tests in laboratory were successfully performed to check the effectiveness of the fall detection system. Of these evaluations, only Doukas and Maglogiannis [2008] performed a pilot study with real people, involving 5 older adults. The results of this study showed that the mobile device to detect the falls was effective in doing so, but the especial vest designed to carry the device was uncomfortable.

Next to wearable sensors, mobile devices and applications have been explored and tested to alert about falls [Cao et al. 2012; Fang et al. 2012; Kaenampornpan et al. 2011]. These applications process the data collected by the phone's accelerometer, and when a fall is detected, send an alerting message first to the user himself, and, if the user does not reply, to a list of emergency contacts.

Another approach to alert about falls is supported by cameras. In that case, the images captured by a set of cameras installed in a given environment are continuously processed and monitored in real time to detect falls, and alert caregivers using a personal computer or a dial center in case of a fall emergency. For instance, Shieh and Huang [2009] propose a "human-shape-based falling detection algorithm". Doukas and Maglogiannis [2011] and Yu et al. [2010] leverage on the combination of audio and video information, known as multimodal processing, using a speech recognition system to double check a possible fall by also analyzing the extracted voice. Fernández-Caballero et al. [2012] "mix accelerometer-based fall detection and computer-vision-based (visible and infrared) fall detection".

Environmental sensors are also an option to detect and alert caregivers about detected falls. Alwan et al. [2006] introduce a floor vibration based fall detector combined with "battery-powered pre-processing electronics to evaluate the floor's vibration patterns and generate a binary fall signal". Whenever a fall is detected a wireless transmitter sends the alert to a communication gateway, that in turn forwards the alert to caregivers. Alertings systems for fall detection and response can enable AA by can enable AA by supporting and improving *care and prevention services*.

As previously noted, alerting applications are also applied to warn caregivers about problems of *adherence to a treatment*. For instance, UbiMed [Silva et al. 2009] is a mobile application that offers automated scheduling, reminders and tracking of prescription drugs intake, including proactive alerts sent to physicians and relatives when the patient fails to adhere to the prescription regime. The medication compliance system [Qudah et al. 2010] is another mobile application that integrates a medication compliance system with the use of biosensors (e.g., electrocardiogram) to "monitor and provide personalized feedback to cardiac patients and health professionals". These two applications also aim at compensating memory loss and improving adherence level to a treatment as described in Section 6.

In addition to mobile applications, some contributions integrate alerts to caregivers in medication dispensers like e-Pill (http://www.epill.com/), EMMA (http://www.inrangesystems.com/) and RMAIS [McCall et al. 2012]), with the goal of assisting people in managing their complex medication regimen autonomously at home, without the active support of a caregiver but still involving the latter in monitoring compliance.

The second most common approach to care in our review uses ***monitoring applications*** to track elderly health, daily life activities, and dangerous situations (e.g., fire, unknown people breaking into the house, or elderly lack of activity), aiming at providing better and faster care when necessary, improving in this way both health *care and prevention services* determinants. Examples of these applications, use wearable sensors to monitor vital signals and body motion, share such information with caregivers who evaluate their behavior and, intervene when there is a problem (e.g., low vital signals, high blood sugar, low pressure) [Megalingam et al. 2011; Liu et al. 2011; Cabrera-Umpiẃrrez et al. 2010]. Monitoring application also leverage on the use of wearable sensors to collect data about seniors' daily life activities to detect low levels of activity, e.g., a symptom of depression or a coming disease, and inform health professionals about this [Kiss et al. 2011; Consolvo et al. 2004; Yen et al. 2011]. Some of these applications are also used as alerting applications that remind the elderly about upcoming events like a visit to the doctor, the time for taking a medicine or the time to buy groceries [Yen et al. 2011] to encourage them to be more active. Some alerting applications that are used for improving *adherence to a treatment* are also bundled with monitoring applications that collect information about medication compliance and sends it back to doctors or the family for following up [McCall et al. 2012; Qudah et al. 2010].

More focused on health information, DigiSwitch [Caine et al. 2011] captures images from daily activities of older adults, allowing them to view this "information as it is collected and temporarily cease transmission of data for privacy reasons". Holzinger et al. [2010] collect vital signal and body position data to detect abnormalities (e.g., faints, low or high heart rate) and call an assistance center (which makes it also an alerting application). Cameras have also been used for the monitoring purpose, Nasution and Emmanuel [2007] leverage on posture- based events recorded by cameras to identify possible intruders. Appiah et al. [2011] and Shankar et al. [2012] adopt cameras aiming at monitoring daily life activities and alerting caregivers in case of unexpected behaviors (e.g., elderly did not wake up or spent many hours on the bed, undesired people inside the house). Monitoring applications can also be used to help health professionals in providing assistance, like the case of Lifeline [Gorman et al. 2003], a monitoring system used by doctors to follow patients with cognitive disabilities while they try to accomplish a task and conveniently help them if they detect that they are lost, having a positive influence in the feeling of safety of patients, part of the *psychological factors* determinant.

Another approach to care comes in the form of ***serious games and exergames***. Both have shown to be effective for improving elderly care by the means of, for instance, rehabilitation sessions in virtual reality environments. This approach presented good results in motivating and improving physical conditions of elderly recovering from hip fracture story [Giotakos et al. 2007]. Moreover, Nintendo Wii Fit has been used to improve elderlys balance during stroke rehabilitation care sessions [Sugarman et al. 2009]. Both applications were tested with real users. The first approach, was tested with 66 participants, 98% of which felt less fear of falling after the physical intervention period. The second test was focused on feasibility, showing positive results in a clinical setting, where the only participant of the study improved balance and self-confidence. Sugarman et al. [2009] state, however, that "further studies need to be done in order to assess the social validity and effectiveness of the use of the Wii and similar gaming systems as a treatment modality". Improvements in reducing the fear of falling have a positive impact on the *psychological factors* determinant the use of these games as part of rehabilitation therapies can improve the *care services* determinant.

Closely related to games, ***training applications*** are also used for care. Deployed on tabletop devices, some training applications have been used during upper extremity motor rehabilitation care sessions in order to improve motor control [Annett et al. 2009]. This approach was in the process of being installed in the rehabilitation hospital. The initial responses the authors received from the therapists were positive, which indicates that these application can potentially improve *care services* by facilitating the delivery of training from real therapists.

Finally, only one IT for care contribution in our review falls well under the category of ***social applications***, improving the *social support* determinant through a cognitive training platform where caregivers can assist patients with cognitive impairment in cognitive tasks that are part of training program [Meza-Kubo et al. 2009]. Although this application can be also classified as a ***training application*** that addresses *psychological factors*, the focus of the contribution is set on the platform to involves the family network in assisting the cognitive training from remote, putting the social aspect upfront.

7.2. Discussion

Most of the care applications focus on assisting independently living elderly, in order to prolong their independence and consequently postpone their entrance in a nursing home. Care applications are characterized by the involvement (in the use of the system) of all three stakeholders of our evaluation framework: beneficiaries, health professional and the family. The goal is often to support remote healthcare monitoring of elderlys daily activities, health status, and adherence to treatments.

Among the applications, alerting applications (mainly for fall detection) and daily monitoring solutions are the most widely researched. In the former, the elderly needs to carry or wear a special device (e.g., mobile phone, body sensors) or be surrounded by sensors, cameras, or microphones to monitor his environment. Such approaches make the daily life of elderly safer in the sense they can receive fast assistance when risky situations are detected (e.g., falls, unconsciousness, potential symptoms of a disease). Proper monitoring and alerting systems can lead to fast diagnosis and reaction by from caregivers in case of emergencies. In addition, they increase the sense of security and diminish the fear of falling [Sugarman et al. 2009; Giotakos et al. 2007], affecting positively not only the wellness of the person being monitored, but also their physiological and emotional conditions.

Privacy issues are critical in these applications since sensible data needs to be collected, stored and analyzed. Due to the risky nature of the situations that care applications are designed to control, accuracy is an important aspect. Lack of accuracy is hence among the most important risks aspects on care applications. Moreover, depending on the approach, the person who is being monitored can feel too much control over him/her in addition to privacy concerns, which may cause some discomfort. Wearing a body sensor or carrying a smartphone all the time increases the intrusiveness of such services.

Exergames, serious games, and training applications have also been explored and tested as means to keep older people mentally and physically active, although only with small user samples and during short periods of time [Sugarman et al. 2009; Annett et al. 2009; Giotakos et al. 2007]. In such preliminary studies, researchers noticed that these games decreased participants' fear of falling, and also improved their balance.

Care and prevention services, along with adherence to a treatment are the determinants most addressed by care applications. In contrast, a few of the care applications we have reviewed have an impact on other determinants including psychological factors, social support and risk of violence and abuse. When addressing psychological factors, the goal is either on facilitating family involvement on cognitive training [Meza-Kubo et al. 2009] (which in turns increases social support) or on facilitating the task of remotely following and assisting daily life activities [Gorman et al. 2003] of patients with cognitive disabilities. More evaluation, however, is needed to establish the effectiveness of these applications. As for the *risk of violence and abuse* determinant, the only solution in our review that can have an impact on this leverage on a mixed monitoring and alerting approach that uses a surveillance system that controls house entrances and alerts caregivers and family members in case of undesired visitors. In this context, an evaluation has found these type of systems are only accepted when their usefulness is clear. Moreover, spatial privacy (where the camera is placed) is less important than activity sensitivity (what is the activity that is being monitored). A camera in the door to provide security is then much more accepted than a one inside the house due to different nature of these different spaces [Shankar et al. 2012].

An important note on applications for care is that they often fall in the borderline between care and prevention (especially, monitoring applications). When the main goal is to facilitate the provision of care in case of emergencies rather than preventing a particular situation from happening, we have categorized the system as a care application. Borderline issues also appear often with compensation, because the provision of care in itself can be seen as a way of compensating for a lack. However, we have generally applied the rule of classifying a system as compensation when the system does not involve a third person to provide some form of care.

Figure 5 of Appendix B presents this summary visually, showing the connections between AA determinants and types of applications with their aggregated characteristics according to our evaluation framework.

8. IT FOR ENHANCEMENT

Enhancement is about enriching the life of people by opening new opportunities for participation, health and security. The last group of contributions we describe in this paper fall under this category.

8.1. Applications for Enhancement

The first and foremost way in which IT enriches opportunities of life it is through ***social applications***. Some of these adopt a holistic approach, trying to enhance opportunities in many aspects of people's social life. Life2.0 [Kälviäinen 2012] is an example of this, envisioning a web-based platform targeted at senior citizens and their local communities, where they can easily see who is around, what is happening and communicate with others in the community, improving their *social support*. The platform addresses also the *employment* determinant by allowing elderly to explore who can help with a task and also offer help or other services on their own. The iNeighbour TV (http://socialitv.web.ua.pt/index.php/projects/ineighbourtv/) also addresses both these determinants by offering similar functionalities but with a user interface more familiar to seniors: their TV sets. NextDoor (https://demo.nextdoor.com/) and HomeElephant (http://www.homeelephant.com/) are other similar community oriented social networking platforms (in this case focused on neighbourhoods), which are not specifically tailored for seniors but that can fit their needs and increase their *social support*. Not focused on local communities but also aiming at a broad range of social needs, the Silverline project (http://silverline.mobi/) is developing a family of smartphone applications tailored for seniors like *Discover*, which will allow them to share their daily activities on the go; and *Inspire*, which delivers inspirational stories in text, picture and video formats on a daily basis with the goal of enhancing their subjective wellbeing.

Other social applications focused more strictly on enhancing socialization, allowing elderly to share something of their interest (and hopefully of interest to others too), interact and communicate with others. NetCarity [Leonardi et al. 2008] addresses *so-*

cial support by facilitating socialization with family and community through tabletop applications such as the *Social Window* and the *Public Square*. In the first, each member of the family is represented by a house, forming a virtual neighbourhood where, by tapping on a house, the senior can get status information and options of communication with that person. In the second, the user interface emulates the central square of a community, where people would physically meet, including news boards and containers for sharing digital media by dragging and dropping local media on the square. Other applications aim to enable novel ways of interacting for people who are away of each other. StoryVisit [Raffle et al. 2011], for example, extends the experience of video-conferencing by allowing adults to read and tell a story book to younger children using a web application that synchronizes the story at both ends of the communication, displaying the text of the story on the screen of the reader, and text with pictures (like a real book) on the screen of the child listener. This allows elderly to stay connected with their family in a funny way, improving *social support* and *communication access*. Similar systems that are commercially available are *Playtell* (http://playtell.com/), *Readeo* (http://www.readeo.com/) and *A Story Before Bed* (http://www.astorybeforebed.com/) Remote social interaction for seniors has also been addressed through the means of simplifying traditional social networking services like facebook. FamilyRibbon (http://www.familyribbon.com) is an example, offering both tablet applications and web front ends to use a simplified user interface of facebook. Similarly, Phiriyapokanon [2011] has proposed a redesign of facebook with an emphasis on metaphors that are common knowledge to seniors, like a newspaper deployed on an iPad

Face-to-face socialization can also be improved with IT to address *social support*. SharePic [Apted et al. 2006] is a tabletop application that allows multiple users to share pictures and collaborate in their management or in the creation of other picture-based resources like postcards and collages, while they are together. Similarly, The Timecard [Odom et al. 2012] and the Shoebox [Banks and Sellen 2009] can enhance face-to-face interactions by triggering conversation when people are together, exploring old memories, which in turn can positively influence *psychological factors* like their self-esteem or coping styles (i.e., the conscious effort placed on solving difficult personal and interpersonal problems). These two applications allow elderly and their families to organize and explore life memories using a situated display embedded in artifacts that imitate familiar physical objects like the shoe boxes people used to put pictures in. The Timecard was particularly seen by users as a way to cope with loss of family members [Odom et al. 2012]. In the same line, Reminiscens [Parra et al. 2013] is a tablet application that stimulates storytelling of personal memories by displaying contextual multimedia around life stories. The goal is to motivate intergenerational face-to-face interaction to address *social support* and stimulate reminiscence to address *psychological factors*. The same goal is pursued by CIRCA [Gowans et al. 2004], but with the focus placed on supporting reminiscence therapies for dementia patients. Although not for face-to-face interactions, other applications that also support reminiscence to address *psychological factors* and allow elderly to share their stories to address *social support* are the Project Greenwich [Thiry et al. 2013]and the Book of Life by the european project SOCIABLE (http://www.cognitivetraining.eu/). The first offer a website for elderly to share their life stories while the second one is a tabletop application that emulates a book where each chapter corresponds to a different stage of life (e.g. infancy, adolescence, and adulthood). A final example worth of mention is MEMENTO [West et al. 2006], a system based on a physical interface, the ANOTO pen and paper, to allow seniors to write their stories in a physical paper while their writings are automatically digitalized. The final story is both digital and physical, enabling sharing via email or in face-to-face interactions.

The knowledge of elderly can be important also for collecting and preserving the collective memory of a community. For example, Memoro (http://www.memoro.org/) is a mobile application to collect videos of elderly telling their stories and advises, automatically sharing the video on a public web site with the purpose of preserving their knowledge and wisdom, positively affecting their *psychological factors*. Also the PACE telementoring platform [Bernard et al. 2011] leverages on the knowledge of seniors to help young people in learning languages or any other skill during a video conference call, which increases elderly *social support*. Similarly, wisdom/knowledge sharing websites like the Elders Wisdom Circle (http://www.elderwisdomcircle.org/) and The Amazings (http://www.theamazings.com/) open new opportunities of *employment* to seniors that want to offer their counselling to others that might need it. In The Amazing, the sharing takes the form of online courses that cover a wide range of topics including, among many others, knitting, water color painting and gardening. The TimeCapsule [Liu and Huang 2011] is a final example for this paragraph, addressing *social support* by offering a social networking service that allows seniors to digitalize old pictures, add location information and write stories about them so other people can later see and comment on these pictures when they pass by the place where the pictures were taken using a mobile application.

Also for enhancing the *social support* determinant, some social applications seek to improve participation of elderly in local community events. The Mirror Motive [Shankar et al. 2012] aims to achieve this by detecting when the old person is near the mirror and then displaying general information about the local community, including invitations to social events that will take place nearby. A more subtle way of participation is by consuming information shared by friends and family, increasing their awareness of their lives. ePortrait [Cornejo-García 2010] connects social networking services to a photoframe situated in the house of the old person. Pictures posted by the family in a closed group of facebook are automatically downloaded to the photoframe. A similar system is proposed by Biemans and Dijk [2009], which uses SIM-based photoframes where family and friends can send MMSs with pictures and text. Using a tablet instead of a photoframe, Rodríguez et al. [2009] propose an "electronic newspaper through which elderly and their families share information, personal reminiscences and stories", interacting also in real time through a turn-by-turn memory cards game.

A second general way of enhancing life is by improving and increasing the means of communication, addressing the determinant of *communication access*. ***Communication applications*** fulfil this role, with some focused solely on improving, facilitating or increasing access to communication mediums. What's Up [Dianti et al. 2012] is an example of this, facilitating intergenerational communication by providing a communication platform and a tablet application specifically designed for elderly to receive messages from their younger relatives and friends, who in turn use their smartphones. The main goal of What's Up is simplicity, giving elderly a tool in which they do not need to do anything while messages will just arrive and appear on their tablets. An evaluation of What's Up based on *think aloud* protocols and questionnaires revealed that the older the user, the simpler the UI that is preferred, putting simplicity as one of the most important features. Other systems similar to What's Up with extended capabilities and commercially available are VideoCare (http://www.videocare.com/) and ConnectMyFolks (http://www.connectmyfolks.com). In the same line, senior oriented smartphones and tablets are comercially available, most offering a simplified UI of smart mobile systems, oriented to users that engage with a touchscreen or a smartphone for the first time in their lives. Examples include the Fujitsu Stylistic S01 (http://www.fmworld.net/product/phone/global/convention/mwc2013/mwc01), Emporia (http://www.emporia.eu/en/home) and Doro phones and tablets (http://www.doro.com).

Other applications address the determinant *communication access* with tools to support person-to-place communication, which provides a communication link between the family that is constantly on the move and the older adult who is staying at home. The Epigraph [Lindley et al. 2009] and the HomeNote [Sellen et al. 2006b] are two noticeable examples, by which people can send messages directly to a place (e.g. home) rather than a person. The first uses an special touchscreen display where elderly can select from a list of channels, each corresponding to one member of the family who can update the channel via email or SMS. The HomeNote is very similar, with the addition that it supports also local scribbling by using a stylus to write over the device, to leave notes that are meant to be read by anyone at home. Similarly, the Message Center [Wiley et al. 2006] relies on a piece of paper for seniors to write messages which are automatically scanned by a special device and sent either via email, SMS or fax to a mobile phone, a PDA or a fax machine. The same device can also receive messages and print them. Other systems in this category are Wayve [Lindley 2012], Collage [Vetere et al. 2009] and On Message @ Home [Perry and Rachovides 2007]

Enhancement also addresses the determinant of *social support* with ***monitoring applications*** oriented to increase participation in the lives of family and friends by increasing awareness of their whereabouts. The Ambient Plant [Shankar et al. 2012] is exemplary of this, with a system composed by two flower pots at different houses that detect when a person is nearby and and notifies about this to the remote side, where lights on the pot will be turn on to inform the person on that side about the presence in the other end. The goal of this system is to increase feelings of social connectedness by letting the elderly know when the family is at home. This simple awareness about family whereabouts has been pointed out as a way of supporting the peace of mind for extended family members (i.e., those living away) [Rowan and Mynatt 2005]. The Home Awareness prototype [Lynggaard and Petersen 2010] has the same goal, only in this case the focus is set on a remote place, collecting information of that place's environment and reproducing it at local side. A special home device is installed at the receiving home to reproduce the remote environment's light, temperature (using a controlled fan) and sound (using skype), which, according to a field trial, can be translated in people having a picture of the remote place constantly in their heads, triggering practical concerns (e.g., it is time to mow the lawn again) and giving them a feeling of satisfaction and connection. Another example in this line is the Digital Family Portrait [Mynatt et al. 2001] that uses a situated display to show daily life events of an elder in the form of icons around a portrait located at the house of the family. The Whereabouts Clock [Sellen et al. 2006a] does something similar, but displaying information about the family at the elder house. Using information of the GSM cell ids in family members cellphones, the system displays location information of each of them in a situated display that has the form of a clock with pictures of the family members moving around. Sellen et al. [2006a] evaluated the Whereabouts Clock and found that visual representations of family whereabouts increased the sense of community. A more recent commercial product in this line is Lively (http://www.mylively.com), which enables automatic activity-sharing between family members using special low cost sensors that are attached to everyday home objects like the fridge or medication containers. These sensors automatically sense when these objects are moved, and depending on those movements, infer what the activity is for later sharing with the family a summary of daily life patterns.

Exergames and serious games that are played with others to enhance socialization can also serve to improve *social support*. There are basically two types of serious games in this domain: those that aim to enhance social interactions and exergames which serious purpose is to enrich physical activities of elderly. In the space of social interactions, Mahmud et al. [2010] propose an inter-generational game, deployed in a tabletop device, where elderly and their grandchildren compete to find a princess in a maze. In the same line, Age Invaders [Khoo et al. 2008] is an augmented reality game deployed on a special display integrated with the floor of the house. On top of it, elderly and their grandchildren play in teams following footprints and other that appear on the floor. Age Invaders is also an example of an exergame that helps to improve physical fitness by enriching physical activities of elderly.

Finally, one last way for enabling AA through enhancement is using ***eLearning applications*** to address *education* and *employment* determinants by allowing elderly to gain knowledge and skills that can help them to improve their *participation* in society. RefocusLab (http://www.liuc.it/cmgenerale/centri/cetic/refocus/default.htm) and SeniorLearning (http://www.seniorlearning.eu) are two platforms of eLearning oriented to elderly. Both are based on the open source eLearning platform Moodle and are proposed by European Projects with the goal of training older adults in information communication technology (ICT).

8.2. Discussion

Enhancement applications improve or open new opportunities for *socialization*, *communication* and both *contribution* to and *participation* in society. In particular, IT has greatly contributed to enrich opportunities of the ageing population in terms of social support and communication access, connecting them better to family, community and professional caregivers and benefiting almost in equal measure independent living, community-dwelling and elderly living under formal care in assisted living facilities. Our review presents a prevalence of social and communication applications above the other types of applications. Interestingly, also monitoring applications have an impact on *social support* by facilitating constant awareness about family and friends' whereabouts. While privacy is not at concern if the applications are perceived as useful, there is a need to support ON, OFF and PAUSE for monitoring [Shankar et al. 2012].

Most of the contributions we have reviewed involve the end beneficiary and the family. To a lesser extend, health professionals are sometimes involved as well. Usually, they demand constant or too frequent interaction through prompts or reminders, which is an aspect that needs to be designed with care not to become intrusive. In the same measure, data collected by enhancement applications very often include personal information and social contacts, which is also an aspect to design carefully not to become a barrier for adoption.

Because of the prevalence of social and communication applications, the most common determinants that are addressed by enhancement applications are *communication access* and *social support*. Since many of these applications have an strong emotional impact, *psychological factors* can also be influenced by enhancement. The risk, however, is that these system could also have unexpected negative effects on people's emotions. For example, when elderly is put in contact with their personal life and memories, we have observed in our practice that some perceive this as a reminder of their age, while at the same time others find it rewarding and joyful. The emotional impact of the application is thereby and important variable to control when building enhancement systems.

On the other hand, few contributions we have analyzed explored the dimension of keeping elderly in their work to address the *employment* determinant. These contributions are mainly focused in allowing older adults to share their knowledge, experience or wisdom for the benefit of younger people or peers. Building systems that can help seniors to keep contributing to society, is an area that still holds many opportunities for innovation. Crowdsourcing could be an area to explore for this. Mutual help systems also hold some potential while raising some concerns about who administer the offering of help to assure that the seniors are not abused [Kälviäinen 2012]. There is also much to do yet in the space of *education*, to keep seniors active in learning new skills that can open opportunities for employment or simply interaction for them.

Another interesting thing to notice is that very few of the enhancement applications exploited persuasion techniques in order to increase social interactions and communication. This means that there is an open space for exploration of persuasive technologies that are specifically designed to motivate socialization.

One aspect that is emphasized by most enhancement applications is simplicity. This emphasis might explain why most applications for enhancement rely on touch or gesture devices, like tablets and smartphones, as means of interaction with the older adult, showing a clear trend towards natural or direct manipulation interfaces, which are usually considered as easier for users that do not have much experience with technology. Also because of this emphasis on simplicity, many social applications operate with the intuition that current popular social networking services are too complex for older adults, considering that the features of social services should be described in no more than 6 sentences [Phiriyapokanon 2011]. In contrast to this, statistics show that senior users of social media continue to increase year after year [Zickuhr and Madden 2012], with one third of the Internet users aged 65 or more using social networking sites. After age 75, however, the Internet use drops significantly.

In summary, enhancement applications, along with care, are the most rich in terms of diversity of features that are used by individual applications, informing about general aspects of life and mediating communication and interaction being the most common features. Much of the work on enhancement address the emotional dimension of increasing the feeling of connectedness by providing awareness about our family or friends whereabouts or enhancing the person's self-esteem by giving some purpose to his or her life. This makes it extremely difficult to evaluate what is the actual impact of these technologies on people's wellbeing, resulting on a lack of strong evaluations in the form of randomized controlled experiments.

Figure 6 in Appendix B represents this summary visually, illustrating the relationship between AA determinants and types of applications.

9. RELATED WORK

Other surveys, reports and studies on ageing and technology exist; some of them also served as starting point for this survey. The motivation why we felt a new survey was needed is that most of these works either focus primarily on technology or they put their emphasis on ageing in general, without trying to bring together the two perspectives and to analyze which IT solutions may serve to alleviate which aspect of the ageing process. The goal of this survey is therefore to fill this gap and to connect researchers and practitioners working in the field of IT with researchers and practitioners working on gerontology, health, psychology and policy making.

The works that are related to this survey can be divided into four major groups: *a*) Health reports; *b*) Ethnographic reports; *c*) Policy-making reports; *d*) and HCI and technology reports;

Health reports specifically focus on ageing problems and their solutions from a medical (non-IT) perspective. In some cases, health reports also specifically mention IT solutions, however typically focusing on specific aspects only, such as, physical activity [Goldsmith 2012; Concannon et al. 2012; Li and Lindenberger 2002; Morrison and Baxter 2012].

Ethnographic reports describe specific aspects of the ageing process and the ageing population [Wenger et al. 1996; Karavidas et al. 2005; Notess and Lorenzen-Huber 2007; Elena Portacolone 2011; Neves 2012; Righi et al. 2012]. For space reasons, we did not elaborate on this aspect in this survey. However, these references may help the interested reader to further strengthen his/her understanding of the topic.

The most representative examples of ***policy-making reports*** are the WHO policy framework for AA [WHO 2002] and the report about the role of IT for AA services prepared by the IPTS (Institute for Prospective Technological Studies of the European Union) [Malanowski et al. 2008]. These works provide an excellent understanding of the ageing process from a policy-making perspective, clarifying what are its determinants and what is needed to deal with the process from a societal perspective. Given their focus on policies and regulations, they however lack insight of how IT can help improve the AA process.

Finally, ***HCI and technology oriented research*** mostly focused on how technology is used or integrated in peoples lives. Many surveys, for instance, focus on usability principles guiding the design of technology. Phiriyapokanon [2011], provides a broad overview of principles to design IT for elderly, along with a summary of the typical challenges older adults may face when using technology. Another good set of principles and general theory about ageing and technology are the reports on accessibility and ICT by the The John Gill Technology Institute (http://www.johngilltech.com/guidelines/). The focus of these works is on decline in the context of ageing, neglecting the opportunities that arise if we consider ageing as an active process.

Other related surveys more specifically focus on usability, focusing on a particular aspect or interface like input devices (e.g., pointing devices, keyboards, mice, joysticks, trackballs, etc.) [Taveira and Choi 2009] or multi-touch screens [Loureiro and Rodrigues 2011]. These surveys provide interesting summaries about what is considered good and bad when designing a system for an ageing population (e.g., touch/gesture devices are more suitable than keyboard and mouse).

The report on the state of technology in ageing services prepared by Alwan et al. [2007], provides a classification of technologies and applications/services for ageing, depending on the scenarios of usage of the technologies. Our classification takes inspiration from some elements of this survey, putting its emphasis however on life course outcomes (prevention, compensation, care, enhancement), which can be facilitated and achieved with IT. Bouma et al. [2006] classify different applications for visual independence from a Gerontechnology perspective. The survey by Xie [2003] studies the interaction of older adults with technology in terms of attitudes, perception and usage. The surveys by Mynatt et al. [2004] and by Kientz et al. [2008] provide an overview of home-based applications for their Aware Home, a three floors house designed for facilitating research on the topic of technology for independent living, while providing an authentic home environment. Breazeal [2011] explores how social robots can be applied in healthcare. With our survey we try to bring all these specific aspects under one common framework that allows one to easily switch between technologies (solutions) and ageing aspects (problems).

10. SUMMARY AND OUTLOOK

In this survey, we reviewed the different interpretations of Active Ageing (AA) according to the existing literature and showed its evolution over time. We discussed how Information Technology (IT) can serve not only to mitigate some of the negative side effects of ageing (e.g., physical and cognitive decline) but also how it can serve to give raise to new opportunities (e.g., by enhancing capabilities). We proposed a conceptual framework that brings together the two different perspectives and correlates the determinants that affect quality of life during the ageing process with the type of support IT can provide to modulate these determinants. We used the framework to systematically review exemplary IT services and applications that explicitly provide support for AA, an exercise that allowed us both to appreciate the extraordinary value IT may bring to older adults and, at the same time, to identify a set of challenges and opportunities.

We summarize these latter as follows, grouped by the four gerontechnology goals that accompanied us throughout this survey:

— ***Prevention***. Modern, IT-assisted prevention aims to promote lifestyle changes early in the life of a person. This is particularly visible in *training applications* and in many of the *serious games* and *exergames* reviewed in the paper. The increasing inclusion of specifically targeted *persuasion strategies*, aiming to increase effectiveness, into games and applications is particularly noteworthy in this context. Although the application of games to enable active ageing – but also to brake social isolation – is just in its beginnings, the number of IT applications in the serious games and exergames categories is already considerable. We read as an indication that the transformation of older adults into active, playful older adults is already ongoing. The question is whether this trend can be sustained with the availability of novel technologies only or whether there is something else that needs to happen for seniors to become more playful. A better evaluation of this aspect is needed to understand both the dynamics and, possibly, how to improve technologies. Partly, this is part of our own future work, e.g., in the context of the *ActiveLifestyle* [Silveira et al. 2013] and *The Virtual SocialGym* research project (http://socialgym.org/)which both aim to enable and motivate older adults to stay physically fit and heavily leverage on suitable persuasion strategies.

— ***Compensation***. Most of the identified IT solutions for compensation are oriented toward compensating the symptoms of *cognitive decline*, such as the loss of memory. This result is somewhat physiologic, in that we focused on software solutions and commodity devices for personal use. Especially for compensation, we however note an increasing integration of *custom hardware* with *dedicated software* and services. On the one hand, hardware is more and more carefully crafted in the form of wearable devices and sensors that are more powerful, more precise and less invasive and that keep the level of additional stress low. On the other hand, we have seen that compensation applications are most effective if they are integrated into the living environment of older adults and which is designed for and aware of their limits and capabilities. In this respect, we expect to see a better integration of applications, devices and domotics in the near future. If we widen our focus a bit, we can see a trend toward bionics and robotics for compensation, which will enhance the human body with artificial extensions and improvements. The challenge here is understanding how to bring together the IT and these novel technologies.

— ***Care***. From an economical perspective, economical restraints will force us to translational and clinical research towards *personalized medicine* (diagnostics and treatment), thereby steering efficient therapy for AA, e.g., with companion diagnostics and increasing cost effectiveness. This demands academy and industry to provide completely novel tools and possibilities for innovation and potential commercialization within life science in close collaboration between health care, academy, and industry, focusing on individual needs. IT has allowed tremendous improvements and spreading of promising telemedicine applications, but, despite the technical maturity, telemedicine services for AA are still limited and the market remains highly fragmented. Telemedicine is a tool that should be integrated as much as possible into the usual practice of future public healthcare, however, the integration of telemedicine service in healthcare systems is still an open challenge. Home (re)habilitation is becoming one of the most appealing applications of telemedicine. The increasing share of the elderly population and the related expected increase in health care costs, are a strong incentive to search for new ways to assist AA for individuals at home, e.g., via dedicated technologies. For instance, we have reviewed several care applications, where monitoring and alerting capabilities are increasingly used in a home or informal environment to enrich the quality of health services.

— ***Enhancement***. An interesting aspect we have noticed throughout our review is that the merger of physical assistive technology with information and communication technologies does not only bring an increasingly wide range of innovative services to prevention, compensation and care, but it also connects people with older adults and keeps them engaged in community activities. Social applications are spreading among older adults and increasingly connect them with friends and their family/-community circles. There is also an emerging thread of emotions-oriented social applications, whose main purpose is to enhance peoples subjective wellbeing. An aspect we have seen is not yet well developed, is education or work for older adults. We expect the advent of MOOCs (Massive Open Online Courses) [Liyanagunawardena et al. 2013] as well as the crowdsourcing of work (e.g., via crowdsourcing platforms specifically tailored to elderly) to play a major role in this respect in the near future. Our future work in this space is represented by the *Reminiscens* project [Parra et al. 2013], which brings together older adults as narrators and young volunteers as listeners in storytelling sessions where a tablet application is used to facilitate the preservation of their memories while stimulating interaction with contextual multimedia and questions.

While in the beginning of IT for AA the focus was mostly concentrated on usability and user experience (in Appendix C we summarize the most important lessons learned), today the landscape if IT for AA is much more varied, open and rich of opportunities. Much has been achieved in terms of interface design and ease of use of technologies for older adults, but today the focus has noticeably shifted toward new services, applications and devices that can be offered to prevent, compensate, care and enhance and to make ones life better - independently of age. Beyond any doubt, the role that IT played so far in enabling this transition was crucial, and its potential and contributions are far from over.

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