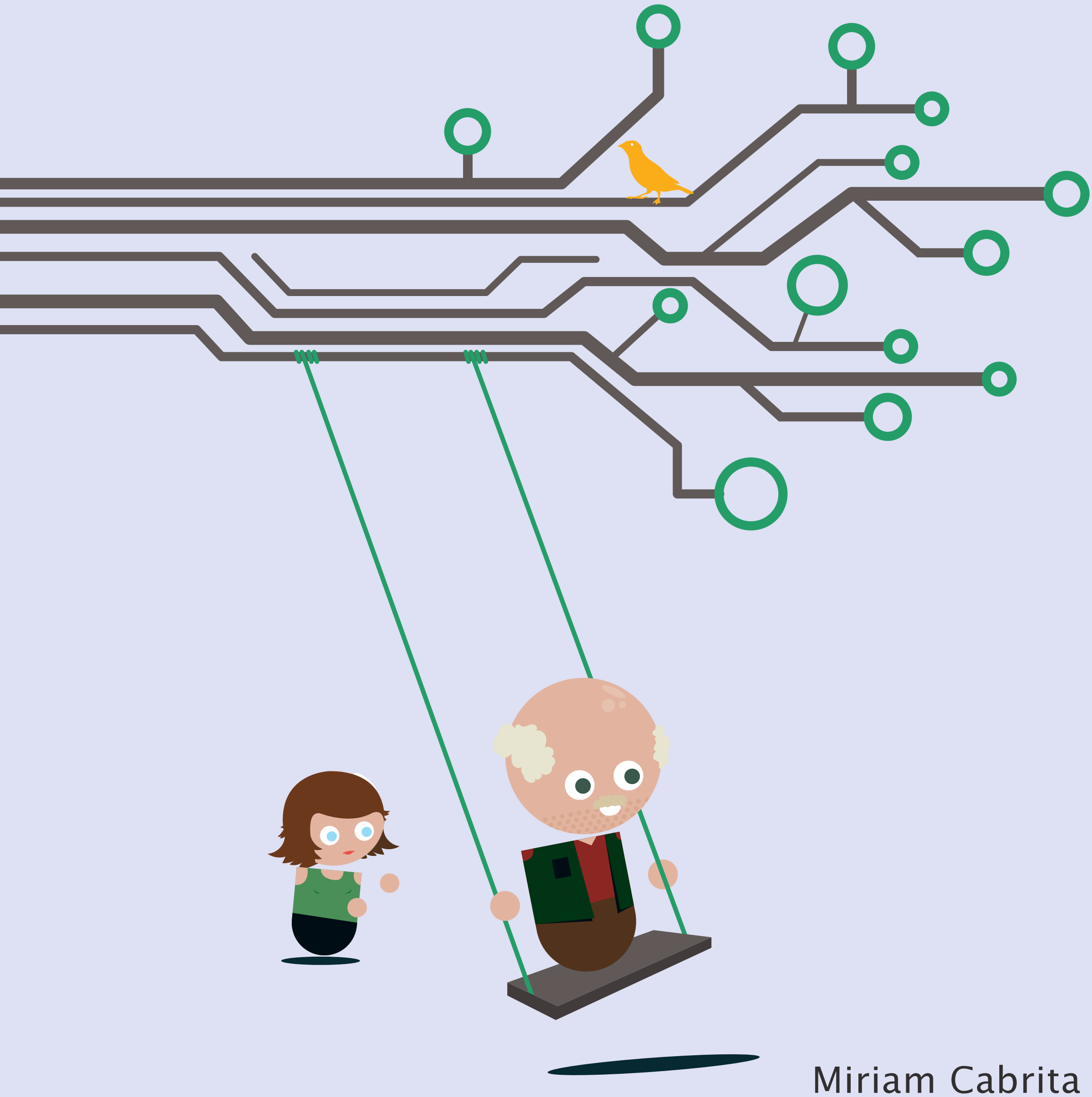
Active and Pleasant Ageing

supported by Technology



Miriam Cabrita

ACTIVE AND PLEASANT AGEING

SUPPORTED BY TECHNOLOGY

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DISSERTATION

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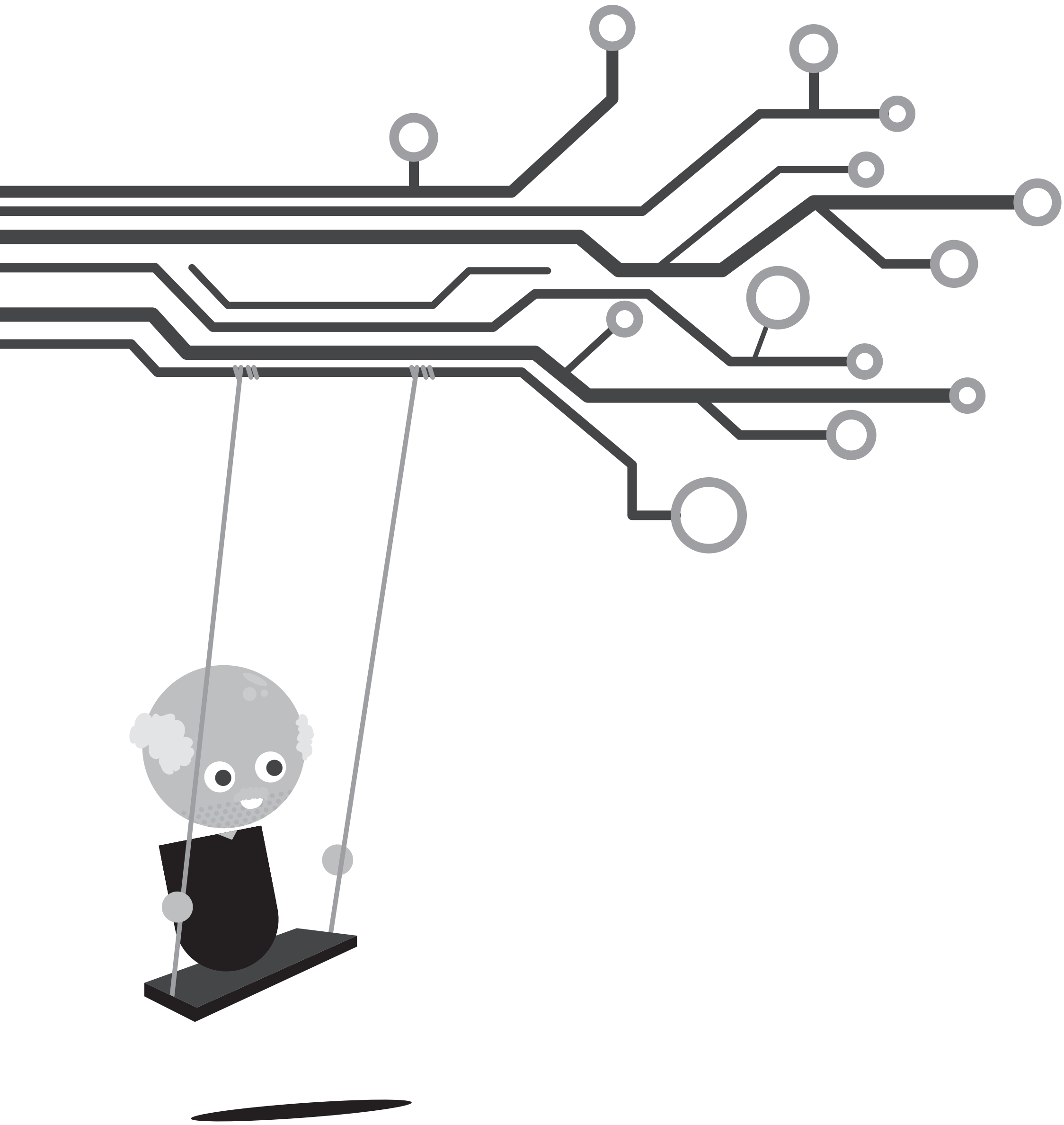

Chapter 1

General introduction

Active and Healthy Ageing

The proportion of the global population aged above 60 years old is growing more rapidly than any other age group[1] creating several social-economic challenges. Finding strategies to preserve functional independence for as long as possible is a priority to reduce the burden on the healthcare sector and enhance quality-of-life for the older population. In 2002, the World Health Organization (WHO) outlined a policy framework for Active Ageing, defined as "*the process of optimizing opportunities for health, participation and security to enhance quality of life as people age*"[1]. This framework focuses on the support that can be provided by the community and public health policies. However, a big part of the responsibility is for older citizens themselves to actively engage in the prevention and management of their own health. In 2015, the *World Report on Ageing and Health* introduced Healthy Ageing as "*the process of developing and maintaining the functional ability that enables wellbeing in older age*"[2]. As such, Healthy Ageing places the individuals as active participants in managing their own health, focusing on the importance of healthy behaviors – including physical activity – as strategies to preserve functional ability in older age. Noteworthy is that both definitions place wellbeing as the ultimate goal, in agreement with the idea of positive ageing from George Vaillant "*to add more life to years, not just more years to life*"[3].

Information and Communication Technologies (ICT) facilitate the empowerment of older adults in managing their health. Telemedicine systems and services – often interchangeably referred to as telehealth or eHealth systems[4] – concern the use of ICT in the prevention, diagnosis and/or treatment of diseases from a distance[5]. For Active and Healthy Ageing, telemedicine services can provide support in monitoring, diagnosis and treatment in several life domains, such as physical and mental health, mobility, social connectedness, everyday activities and leisure[6].

The main aim of this Thesis is to explore how technology can be utilized in the support of Active and Healthy Ageing in daily life, by promoting physical activity and emotional wellbeing.

Figure 1 presents the three key research topics of this work. The first topic was already introduced: Active & Healthy Ageing. The second topic is *physical activity*, one of the focal points in strategies to support Active & Healthy Ageing. The third topic is *wellbeing*, the ultimate goal of Active & Healthy Ageing. Our research will adress the intersections between the pairs of these three topics (*highlighted in light grey*). The research on *Active and Pleasant Ageing*, which gives title to this PhD Thesis, emerges in the overlapping area between the three topics (*highlighted in dark gray*). Particularly, we investigate how technology can support Active and Pleasant Ageing in everyday life. In the next sections, we address each one of these topics in further detail, state the objectives of the Thesis and we end the section with a description of the outline.

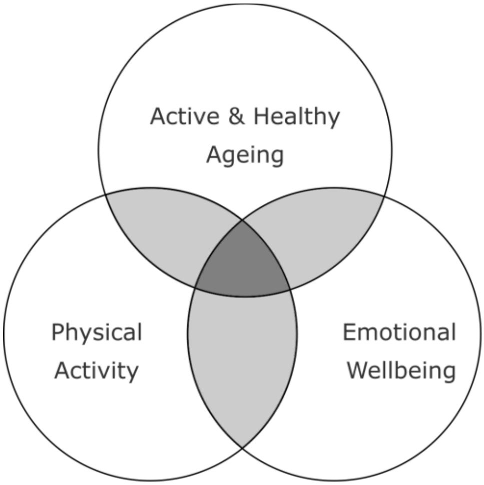

Figure 1. Core elements of this PhD Thesis on Active and Pleasant Ageing.

Physical Activity

Maintaining an active lifestyle is one of the key factors contributing to Healthy Ageing. Physical activity has well-established benefits for physical health[7,8] and to preserve functional independence[9,10]. Physical activity, in this context, is defined as the total of voluntary movement, produced by skeletal muscles during every day functioning, including but not limited to exercise[11].

The "Global Recommendations on Physical Activity for Health" for the age group 65+ advises at least 150 minutes of moderate-intensity physical activity throughout the week, or at least 75 minutes of vigorous-intensity physical activity throughout the week or a combination of both, performed in bouts of at least 10 minutes. Additionally, older adults should engage in exercise to enhance balance at least 3 times a week and muscle-strengthening activities at least 2 days a week. These guidelines also highlight that, in this age group, "*physical activity includes leisure time physical activity, transportation (e.g. walking or cycling), occupational (if the person is still engaged in work), household chores, play, games, sports or planned exercise, in the context of daily, family and community activities*"[12]. All daily activities are crucial as even low-intensity physical activity provides health benefits[13]. This means that, next to flexibility, strength and balance exercises, older adults should be active in their daily life, reducing the sedentary time (i.e. time spent sitting or lying).

Despite the well-known benefits of an active lifestyle for physical health, most older adults do not reach the recommended activity levels. According to the results of a Eurobarometer survey (data collected in 2002 and 2009) on sports and physical activity among citizens from the 28 EU member states, the older adults are less likely than any other age group to be engaged in regular physical activity of any intensity (i.e. light-, moderate- and vigorous-intensity). Additionally, those aged 55+ reported the longest time spent sitting on average per day, only after the school-aged population[14]. In the USA, by age 75, one third of the men and two thirds of the women report not engaging in any regular physical activity[15]. When asked about the barriers to engage in regular physical activity, older adults refer to poor health[16,17], but also provide reasons such as lack of interest[16–18], lack of time and not enjoying the activities[18]. Within this Thesis, we look at approaches to promote physical activity in the daily lives of older adults to support Active and Pleasant Ageing.

Emotional Wellbeing

In line with the focus of Healthy Ageing on *maintaining the functional ability that enables wellbeing in older age*, the last two decades experienced a move from clinical psychology focused on symptoms, to a new science focusing on the psychology of strengths. As a result, the science of Positive Psychology emerged with a focus on the promotion of optimal functioning and wellbeing based on both personal and environmental resources[19], supporting individuals and communities to thrive and build the best in life. Since its introduction by Martin Seligman and Mihaly Csikszentmihalyi in the millennium issue of American Psychologist, the science of positive psychology has gained interest from various fields, such as education[20,21], productivity in the workplace[22], organizational management[23,24] and health.

Wellbeing *is* the topic of Positive Psychology[25]. Wellbeing is a complex construct with many definitions and descriptions being found in literature[26]. Two approaches are identified when looking at the historical background of the study of wellbeing: the eudemonic tradition, which focus on optimal human functioning and self-realization (e.g., [27,28]), and the hedonic tradition, which is centered on optimal experiences. Emotional wellbeing belongs to the hedonic tradition, and concerns the presence of positive emotions (e.g. joy and calmness), the absence of negative emotions (e.g. sadness and anger), and satisfaction with life[29–31]. As such, the experience of positive emotions in daily life is expected to enhance emotional wellbeing[32]. Although some lines of research defend a distinction between mood, emotions and affect[33], there is no consensus in literature and therefore, for the purpose of simplicity, we adhere to the term *positive emotions* throughout this Thesis. Positive emotions are influenced by daily contexts and situations and thus prone to fluctuations in daily life[34,35]. Given that we look for strategies to support Active and Healthy Ageing in daily life, emotional wellbeing – and particularly its construct positive emotions – is the third core topic of the Thesis.

This Thesis

The experience of positive emotions in daily life contributes to Active and Healthy Ageing by influencing physiological parameters, for example, by improving immune response and cardiovascular function (e.g. [36,37]). However, physiological parameters are not the most relevant parameters from the perspective of the older adults. As people age, the perception of being healthy tends to be more related to the preservation of functional abilities, than to the absence of disease[2,38]. To the best of our knowledge, there is no overview on how positive emotions relate to "*functional ability* [...] *as people age"*. A relation between functional ability and positive emotions would underline the link between physical and mental health among older adults and open new horizons on interventions supporting Active and Healthy Ageing. Therefore, placed in the intersection of the topics Active and Healthy Ageing and Emotional Wellbeing, the first objective of this Thesis is:

Objective 1*: To investigate how positive emotions relate to functional ability of older adults living independently*.

Within the scope of this Thesis we hypothesize that positive emotions can also contribute to Active and Healthy Ageing by improving the receptivity and adherence to behavior change strategies, in our case by supporting the adoption and maintenance of an active lifestyle. Firstly, in accordance with the Broaden-and-Build Theory[30], positive emotions act as openers for acceptance and adoption of new behaviors. In this way, we can target the experience of positive emotions, to nudge individuals towards new activities, and consequently initialize new behaviors. Secondly, positive emotions play a role in the maintenance of behaviors, as the experience of positive emotions while performing an activity is a motivator to repeat that activity[39]. Additionally, engagement in activities that individuals know are good for them, might lead to a feeling of fulfillment and accomplishment, leading to more positive emotions and contributing to an 'upward spiral of lifestyle change'[40].

Several meta-analyses indicate that being physically active is associated with a higher *psychological* and *social wellbeing* in older adults[41–43]. However, when looking at *emotional wellbeing*, the relationship with physical activity is less clear. Specifically, there is a gap in the literature when it comes to the relationship between emotional wellbeing – and in particular positive emotions – and non-structured physical activity (i.e. beyond exercising). We hypothesize that by identifying those activities (and their respective social and physical contexts) that are associated with both positive experiences, as well as physical activity, we are likely to define more effective interventions that support individuals in becoming more active in their daily life.

At the beginning of this PhD research, the dynamics between physical activity and positive emotions in the daily lives of older adults had been scarcely investigated. Within a sample of 13 adults (aged 50-60 years old), a study of Kanning and Schlicht using self-reported activities and mood, has suggested that episodes of physical activity were positively associated with three dimensions of mood: valence (e.g. content and happy), energetic arousal (e.g. awaked and fatigue) and calmness (e.g. calm or relaxed)[44]. An interesting suggestion of this study is that the positive effect of physical activity on mood, is stronger when the initial mood is at low level. This study supports the idea of interventions promoting physical activity as a tool to improve mental health. A limitation was the lack of an objective overview as the authors themselves assigned the type of reported activities (e.g. *going for a walk* or *reading a book*) into physically active or inactive episodes. In a replication study from the same research group, using objective measures of physical activity (accelerometry) among a sample of university students, the authors found similar results in what concerns the dimensions valence and energetic arousal, but not in calmness[45]. Both studies provide limited indication that physical activity and positive emotions *do* relate in daily life.

Longitudinal studies regarding this topic are hardly done, what can be partially explained by the fact that the study of emotional states and physical activity involves two disciplines: human movement and psychology, respectively[46]. Additionally, studying behaviors in daily life often requires extensive diaries to be filled in for long periods of time. Recent developments in technology allow for innovative research methods, namely ambulatory assessment, to gather detailed insight into everyday behaviors, thoughts and feelings during everyday activities in a less obtrusive manner[47]. Ambulatory assessment has been acknowledged as being particularly interesting in the context of performing research on the relation between physical activity and positive emotions[48]. Therefore, the second objective of this Thesis is state as follows:

> **Objective 2**: T*o improve the understanding on the relation between positive emotions and physical activity in the daily lives of older adults living independently using ambulatory assessment.*

Technology in the support of Active and Health Ageing

Mobile technology, such as smartphones and on-body sensing, allows for continuous monitoring of parameters in daily life and for communicating to the user at opportune times (e.g. provide feedback or motivational messages[49]). Moreover, mobile technology allows for the interventions to be designed and adapted to the individual user, often called personalization or tailoring[50]. Tailored interventions are even more important when targeting older adults than other populations considering the vast heterogeneity in the physical and cognitive capacities of this age group. All-in-all, mobile technology allows interventions to be embedded in everyday life, making it a suitable media to deploy interventions aimed at the support of Active and Healthy Ageing.

Mobile technology has been frequently used in the monitoring and promotion of physical activity[51]. For example, SMS functionalities have been incorporated in physical activity interventions[52]. Contrarily, the use of mobile technology to monitor or promote emotional wellbeing in everyday life is far less explored. Building on the concept of *Positive Computing* introduced by Sander[53], Riva et al. proposed an approach called *Positive Technology*. Based on principles of Positive Psychology the authors state the aim of Positive Technology as "*to use technology to manipulate and enhance the features of our personal experience with the goal of increasing wellness, and generating strengths and resilience in individuals, organizations and societies*"[54]. More specifically, the authors link ICT-related topics to the constructs of wellbeing. To our particular interest, the authors suggest that through affective computing or emotional design, technology might enhance positive and pleasant experiences, and therefore, enhance emotional wellbeing. However, this relates to how the technology is designed (e.g. aesthetical and functional values) and not to the purpose of technology, as in behavior change systems.

Given the theoretical premises from the previous section, and the opportunities provided by mobile technology to deploy interventions in daily life, we introduce the concept of *Active and Pleasant Ageing*, combining the promotion of physical activity and emotional wellbeing, thereby supporting Active and Healthy Ageing. To the best of our knowledge such an approach – one that combines support of Active and Pleasant Ageing with technology – has not yet been considered. The third and last objective of this Thesis is stated as follows.

Objective 3: *To investigate how technology can support Active and Healthy Ageing targeting the promotion of physical and emotional wellbeing in everyday life.*

Outline of the thesis

In line with *Objective 1*, we started this research by performing a systematic review of the literature on the relation between positive emotions and functional ability of older adults living independently (**Chapter 2**). There is solid evidence that being physically active plays an important role in the prevention of functional decline. But how do positive emotions contribute to the preservation, or decline, of these functional abilities? Which parameters should be monitored on a daily basis to detect functional decline? These are examples of questions that we aimed to address in the systematic review.

Pursuing *Objective 2*, the first empirical study presented in this Thesis investigates the social and physical context of daily physical activity (e.g. location, social companionship and type of activity) and corresponding pleasure in the daily life of older adults. Some questions of interest were (1) how do older adults spend their time? with whom? where?; (2) how much do older adults enjoy these activities?; (3) how do daily activities moderate the relation between pleasure and physical activity?;

(4) how do the daily activities distribute themselves in the dimension of physical activity and the dimension of pleasure?. To answer these questions, ten older adults participated in an observational study during one month in which physical activity was monitored using an accelerometer and the activities of daily living, context and respective pleasure were monitored using experience sampling method in a smartphone application (**Chapter 3**).

Moving towards *Objective 3*, we investigated how older adults experience health technology in their daily life and what their expectations are. This study was divided into two parts. In the first part, we investigated current practices in managing health in daily life, attitudes towards using technology and expectations from technologies, by performing semi-structured interviews with twelve older adults. This study analyzed four health domains: physical function, cognitive function, nutrition and wellbeing (**Chapter 4**). After assessing expectations of technology, we provided the same older adults with a short intervention – consisting of goal-setting and feedback – to coach physical activity and monitor emotional wellbeing in daily life. The data collected through step counters and experience sampling method was analyzed, and compared to the experience of the subjects, reported through semi-structured interviews (**Chapter 5**).

In the last chapter (**Chapter 6**) we looked separately at four components of technology to support Active and Healthy Ageing – *sensing*, *reasoning*, *coaching* and *applications* – with physical activity and emotional wellbeing as core parameters. For each one of these activities we looked at the past and state-of-the-art, incorporating the lessons learned from the literature study and empirical studies. Finally, we provided a glimpse at future trends on the field of technologies supporting Active and Healthy Ageing.

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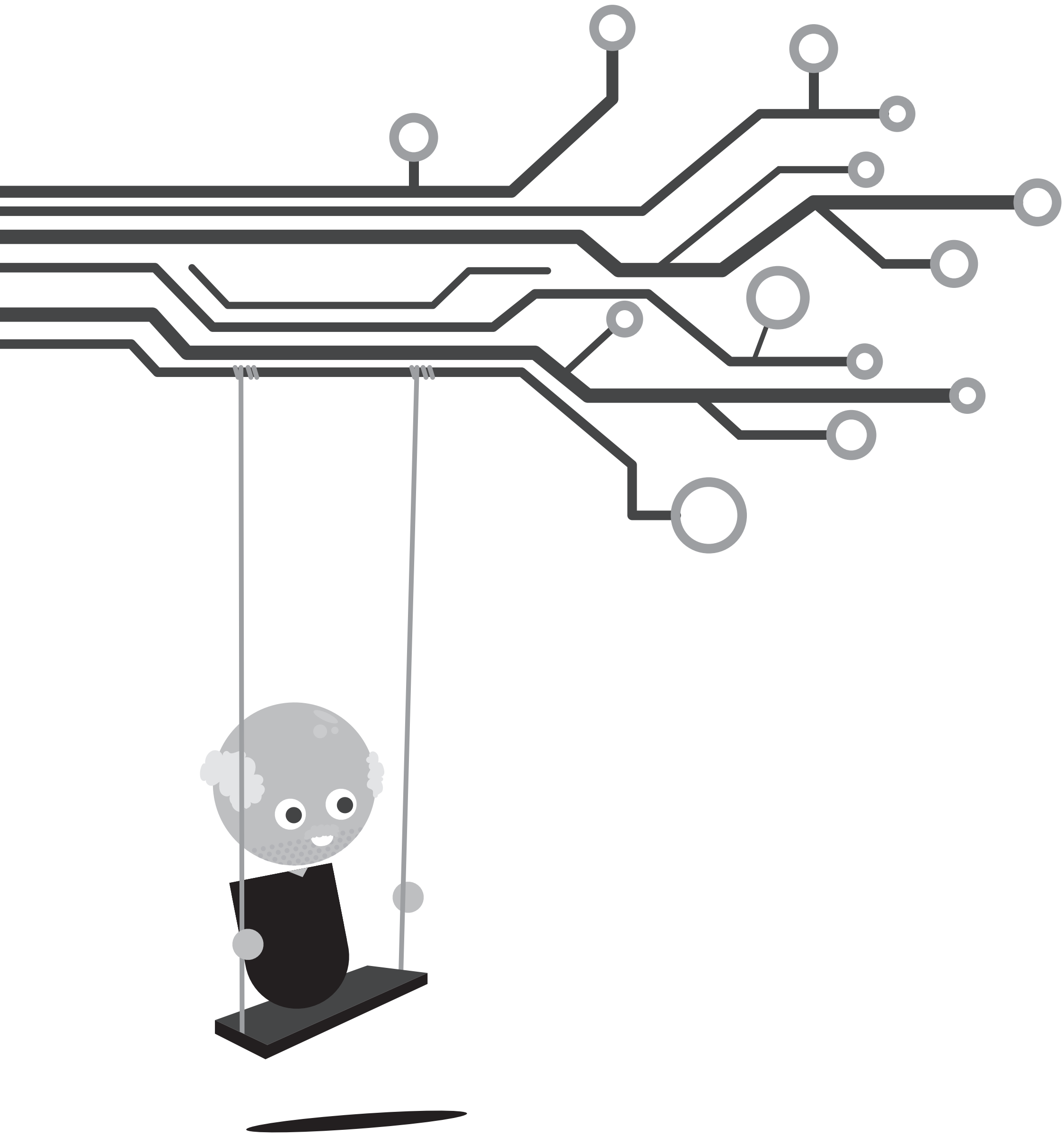

Chapter 2

Relation between positive emotions and the functional status of older adults living independently: a systematic review

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Abstract

Objectives: Literature suggests that positive emotions positively influence physiological parameters but their relation to functioning in the daily life of older adults living independently remains unclear. The present work aims to investigate the relation between positive emotions and functional status in daily life of older people living independently.

Methods: A systematic literature review was conducted using the PubMed, PsycINFO and Scopus electronic databases. Included works were peer-reviewed empirical studies that analysed the relation between positive emotions and ability to perform activities of daily living (ADL) with older adults living independently.

Results: After removal of duplicates, ten out of 963 papers met the inclusion criteria. Cross-sectional studies (n=6) provided limited evidence about a relation between positive emotions and functioning in daily life. However, longitudinal studies (n=4) provide significant evidence for an interaction between the two factors, suggesting that time influences this interaction.

Conclusions: The variety on the design and samples of the studies included in this review does not allow a cohesive conclusion of the results. Nevertheless, limited evidence suggests that higher frequency in the experience of positive emotions might be associated with lower functional limitations. The issue of causality in emotions-functioning remains unclear from the review. Further observational studies are highly recommended, supported by innovative technologies.

Introduction

The proportion of the global population aged above 60 years old is growing more rapidly than any other age group[1]. The high prevalence of multimorbidity among the older population[2] brings several challenges, such as the growing demand for healthcare in society and the need for support of independent living.

As people age, the perception of being healthy tends to be more related to the functional abilities of the individual, rather to the absence of disease[3,4]. Following this perspective, the World Health Organization defines Healthy Ageing as "*the process of developing and maintaining the functional ability that enables wellbeing in older age*"[4]. This functional ability concerns the daily activities that support both the survival of the individual (often named basic activities of daily living) and the interactions with his environment (also known as, instrumental activities of daily living). There is growing evidence from both theoretical and empirical research that promotion of wellbeing can lead to improvement of functioning, or delay of decline[5,6].

The literature often distinguishes many components of wellbeing. One of those components, positive emotions, is considered part of our emotional wellbeing[7]. Emotional wellbeing, also known as subjective wellbeing, concerns the experience of pleasurable engagement with the environment, eliciting feelings, such as happiness, joy or serenity[8,9]. In contrast to other wellbeing components, such as life satisfaction[7] and psychological wellbeing[10], that reflect more stable patterns of individual functioning, positive emotions concern feelings and emotions at a certain moment and are prone to influences from the environment[8]. Because of their daily fluctuations, positive emotions are more suitable for daily measurement than any other aspect of wellbeing[11]. Despite the fact that some lines of research defend a distinction between mood, affect and emotions[12], there is no consensus in literature and therefore we use these terms interchangeably, referring to positive emotional states.

Several reviews suggest that positive emotions directly influence health, for example, by alleviating symptoms and pain and improving immune response and longevity (e.g. [6,13–15]). However, to the best of our knowledge, there is no comprehensive review of the literature in what concerns the relation between positive emotions and functional status in older adults living independently, a growing part of the world population. As functioning concerns activities and their context, it can be hypothesized that a person's functional status might influence the experience of positive emotions in daily life. Pressman and Cohen suggest both a direct and indirect route through which positive emotions in turn might influence health that may also account for the relationship between positive emotions and functional status[13]. A direct route may involve mainly direct influences on physiological functioning and disease, mediated for example by positive influences of positive emotions on (para)sympathic activity, the opioid system and health practices such as sleep, exercise and diet. A more indirect route suggest that positive emotions might buffer potentially pathogenic response towards stress. This is related to the broaden-and-build theory of positive emotions. As proposed by this theory, people who experience positive emotions more frequently are more likely to build a variety of resilience resources, such as environmental mastery and social support[8,16], which may help to overcome stress and induces a broader range of possible behaviors[17]. In line, it can be hypothesized that an increase in daily positive emotions might slow down or delay functional decline. The present investigation of the relation between positive emotions and functional decline will thus benefit the development of daily life interventions aiming at prevention of functional decline, thereby reducing health care costs and demands.

The present work involves a systematic review which aims to investigate whether there is evidence, from observational studies, on the relation between positive emotions and functional status of older adults living independently. Second, we aim to investigate the causality of this relation.

Methods

Search strategy

Electronic literature searches were performed on the PsycINFO, Pubmed and Scopus databases, including publications up to May 2015, with no restriction on year of publication or language. A list of positive emotions and functional status related keywords was used to identify relevant studies, through an iterative process of search and refinement. Table 1 lists the final key terms.

Table 1. Key terms divided by outcomes (positive emotions and functional status) and target group.

Key terms		
Positive emotions	**Functional status**	**Target group**
positive emot* or positive mood or positive psychology or emotional wellbeing or emotional well-being or subjective wellbeing or subjective well-being or hedonic wellbeing or hedonic well-being or positive affect*	functional decline or functioning or functional status or health status or activities of daily living	older adult* or elderly or seniors or geriatrics or aging or ageing
AND	AND	

Eligibility criteria

Study population: eligible studies targeted general older adults living independently. Articles in which it was clearly defined that the target population suffered from a specific disease or condition were excluded, as it is known that chronic conditions influence the emotional experience of the patients[18,19].

Study design: included studies were observational, peer-reviewed, and investigated the relation between positive emotions and functional status.

Outcome variables: included studies assessed the ability to perform daily activities independently, whether referring to basic (e.g. bathing and eating) or instrumental (e.g. shopping and managing finances) activities of daily living. The final selection of articles included studies that assessed discrete emotion adjectives (e.g. happiness and joy) and not tapping into trait-like factors, such as optimism and sense of humor. Similar distinction between positive states and trait-like factors was performed in other reviews of literature (e.g. [14]).

Study selection

The inclusion and exclusion criteria for the selection based on title and abstract were decided, in an iterative process, by three researchers (MC, SL and HT) and are enumerated in Table 2.

Table 2. Inclusion and exclusion criteria used in the systematic review process.

Inclusion Criteria	Exclusion Criteria
(1) Participants referred to as older adults included in a general sample	(1) Studies targeting institutionalized older adults exclusively
(2) Observational studies reporting on the relation between positive emotions (as discrete or as sum value) and functional status (as the ability to perform daily activities)	(2) Studies that reported on mixed measures of positive and negative emotions (3) Studies which data was acquired via proxy
(3) Studies published in peer-reviewed journals	(4) Studies written in other language that not English, Dutch or Portuguese
(4) No limitation on date of data collection or date of publication	

Two researchers performed the selection based on title and abstract (MC and SL). During the title-based screening, in a sample of 100 randomly selected articles, the Cohen's kappa between the two researchers was 0.84 (an interrater agreement of 95%). The selection based on the abstract resulted in a Cohen's kappa of 0.82 (an interrater agreement of 91%). The selection based on full articles was carried out by MC, followed by review and refinement by SL. Disagreements between reviewers were discussed until a consensus was reached. The reference lists of selected articles were checked to verify if there were any relevant articles that had not appeared in our initial search. All the references were checked again *a posteriori* (in October 2015) to ensure that no relevant articles had been missed.

Data Collection and Synthesis

Relevant data from the selected studies were summarized in review tables previously agreed on by two authors (MC and SL). Characteristics of the study population (demographic information), method (recruitment, study design, assessment tools, and data analysis) and study outcomes regarding the relation between positive emotions and functional status were extracted and summarized. Results were grouped according to the aims of the review.

Results

The search query retrieved a total of 963 articles (1485 before removal of duplicates). Figure 1 shows the number of studies included and excluded at each stage of the systematic review process. The proportion of male participants in the study varied from 17% to 51%. All studies were performed in developed countries: five in Western

Europe, three in the United States of America, one in Australia and one in Japan. The mean age of the participants ranged from 61 up to 101 years old. The oldest study included started in 1990. Table 3 is the summary of the characteristics of each study and its outcomes.

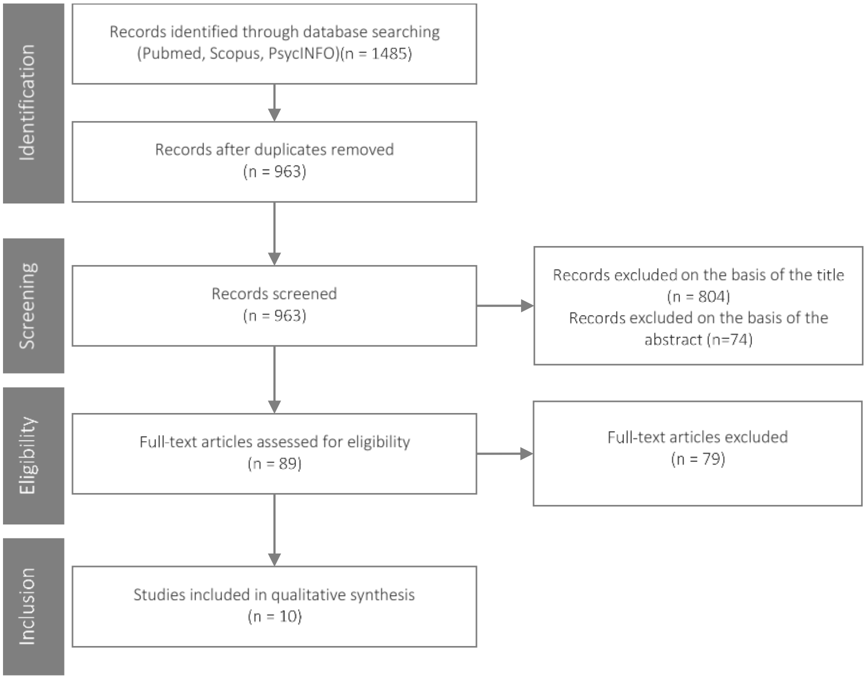

Figure 1. Flow diagram of the systematic review.

Table 3. Characteristics and summary of the outcomes of the studies included in this review.

Source	Study design, time span, sample size	Age	Measure of PE	Time span assessment PE	Measure of functioning	Aim of the study	Outcomes
Cho et al.[27]	CS, N = 306 (234 centenarians and 72 octogenarians)	N.A.	4-positive items of BABS (exclude 'satisfaction with life' term)	Past two weeks	7 items of instrumental ADL and 7 items of physical ADL[25]. 3 items extracted through exploratory factor analysis: dressing, taking care of appearance and getting out of bed.	Analyze the influence of, among other factors, physical functioning on subjective wellbeing of the oldest-old, based on successful ageing and developmental adaptation models.	Higher degree of physical health impairment associated with lower levels of experience of positive affect (p<.001).
Gagliardi et al.[28]	CS, N = 2218 (1518 in Germany, and 600 in Italy)	Germany: 67.9, SD: 9.2 Italy: 69.4, SD: 9.1	10 positive items of PANAS	Past year	Not defined ADL index composed of 10 items.	Analyze the associations between personal and mobility resources with positive emotions.	Better functioning predictor of higher levels of positive affect in Italy (OR=0.91, p=.001) but not in Germany (p=.286).
Isaacowitz & Smith[29]	CS, N = 516	Men: 84.7; Women: 85.1; (70-105)	10 positive items of PANAS	Past year	Independence in ADL[26] and IADL[49]	Analyze the relation between age and affect in the young-old (70-84) and oldest-old (85+).	Functional status not found to be a significant predictor of positive affect at any age among a population of 70+ years old.
Kendig et al.[30]	CS, N = 1000	73.4	Positive scale of PGCAS	Past year	Independence in 6 IADL with Multilevel Assessment Instrument[50]	Investigate the mediating effect of disability in the relationship between physical illness and wellbeing.	IADL limitations associated with lower experience of positive affect (p<.01).
Schüz et al.[31]	CS, N = 2787	61.38 (40-85)	10 positive items of PANAS	Past month	Physical functioning subscale of SF-36[22]	Investigate the relation between subjective wellbeing and health using latent class analysis.	Latent class analysis in which the *healthier* class (n=807) was associated with the highest mean value of positive affect and the highest probability for being above the median on the physical functioning tests. Contrarily, the *unhealthiest* class had the highest probability of functional limitations and positive affect below the mean.

Brummett et al.[36]	LG, 6 years, N = 422	67.9 (60-85)	3-items of SF-36 ('have you been a happy person?', 'did you feel full of pep?', 'Have you felt calm and peaceful?')	Past four weeks	Ability to (1) walk 400 meters without resting, (2) walk up and down from one floor to another without resting and, (3) carrying 5 kg (e.g. shopping bag).	Analyze the role of positive emotions (value at baseline and change between baseline and follow-up) as predictors of change in functional status over a period of 6 months.	Baseline value of positive emotions not significant predictor of changes in functional status when controlling for other factors, such as marital status and social contact (p=.144). Change in positive emotions significant predictor of change in functional status at follow-up (p=.004) also in the fully adjusted model.
Franke et al.[34]	LG, 6 months, N = 11	101, SD:0.6	5-positive items of BABS	Past few weeks	Ability to perform 13 ADLs[25] at baseline; upper extremity functioning and basic- and advanced lower extremity functioning[51] every two months for a period of six months.	Assess the extent to which, among other factors, positive emotions are prospectively associated with functional limitations in centenarians.	Higher levels of positive affect predicted better global function (b=0.76), basic- (b=0.80) and advanced lower extremity function (b=0.72) at p<.01. Better upper body function is also predicted by higher levels of positive affect (b = 0.59, p<.05).
Freedman et al.[32]	LG, N = 751	9.7% 50-59, 54% 60-69, 24.8% 70-79, 11.9% 80+	Pleasure (number of minutes feeling pleasant and unpleasant on the previous day), calmness and happiness	During the activity	Difficulties walking or climbing stairs, dressing or bathing, doing errands alone such as visiting a doctor's office or shopping.	Investigate relationships between functional disability and subjective wellbeing among older couples.	Number of minutes spent feeling pleasant negatively associated with having disabilities (p<.05) and also with the severity of the disability (p<.01). Having disability was not significantly associated with experience of happiness or calmness during reported activities.

Table 3 (cont.)

Source	Study design, time span, sample size	Age	Measure of PE	Time span assessment PE	Measure of functioning	Aim of the study	Outcomes
Hirosaki et al.[35]	LG, 2 years, N = 505	73.4, SD: 6.2	5 positive items of GDS-15	Not defined	Independence in 7 ADLs: walking, ascending stairs, feeding, dressing, using the toilet, bathing and grooming	Investigate whether positive emotions independently predict a lower risk of functional decline among Japanese community-dwelling older adults without disabilities in ADL at baseline.	Higher experience of positive affect significantly associated with lower risk of functional decline at follow-up (OR=0.74, p<.001). Looking at discrete emotions, happiness (p=.005) and feeling of energy (p=.001) also predicted lower risk of decline.
Wahl et al.[33]	CS and LG, 4 years, N = 87	82, SD: 4.26	10 positive items of PANAS	Past month	Difficulty in 10 items representing 10 out-of-home activities	Examine both possible causal directions between functional status and positive affect and test the strength of this relation. The study includes a sample of sensory impaired and other of sensory unimpaired participants. In this review we only concern the results of the sensory unimpaired individuals.	In the final cross-lagged analysis, higher experience of positive affect associated with better functional status (p<.001). Functional status at baseline predictor of positive emotions at follow-up (p<.001). Positive emotions at baseline not a significant predictor of functional status at follow-up (p>.10).

Note. In longitudinal studies the age reported is the value at baseline.
PE=Positive emotions
LG = Longitudinal; CS = Cross-sectional;
ADL = Activities of Daily Living; IADL = Instrumental Activities of Daily Living
SF-36 = Short-Form questionnaire 36; BABS = Bradburn Affect Balance Scale; PANAS = Positive Affect Negative Affect Scale; GDS-15 = Geriatric Depression Scale-15;
PGCAS = Philadelphia Geriatric Centre Affect Scale

Measures of positive emotions and functional status

Nine studies assessed positive emotions using the following standardized questionnaires: 4 or 5 positive items of Bradburn Affect Balance Scale (BABS[20]), 10 positive items of Positive Affect Negative Affect Scale (PANAS[21]), 3 items of Short Form of the Health Survey (SF-36[22]), 5 positive items of the Geriatric Depression Scale-15 (GDS-15[23]), and positive scale of Philadelphia Geriatric Centre Affect Scale (PGCAS[24]). One study asked the participants to rate the experience of positive emotions associated to each activity reported in a diary.

Six different standardized questionnaires were used to assess functional status – such as the ADL scale of the Older Americans Resources and Services Questionnaire (OARS[25]) or the Barthel Index[26] – whereas in the other four studies, the assessment method was either unclear or included a non-standardized set of questions.

Evidence on the relation between positive emotions and functional status

The cross-sectional studies analyzed (N=6) found no evidence[27] or limited evidence[28–31] for a significant relation between positive emotions and functional status of the older population.

Gagliardi et al. concluded that having more limitations in ADL was related to lower positive emotions in the Italian cohort (OR 0.91, p=0.001), but not in the German sample[28]. The Italian cohort experienced, on average, more limitations in ADL than the German cohort but higher levels of positive emotions. Isaacowitz and Smith found a significant relation between positive emotions and functional status only for the female population but not when analyzing a mixed sample of 'young old' (70-84) or 'oldest-old' (85+) adults[29].

In a latent class analysis, Schüz et al. defined the 'healthiest' class (n=807) as, among other factors, those with highest mean values of positive emotions and the highest probability of scoring above the median functional status[31]. Conversely, the 'unhealthiest' class (n = 258) was characterized by the lowest values of positive emotions and for being more prone to functional limitations.

Freedman et al. investigated the influence of existence of disability and severity on the frequency and intensity of the experience of positive emotions in daily life[32]. Participants with functional disability, experienced, on average, significantly lower levels of happiness (p=0.007) and calmness (p=0.046). Having a disability significantly predicted fewer number of minutes spent feeling pleasant on the previous day ($p<0.05$). However, disability was not significantly associated with the intensity of happiness and calmness. Independently of the measure of wellbeing adopted, the participants in the study with a disability reported worse subjective wellbeing than those without a disability.

Finally, Wahl et al. reported strong associations between baseline values of positive emotions and functional status ($p<0.001$)[33].

The causality on the relation between positive emotions and functional status

Longitudinal studies suggest significant associations between positive emotions and functional status in various directions. Figure 2 shows all the reported relations between baseline and follow-up values of positive emotions and functional status, the time span between baseline and follow-up, and the strength of the relation.

In a study with a sample of centenarians (n=11), Franke et al. found significant association between the baseline experience of positive emotions and at 6-months follow-up values of global function ($r=0.76$, $p<0.01$), upper body function ($r=0.59$, $p<0.05$), basic lower function ($r=0.80$, $p<0.01$) and advanced lower function ($r=0.72$, $p<0.01$)[34]. However, when analyzing positive emotions at baseline as predictors of functional status at follow-up, Wahl et al. did not find any significant association[33].

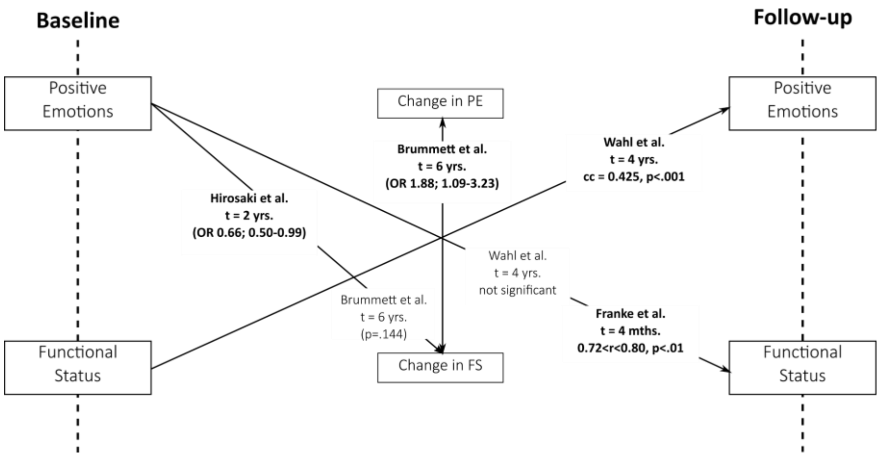

Figure 2. Relations between positive emotions (PE) and functional status (FS) analyzed in the four longitudinal studies included in this review. Time span and significance level (or confidence interval) for each study. The statistically significant relations are shown in bold.

Hirosaki et al. reported that a higher frequency of experience of positive emotions at baseline predicted a lower risk of functional decline at follow-up[35]. This association was significant for, among other, two discrete positive emotions: happiness (OR 0.50, CI 0.25-0.99, p = 0.044) and energy (OR 0.46, CI 0.22-0.95, p = 0.036). In another study, Brummett et al. reported that, adjusting for sociodemographic information and lifestyle, lead to a decrease in the significance of the predictive value of positive emotions[36].

Only one study investigated the role of functional status as predictor of positive emotions, or change in positive emotions, at follow-up. Wahl et al. reported that baseline values of functional status were able to predict frequency in the experience of positive emotions at 4-years follow-up (p<0.001)[33].

Finally, only one study evaluated the relation between change in the frequency of experience of positive emotions and change in functional status. Brummett et al. verified that, after adjusting for the covariates, a decrease in the frequency of positive emotions was associated with a higher probability of functional decline over a 6-year period (OR 1.88, CI 1.09-3.23)[36].

Discussion

This review aimed to investigate whether there is evidence from observational studies on the relation between functional status and positive emotions of older adults living independently. Despite mixed findings within and between studies, eight of ten studies in this review reported a significant relation between positive emotions and functional status, in the sense that higher frequency in the experience of positive emotions is associated with better functioning. Results also suggest that more frequent experience of positive emotions and high functioning might define trajectories of healthy ageing. There are also indications that increase in the frequency of experience of positive emotions might delay, or slow down the functional decline. Due to the various study designs, mixed study findings within and between studies, and the diversity in sample populations, however, one cohesive conclusion cannot be drawn from this review. For the same reason, a meta-analysis of the results was not performed.

These diversity in samples and design methods might explain why some studies find significant relations between positive emotions and functional status and others not. For example, the average age of the population samples ranges from relatively young older adults (55+) until the oldest old (100+). The literature is not consistent on the effect of age on the experience of positive emotions. While some studies suggest that older adults experience higher intensity of positive emotions than younger adults[37], others state that it is not possible to talk about the relation age-emotions without considering personality, contextual and sociodemographic information[29,38]. Finally, others suggest that positive affect decreases with age, possible due to changes in functional status and health[39]. Cultural background and geographical location might also be considered in future research, as it might condition the experience of emotions. For example, using the same study design in Germany and Italy, Gagliardi et al.[28] reported a significant influence of positive emotions on functional status only in the Italian sample. The authors suggest that German cultural beliefs value the community wellbeing rather than the individual wellbeing, as in Italy, possibly leading to higher perception of positive wellbeing in Italy than in Germany. Literature elsewhere discusses different patterns of disability and wellbeing over the lifespan in different cultures[40] and also that the relation between health and emotions is stronger in countries with low- and in high-income economies[41]. Future research should not take the older population as a group, but look at separated age groups as well as to consider cultural background of the samples.

The studies' design varies on the assessment tools used, the time span between baseline and follow-up of the longitudinal studies, and the recall time for assessment of emotions (from emotions associated to an activity to emotions over the past 12 months). Each one of the ten studies included used a different assessment tool to evaluate the functional status of the older adults. For example, one of the studies only considered out-of-home activities while others only considered those basic ADL that are generally seen as a requirement for independent living. There were also several differences in the methods of measuring positive emotions, in terms of both the assessment tool used and the recall time asked for the evaluation of emotions. Future studies should agree on the assessment tools to get a better overview of the outcomes.

The causality in emotions-functioning remains unclear from the review. There is limited evidence suggesting a protective role of positive emotions on functional decline[34,35] and that a decrease in the frequency of experience of positive emotions predicts functional decline[36]. Moreover, there is also limited evidence suggesting that higher functional status at baseline predicts higher experience of positive emotions at the moment of the follow-up[33]. These findings in both directions of the relation between functional status and positive emotions support the theory of 'upward spiral of positive emotions'[42] suggesting that improvements on functional status leading to higher intensity or frequency in the experience of positive emotions, which consequently may lead to adoption of preventive and protective behaviors that improve functional status, and so forth. This is also supported by the fact that older adults who adopt healthy lifestyles are more likely to report very positive attitudes to health compared to those who do not adopt healthy lifestyles[43]. Therefore, future interventions should aim to promote positive emotions, as it might increase resilience and open to healthy behaviors, thereby delaying functional decline.

Strengths and limitations

To the best of our knowledge, this is the first study dedicated to reviewing observational studies on the relation between positive emotions and functional status of older adults. Although a cohesive conclusion of the results is not possible, we consider that the added value of our work is to exactly elicit the numerous results obtained and the non-uniformity of methods, and sometimes even concepts. This review expands work performed in other reviews that suggest that subjective wellbeing has a direct influence on health and longevity[13,44]. Our results suggest that subjective wellbeing also relates to the functional status and functional decline over time.

We restricted our search to measures of hedonic wellbeing, which can be considered both a strength and a limitation. It is a strength because it makes our study unique. We were thus interested in investigating how the experience of discrete positive emotions (e.g. happiness and joy) might be related to functioning, defined as the ability to perform activities of daily living independently. In addition, during the review process, it became clear that there is a lack of consensus on the term positive emotions. When analyzing the first selection of results based on the abstract selection, we identified more than 30 different factors named as *positive emotions*, such as self-esteem or work satisfaction. Being loyal to our narrow definition of positive emotions, the number of suitable studies was limited.

We restricted our results to studies of non-clinical samples as we aimed for a representative sample of the older population living independently. Our results expand literature elsewhere that shows that in clinical samples, positive emotions are associated with less functional decline[45,46]. We can now say that there are indications supporting this association also in non-clinical samples, although more empirical studies are highly recommended.

Towards future research and interventions

The results of our review are not conclusive; however, there is some indication that more frequent experience of positive emotions relates to better functioning and might delay functional decline.

First of all, future studies need to be more theoretical in their approach to the study of positive emotions and functional status. Pressman and Cohen propose a framework to better discern the (in)direct physiological and psychological pathways through which positive emotions might influence health[13]. This framework might also account for potential pathways from positive emotions to functional status. Such theoretical approach will also facilitate better reasoning for the inclusion of, for example, specific measures used and the time-span of positive emotions assessed.

Our results suggest a clear need for empirical studies on the relation between positive emotions and functional status of the older populations. As monitoring the pattern of positive emotions might be more important than one single measurement[11], detecting a decline in the offset of positive emotions might flag early detection of functional decline. For future research, we recommend longitudinal studies with repeated measurements that monitor positive emotions frequently (i.e. daily or weekly) and assess functioning at more distant points in time (e.g. every three months). The emergence of new research methods as experience sampling using mobile technology or systems that require no interaction with the user (e.g. environmental sensors) supports new researches that provide better insights on the dynamics of positive emotions of the older adults[47].

Interventions aiming at healthy ageing might be enhanced by coaching older adults to physically and mentally healthier lifestyles. Interventions based on positive psychology principles have shown promising results also with the older population group (e.g. [48]). Mobile and environmental technology can be seamlessly integrated in daily life facilitating real-time interventions, and therefore suitable for cultivating positive emotions.

Conclusion

To the best of our knowledge, this is the first systematic review that aims to analyze the relation between positive emotions and the functional status of older adults living independently. Most of the included studies, both cross-sectional and longitudinal in design, reported a significant association between positive emotions and functional status. Many of these studies, however, also reported mixed or inconclusive findings. We must therefore conclude that there is some, but limited, evidence suggesting that more frequent experience of positive emotions relates to better functional status and to delay of functional decline. A cohesive conclusion cannot be drawn from our review due to the low number of studies, as well as disparities among design methods and sample populations. The future for studying relations between physical and mental health looks promising with the development of new sensing technology, innovation methods, and with the older population becoming more confident in the use of technology.

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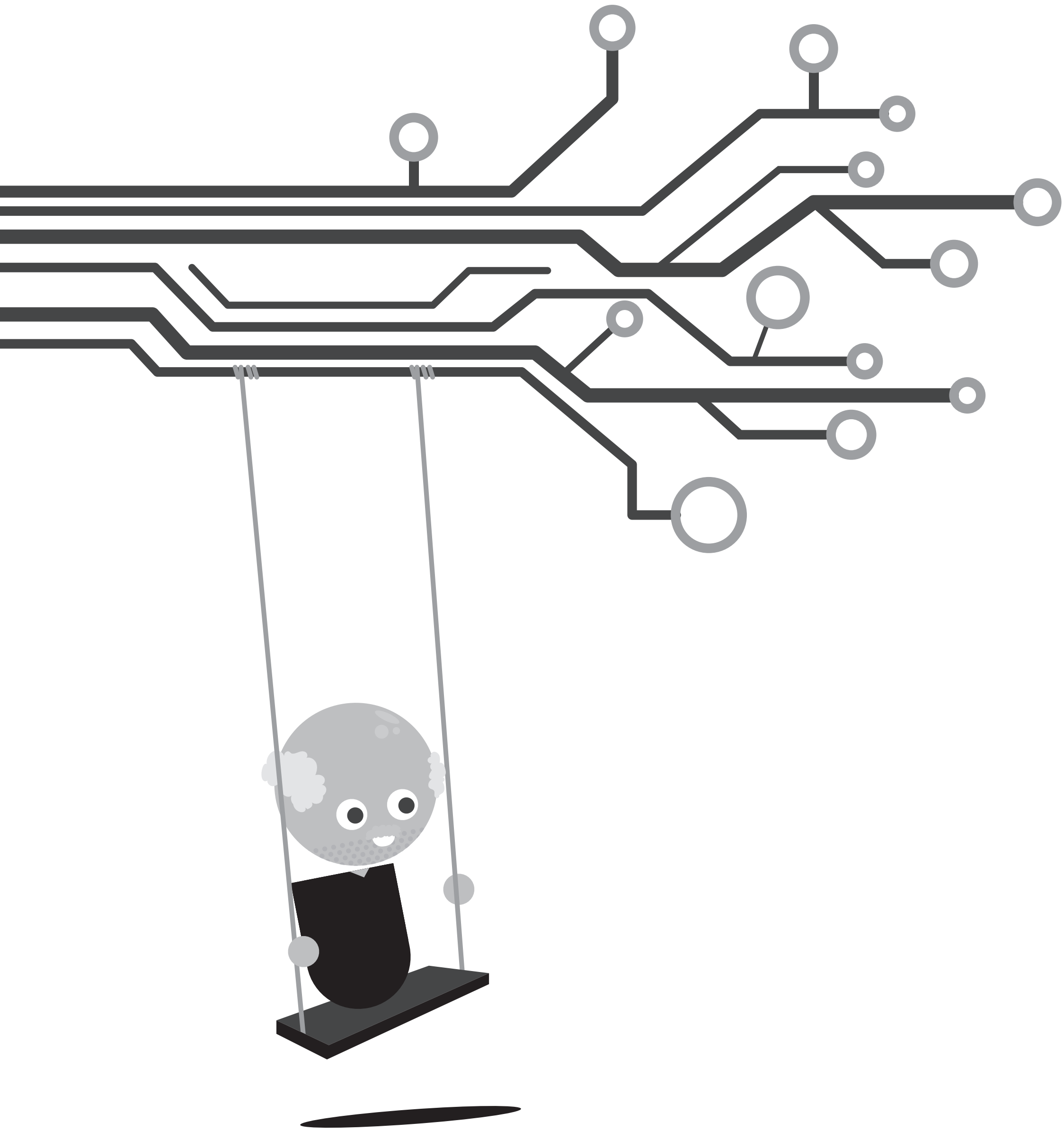

Chapter 3

An exploratory study on the impact of daily activities on the pleasure and physical activity of older adults

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Abstract

Background: Pleasure is one determinant of intrinsic motivation and yet a dimension often forgotten when promoting physical activity among the older population. In this study, we investigate the relation between daily activities and physical activity, experience of pleasure, and the interaction between pleasure and physical activity in the daily lives of community-dwelling older adults.

Methods: Participants carried a hip-worn accelerometer during 30 consecutive days resulting in a total of 320 days of data collection. Current activity, location, companion and experience of pleasure during each activity were assessed through experience sampling on a smartphone every 1-2 hours. Between- and within-individual differences were analysed with multi-level models and 10xN=1 regression analysis.

Results: Outdoor activities were associated with higher physical activity than indoor activities ($p<0.001$). Performing leisure activities, outdoors and not alone significantly predicted pleasure in daily life (all p's<0.05). Being more active while performing leisure activities resulted in higher experiences of pleasure ($p<0.001$). However, when performing basic activities of daily living (e.g. commuting or households) this relation was inverted. Results provide meaningful indication for individual variance. The 30 days of data collected from each participant allow for identification of individual differences.

Conclusions: Daily activities and their contexts do influence the experience of pleasure and physical activity of older adults in daily life of older adults, although similar research with larger population is recommended. Results are in accordance with the literature, indicating that the method adopted (accelerometry combined with experience sampling) provides reliable representation of daily life. Identification of individual differences can eventually be automatically performed through data mining techniques. Further research could look at innovative approaches to promote Active Ageing using mobile technology in the daily life, by promoting physical activity through recommendation of pleasurable activities, and thus likely to increase the intrinsic motivation to become physically active.

Introduction

An active lifestyle provides powerful benefits in the general health and wellbeing of the older population. An adequate level of daily physical activity improves the overall physical function, delaying functional decline and supporting independent living. To be physically active includes, but it is not limited to, participate in structured physical exercise. It also means to be active throughout the day, for example, by avoiding long periods of inactivity. Low-intensity walking activity is also suggested to be associated with better health[1]. The 'Global Recommendations on Physical Activity for Health' from the World Health Organization, highlight the importance of daily activities, such as household chores, games and transportation, for people aged above 65 years old[2]. At the same time, older adults should maintain an active lifestyle also in terms of being engaged with their community and environment[3]. Some older adults can achieve an active lifestyle by themselves; however, others might benefit from an external nudge to become active[4]. Technology can play an important role here, by incorporating several strategies to support people in being physically active and actively engaged in their social environments.

The research presented in this manuscript is the first step towards the development of a tailored approach to promote physical activity and mental wellbeing in the daily lives of the older adults, through the recommendation of pleasurable, or enjoyable, activities. However, before designing an intervention, it is important to deepen the current knowledge on the interactions between physical activity, positive emotions and daily activities, being this the focus of the presented study. There are several reasons for this. First, participation in pleasurable activities in older age is associated with better physiological function and better sleep[5], improving general health and wellbeing. Second, there is growing evidence supporting the link between positive emotions and general health[6–10]. Third, according to the Broaden-and-Build Theory, those who experience higher levels of positive emotions are more likely to build a variety of resources, such as environmental mastery and social support[11]. These resources improve resilience to change, a very important characteristic for this population, as biological and social changes are likely to occur. Furthermore, the 'upward spiral of lifestyle changes'[12], a derivation from the previous theory, defends that positive emotions act as openers for acceptance and adoption of new behaviors, key characteristics when promoting behavior change. Finally, according to the Self-Determination Theory, the enjoyment or pleasure experienced is an intrinsic motivator to repeat a certain activity[13], also already evaluated in the physical activity context[14]. One can thus hypothesize that people are more inclined to do what they like to do. This means that, when suggested an activity that they are familiar with, and have previous positive experiences with, they are more likely to follow the recommendation.

When aiming at increasing physical activity through promotion of pleasurable activity, it is important to take a deep look at the individual daily life contexts, and their impact on physical activity and emotional experience while performing the regular daily activities. Gaining this insight is only possible by looking at the routine over several weeks. Mobile technology provides the means to gather real-time information in daily life for long periods of time[15]. Accelerometers and experience sampling have been successfully used in the past to evaluate the contexts of sedentary behavior among older adults[16], in which most of the sedentary time was performed within the home environment and alone. Also, the influence of contexts on positive affect during physical activity has been evaluated using a similar method with the adult population in which it was reported that social activities might enhance positive emotions while performing physical activity[17]. However, none of the studies above mentioned looked at several weeks period within individual. Our study intends to extend the previous studies by investigating: (1) *how do daily activities relate to physical activity*, (2) *how do daily activities relate to the experience of pleasure,* and (3) *how do daily activities influence the relation between physical activity and pleasure in the daily lives of the older adults*. Combining the information gathered on the influence of daily activities on physical activity and experience of pleasure in daily life, we can further work on developing technology-based interventions that will support older adults becoming more active through the promotion of pleasurable activities. Moreover, this research contributes to the understanding of emotions in the daily lives of the older population.

Research Hypothesis

We establish that daily activities are defined by five categories: location (*where the person is*), activity (*what the person is doing*), social companion (*with whom is the person doing the activity*), emotional experience (*how is the person feeling*) and physical activity (*amount of movement performed*). Similar categorization is adopted in other studies relating daily context information to physical activity in daily life (e.g. [16,17]). We have four hypothesis that are investigated in the current study.

H1. Social activities are more pleasurable than activities performed alone. The social environment plays a clear role on the wellbeing of the population. Participation in social activities has constantly been associated with higher experience of general wellbeing[18] and positive emotions[19–22].

H2. Outdoors activities are more pleasurable than activities performed at home. Previous research suggests that outdoor activities are associated with higher levels of positive emotions in the older population[19,23,24]. However, Gagliardi et al., when comparing German and Italian population, found a significant relation in the German population but not in the Italian, suggesting that there are cultural differences[19].

H3. Leisure activities are more pleasurable than basic activities of daily living. Time spent in recreational/hobby activities is a predictor of daily mood independently on level of cognitive impairment[23]. Participation in leisure activities increases overall levels of positive emotions[20] and delays functional decline[25].

H4. There is no relation between physical activity and pleasure. There is solid evidence for the benefits of exercise programs on mental health[26,27]. However, the relation between physical activity and positive emotions is much less explored. There is some small evidence for relation between positive emotions and physical activity[28] but further work needs to be done to understand the mechanisms influencing this relation. We hypothesize that there is no relation because we choose an emotion, pleasure, that is not, *per se*, associated with high or low arousal emotions. Pleasure can be experienced with very relaxing activities but also with very exciting ones.

Methods

Participants and Setting

Ten community-dwelling volunteers were recruited from the area of Enschede, the Netherlands. Volunteers were invited for an interview in office, or at a location of their choice, in which the background, objectives and setting of the study were explained. Duration of the interviews was adjusted according to the technology affinity of each subject. Older adults included in the study reported being actively engaged in the community (e.g. performing volunteer work or integrated in associations) and did not have any limitations on activities of daily living, assessed with the Katz Index[29]. These inclusion criteria aimed to identify role models in the older population. When these criteria were met, the system composed of an accelerometer and a mobile phone was given to the subjects, together with a detailed manual explaining all the functionalities. The participants were encouraged to contact the research team in case of any doubt or problem with the technology. After two weeks, the researchers contacted the participants to guarantee that they were still engaged with the research. Approximately one month after the first interview, the participants were contacted to set up a new meeting to return the technology and finalize the study. The first five subjects participated in the study between October and November of 2014 and the other five in the same months of 2015. Written informed consent was obtained from all volunteers, and a small compensation was provided for participating in the study.

Measurements

Health status. Health condition was assessed on basis of frailty and in three specific domains: physical, cognitive and nutritional. This assessment follows the frailty screening used within the PERSSILAA project (www.perssilaa.eu). General frailty was assessed with the Groningen Frailty Indicator[30], in which a score higher than 4 indicates 'frailty'. Physical limitations were assessed using the Katz Index[29] (score higher than 4 considered robust) and the physical functioning scale of the Short Form-36 Health Survey[31] (score higher than 60 considered robust).

Physical activity. Physical activity was measured throughout the day with the Activity Coach, a system composed of a hip-worn three-axial accelerometer and a smartphone application, shown in Figure 1 (for more information on the platform refer to [32]). This application has been used in several research projects in the rehabilitation and health promotion field in the past (e.g. [33–35]). The acceleration was quantified as Integral Module of Acceleration (IMA) per minute, with a_x, a_y and a_z representing the accelerometer output in the three dimensions and T the time interval of integration, as presented in Equation (1):

$$IMA(t) = \frac{1}{T}\left(\int_{t-T}^{t}|a_x|\,dt + \int_{t-T}^{t}|a_y|\,dt + \int_{t-T}^{t}|a_z|\,dt\right).$$

For more information refer to [36]. The participants did not receive any physical activity goal or feedback during the measurement period.

Figure 1. ProMove-3D activity sensor (Inertia Technology, Enschede, the Netherlands) used in the measurement of physical activity (*left*) and main screen of the smartphone application showing measurement period (*right*).

Daily environments. The daily environments and pleasure experienced during the activities were assessed by experience sampling method[37] on the Activity Coach smartphone application (Figure 2). The participants were prompted approximately every hour from 8 AM to 8 PM with a question asking what they were doing at that moment. A set of common activities (e.g. *preparing food*, *eating*, *resting*, and *playing with children*) was shown on the screen as well as the option to manually input an additional activity. After reporting the activity, the subjects were asked about the location where the activity took place (*home*, *workplace*, *somewhere outside* or *somewhere inside*) and the social companion while performing that activity (e.g. *alone*, *spouse*, and *friends*). The name of the activity was continuously displayed so that the participants had a reference on the activity they were reporting on.

Pleasure. Pleasure is the outcome variable of this study, as according to the Self-Determination Theory[13], previous pleasure experience while performing an activity is an intrinsic motivator to repeat that activity. As an exploratory study, and do not wanting to increase the complexity of the study and demand from the participants, we have chosen *pleasure* as the positive semi-axis of the valence dimension of emotions. The arousal, or activation dimension, was not considered in the current study. In other words, participants were asked about their general experience of pleasure, not looking at whether that experience was accompanied by an experience

3

of low activation (e.g. calmness) or high activation (e.g. excitement). For more information about the circumplex model of affect refer to the work of Russell over the past 30 years[38–40]. Pleasure was assessed, together with the information regarding daily activities and their contexts, on the smartphone by experience sampling. After reporting on the activity currently being performed, location and social companion, the respondents rated on a visual analogue scale, ranging from 0 (*not at all*) to 10 (totally), how pleasurable that activity was to perform.

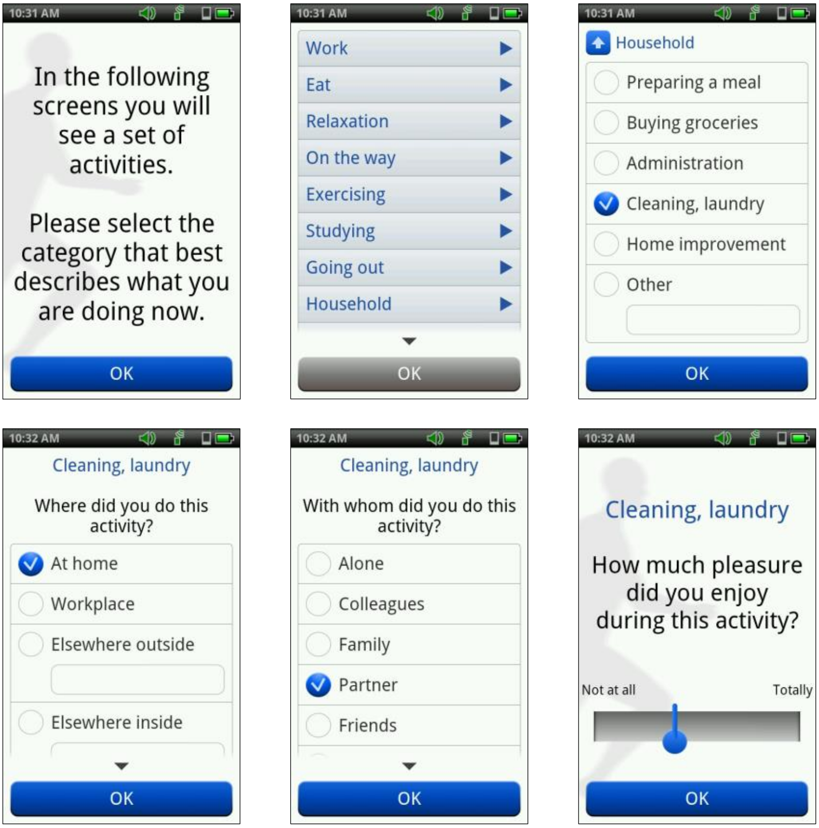

Figure 2. Screenshots of the experience sampling application showing the hourly questionnaires.

Data analysis

Pre-processing

The outcome variable pleasure was transformed to provide an indication of variability. Considering that some subjects only used part of the scale (e.g. 7 – 9 points) and others used the full scale, using the raw values, an increase of 0.5 points in pleasure would represent a significant change for some subjects, but not for others. Therefore, we normalized the values of pleasure within subject so that 0 and 100 correspond to the minimal and maximal value of pleasure, respectively. In this case, 50 (per cent) corresponds to the median value of pleasure reported by each subject. The tests for the distribution of the transformed pleasure suggest normality in terms of skewness (-0.9) and kurtosis (2.49).

To calculate the amount of physical activity performed during an activity, we established, for each experience sampling event (ES-event), a 10-minute time window centered in the moment of answering the questionnaire on the smartphone. The total IMA performed during this period was considered. It is known from previous technical trials that sensors can provide abnormal high values of IMA, for example, due to bumps. Therefore, outliers of IMA values were filtered, resulting in a pre-analysis filtering of 2% of the data points. Due to the high positive skewness of the raw values of IMA, we applied the cubic root and the data distributions suggested normality (skewness 0.08, kurtosis -1.1). Finally, outliers were removed resulting in a final sample of 2219 ES-events.

Types of activities, locations and social companions were categorized in dichotomous variables. Activities related to self-care, eating, performing households and commuting were considered as *basic activities of daily living* (bADL), as these are activities that each individual is, somehow, obliged to do. All other activities were classified as *leisure activities*. This distinction was not performed on basis of the intensity of physical activity associated with each daily activity, but, instead, on basis of the assumption of the motivation why the individual performed each activity. While the activities defined as bADL correspond the activities that the person has to do (for surviving or for being able to perform other activities, as in commuting), the activities considered as leisure incorporate all the non-mandatory activities, such as going out or relaxation. Location was dichotomized as ‘at home’ and ‘not at home’. In terms of social companion, each event was classified as being performed ‘alone’ or ‘not alone’.

General mechanisms predictors of physical activity in daily life

Multilevel regression analysis was performed using SPSS version 22 with repeated measurements nested within subjects. Fixed- and random effects were calculated with type of activity, location and social companion as predictors.

General mechanisms predictors of pleasure in daily life

Multilevel regression analysis was also performed in this case with repeated measurements nested within subjects. Model 0 was the null model (without predictors) revealing how much variance in pleasure was associated with subject differences. In model 1 we added the main effects of the daily environments (i.e. *type of activity*, *location* and *social companion*). Model 2 included physical activity as a predictor of pleasure. Based on data visualization of variability of pleasure, we denoted that the day of the week, particularly Monday's, seemed to have an influence on pleasure. Therefore, in model 2 we added 'Monday' as predictor of pleasure. Model 3 included interaction between physical activity and each property of daily environments. Finally, Model 4 included the subject-level predictors (age, gender, frailty indicator, physical functioning and body mass index (BMI)).

Individual mechanisms analysis

We have tested the possibility of including random slopes but the models could not be reliably estimated by SPSS, leading to problems of convergence, most likely due to the small sample size (N=10). Therefore, we decided to run models only with a random intercept. Post hoc random variability was investigated by performing linear regression models (10 times N=1).

Results

Descriptive analysis

Table 1 summarizes the demographic and health related information of the subjects. Ten older adults (aged 65 – 83; M = 68.7, SD = 5.5, 4 males) participated in the study during approximately 30 days (range 24 to 38 days). Three participants were living alone at the time of the study and all participants had a computer and internet at home. Nine participants were considered robust and one was pre-frail. None of the participants had physical or cognitive functioning limitations. All participants had normal nutrition status according to the MNA; however, 4 participants were pre-obese and 1 was obese, on basis of the BMI.

Participants were measured for a total of 320 days. In total, 2301 experience sampling points (ES-points) were collected with the number of points per subject ranging from 186 to 318. When looking at the whole sample, approximately three thirds of the activities were performed at home (59-88%), more than half of the activities were performed alone (30-96%) and the proportion of activities reported as bADL and leisure was approximately 50% (33-58%). Table 2 summarizes the characteristics of the study and frequency of answers. Outcome variable pleasure did not show severe deviations from normality for the whole sample neither within subject.

Table 1. Basic characteristics of study participants.

Characteristic	N = 10
Age	
Mean (SD)	68.7 (5.5)
range	65-83
Male	4
Living alone	3
PC at home	10
Internet at home	10
BMI, mean (SD)	25.2 (3.5)
Normal Weight	5
Pre-obese	4
Obese	1
Frailty Level	
Frail	0
Pre-frail (score)	1 (4)
Robust (range scores)	9 (0-3)
Physical functioning, mean (SD)	91.0 (8.3)
Limitations	0
No limitations (range scores)	10 (70-100)

Table 2. Study characteristics of all participants and range per subject.

Parameter		All participants	Range per participant
Measurement days		320	24 - 38
ES-events		2301	186 - 318
Pleasure			
	mean	7.31	5.75 - 8.73
	SD	1.58	0.48 - 2.14
Location			
	% activities at home	72.5	58.5 - 87.9
Social Companion			
	% activities alone	56.9	30 - 96
Type of Activity			
	% bADL activities	45.5	32.9 - 57.9

General mechanisms predictors of physical activity in daily life

Type of activity, location and social companion while performing an activity significantly predicted physical activity in our sample ($p<0.001$). Leisure activities required less physical activity than bADL ($b = -3.23$, $t = -11.92$). Regarding the location, activities performed outdoors were associated with higher levels of physical activity ($b = -3.28$, $t = 10.14$). Social activities required, in general, less physical activity than activities performed alone ($b = -1.96$, $t = -6.43$). There was significant variance of intercept across models suggesting variability between subjects. Table 3 provides the results of this analysis. Random slopes analysis was almost significant for social companion and type of activity, suggesting significant different effect between subjects.

General mechanisms predictors of pleasure in daily life

In the following analysis we used the normalized values of pleasure within subject with 0 corresponding to the minimum value of pleasure indicated by the subject, 100 to the maximum and 50 to the median value. An intra-class correlation of 0.41 provided strong evidence to nest repeated measurements within subjects, meaning that 41% of the variation of pleasure between measurements could be explained by subject differences. Table 4 provides the results of multilevel models 0 to 4.

Table 3. Predictors of physical activity in the daily life of older adults living independently.

	Model 0	Model 1		
Predictors	b	b	t	p
Repeated Measurement-level				
Intercept	21.561	23.306		
Type of activity		-3.230	-11.919	<0.001
Location		3.275	10.139	<0.001
Social companion		-1.957	-6.428	<0.001
Variance components				
Between subjects	3.516*	3.460		0.036
Model fit statistics				
-2Log Likelihood	14738.977		14499.516	

*p<0.05
Predictors level 1: type of activity (leisure = 1), location (not at home = 1) and social companion (with someone else = 1).

3

H1. Social activities are more pleasurable than activities performed alone.

Social companion (alone vs. with someone else) is a strong predictor of the experience of pleasure while performing an activity, despite the other predictors. Activities performed with someone else provided 6% more pleasure than activities performed alone (p<0.001, Models 1, 2 and 4), confirming our initial hypothesis.

H2. Outdoors activities are more pleasurable than activities performed at home.

Outdoors activities resulted in an increase of pleasure of 2% above the median value when compared to activities performed at home (p<0.05, Models 1 and 4, p<0.01 Model 2), also when adding all other predictors, confirming our hypothesis.

H3. Leisure activities are more pleasurable than basic activities of daily living.

Type of activity (leisure vs. bADL) was found to be the strongest predictor of pleasure. Performing a leisure activity, results in an increase of 10% of pleasure above the median when compared to bADL (Models 1 and 2, p<0.001), confirming the hypothesis.

Table 4. Predictors of pleasure in the daily lives of older adults living independently.

N=2219	Model 0	Model 1	Model 2	Model 3	Model 4
Predictors	b	b	b	b	b
Repeated Measurement-level					
Intercept	-1.842	-10.572	-8.811	-6.535	-10.872
Type of activity		9.875***	9.360***		
Location		2.050*	2.475**		2.057*
Social companion		6.259***	5.890***		5.781***
Weekday			-2.135*	-2.136*	-2.153*
Physical Activity (IMA)			-0.088*		
Interactions					
IMA * Type of activity				0.312***	0.300***
IMA * Location				-0.073	
IMA * Social companion				0.014	
Subject-level					
Gender					2.908
Age					-0.142
BMI					0.421
GFI					2.053¥
SF-36					-0.245
Variance components					
Between subjects	0.066	0.170	0.259	0.237	0.590
Model fit statistics					
-2Log Likelihood	19054.143	18811.197	18800.103	18777.224	18772.324

IMA – Integral of Modules of Acceleration

¥p<0.1, *p<0.05, **p<0.01, ***p<0.001

Predictors level 1: type of activity (leisure = 1), location (not at home = 1), social companion (with someone else = 1), weekday (Monday = 1) and physical activity (IMA). Predictors level 2: gender (male = 1), age (years), BMI, result of GFI and results of SF-36.

H4. There is no relation between physical activity and pleasure.

Contrarily to what hypothesized, amount of physical activity while performing an activity was a weak, but statistically significant, predictor of pleasure, with more physical activity resulting in 2% less experience of pleasure (Model 2, $p<0.05$). When looking at the interaction effects between physical activity and properties of daily living, only the interaction between type of activity and physical activity was a significant predictor of pleasure ($p<0.001$, Model 3). While engaged in leisure activities more physical activity results in higher levels of pleasure while in bADL, more physical activity results in less experience of pleasure (see Figure 3).

Post-hoc analysis

At a subject level, only the results of the frailty indicator were significant predictors of pleasure ($p<0.1$). Based on post-hoc analysis, we included Monday as a predictor of pleasure. Activities performed on Monday's resulted on less pleasure than activities performed on the remaining weekdays ($p<0.01$, Models 2-4). This effect remains significant even when adding other predictors and interactions.

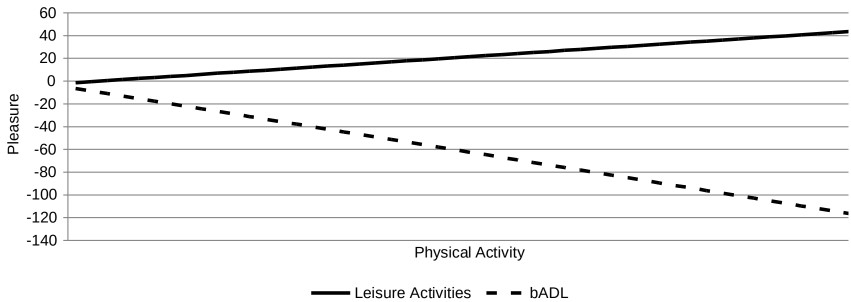

Figure 3. Relation between physical activity and deviation from the median value of pleasure when performing leisure activities (*solid line*) and bADL (*dashed line*). When looking at the full sample of activities, more physical activity relates to less experience of pleasure. However, when looking only at the subsample of leisure activities, more physical activity is associated with more pleasure while performing the activity.

Individual mechanisms

As the reduced sample size did not allow us to look at random effects, we performed individual analyses with linear regression models. The predictors are the same as in the Model 3 of the multilevel analysis. Table 5 provides the results of this analysis, with the strength of the predictors differing strongly among participants. Whereas the pleasure of some subjects is significantly predicted by one or two properties of daily environments (e.g. participant 2 and 4), the experience of pleasure of other participants does not appear to be influenced by daily environments (e.g. participant 5 and 6). For 3 out of the 10 participants, activities performed accompanied represented approximately 15% more pleasure than their personal median value of pleasure, social companion being the most relevant determinant of daily environments in pleasure. We can see that for both the full sample and individual participants, performing an activity with someone else predicts higher pleasure than performing the same activity alone.

Figure 4 shows the relation between physical activity and pleasure for each subject and the average for the overall sample population considering the location, social companion and type of activity performed. Also visually individual differences are clear with for example, opposite slope signs when looking at the outdoors context. In this case, the original values of pleasure are shown (i.e. not the normalized values) in order to provide a loyal representation of the individual answers. Furthermore, this representation provides a clearer visualization considering that the participants use different parts of the pleasure scale, as already mentioned, and we want to show the variability within individual.

Table 5. Results of the regression analysis for each participant in the study.

	Participant									
	1	2	3	4	5	6	7	8	9	10
Predictors	b	b	b	b	b	b	b	b	b	b
Physical Activity (IMA)	-0.123	-0.637	-0.265	-0.450**	0.017	-0.194	0.063	-0.421*	-0.063	-0.099
Type of activity	2.546	10.317**	0.325	-7.672	5.727	3.230	7.515*	9.998*	11.747**	6.508**
Location	2.139	-3.150	8.130**	5.273	-0.279	-1.692	-0.861	4.202	1.671	0.632
Social companion	3.362*	14.913***	0.387	15.651***	1.465	-0.050	6.365**	15.111***	-1.198	3.450
Weekday	0.250	-12.398**	0.881	-1.507	-3.649	1.991	-4.809	-3.530	0.400	0.357
Physical Activity * Type of activity	0.086	0.900	0.309	0.897***	0.342	0.311	-0.115	0.504	0.024	0.007
R-squared	.081	0.384	0.082	0.194	0.089	0.042	0.102	0.350	0.098	0.150

*p<0.05, **p<0.01, ***p<0.001

Predictors: physical activity (IMA), type of activity (leisure = 1), location (not at home = 1), social companion (accompanied = 1) and weekday (Monday = 1).

3

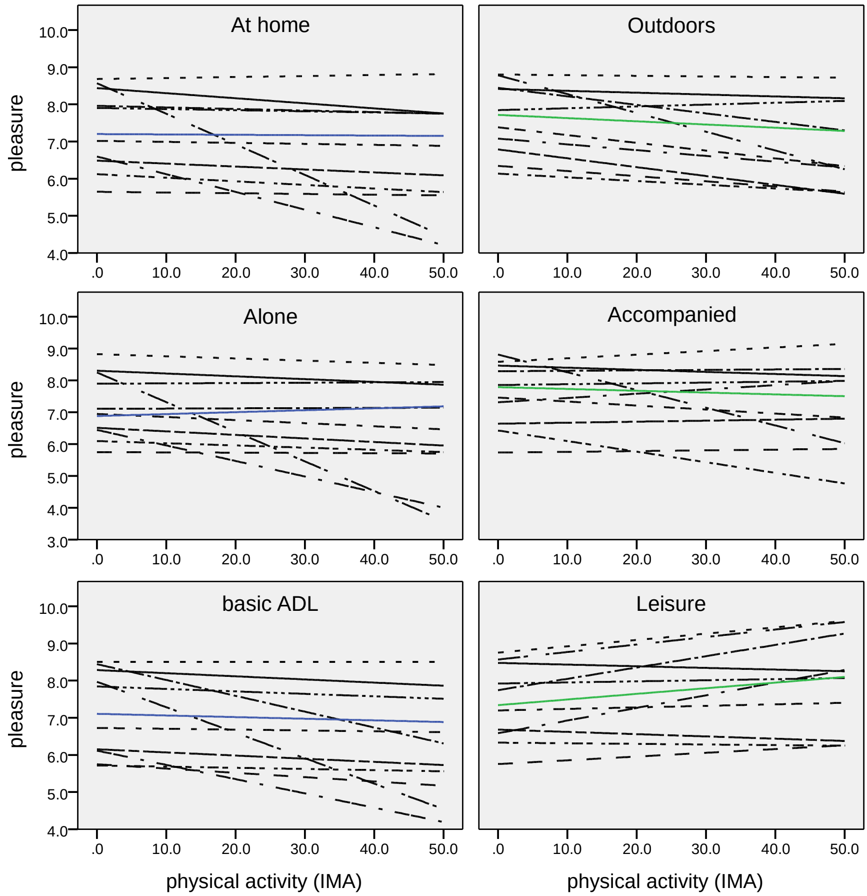

Figure 4. Impact of daily activities and their contexts on the relation between physical activity and pleasure. Individual (*dashed lines*) and group trends (*blue and green lines*) on the relation between physical activity and pleasure categorized according to location (*top*), companion (*middle*) and type of activity (*bottom*).

Discussion

The objectives of this study were to perform an exploratory investigation on (1) how daily activities relate to physical activity, (2) how daily activities relate to the experience of pleasure, and (3) to which extent these daily activities explain the interaction between pleasure and physical activity, in the daily lives of community-dwelling older adults. Data was collected with an accelerometer and experience sampling on a smartphone. No feedback was provided to the participants during the study. The results of our study confirm the first 3 hypothesis which stated that social activities, outdoor activities and leisure activities are more pleasurable than activities performed alone, indoor activities and basic activities of daily living, respectively. However, the last hypothesis, stating that there is no relation between physical activity and pleasure, is partially rejected. This result suggests that the type of daily activity has a moderator effect in the relation between physical activity and pleasure.

This research was designed to gather information for the design of strategies to promote physical activity through recommendation of pleasurable activities. Preliminary recommendations for technology development can be drawn from the presented study.

First, our results support the idea of tailoring interventions when promoting pleasurable activities. Although general effects can be taken from the full sample, looking at the results of the within-individual analysis, we see that, as expected, the predictors of pleasure are highly personal. By gathering data over approximately 30 consecutive days (ranging from 24 to 38, according to the availability of each individual), we can conclude that there are individual differences. In the future, these differences might be detected automatically using data mining techniques, and therefore, tailor each intervention to the preferences of the individuals, even in the cases that the preferences change over time.

Second, older adults spend most of their time at home and alone. This fact is certainly not surprising, but the proportions are, by the fact that our sample was relatively healthy, and active in the community, representing, what we named as, the *role models*. The study took place during Winter time, and therefore, people are more likely to spend time at home. However, it is still alarming that, for example, in one of the subjects, 88% of the activities reported during one month took place at home and 96% alone. The World Health Organization emphasizes the importance of being engaged in the community and environments for a healthy lifestyle[3]. Interventions that stimulate social inclusion of older adults are highly recommended as well as interventions that coach the individual to go outdoors, as the home setting is where the older adults spend most of their sedentary time[16].

Third, motivation of physical activity *by proxy* is recommended based on our results, expanding the results from [28]. By motivation by proxy, we mean a coaching strategy that motivates people to engage in outdoor- or social activities, increasing physical activity indirectly. For example, instead of recommending an individual to go for a walk, one can inform about a new exhibition in the local museum. By going to this exhibition, the individual needs to move. Combining the results from objective 1 and 2, we see that promotion of outdoors activities are the most valuable considering that these activities result both in higher experience of pleasure and more physical activity. Promotion of leisure activities is also highly recommended, as the experience of pleasure increases with physical activity when individuals are engaged in leisure activities, but not in bADL. *Post-hoc* analysis suggests that this effect in bADL is due to household activities. It is known that household activities are a source of physical activity in the daily living[41], however, our study suggests that it is not the most pleasurable one, and therefore, not likely to be a good motivator to perform physical activity.

Fourth, we can see that 30 days of measurement, with approximately 6 events per day, generates enough data to analyze the influence of daily environments on the experience of pleasure. However, this is a very demanding procedure which should be reduced in the future. Future research could investigate whether it is possible to obtain the same degree of information with a shorter study. Participants of the study reported that answering questions every hour for one month is an annoying task. However, identifying what is pleasurable for each individual without becoming cumbersome remains challenging. New technological developments such as emotion recognition tools (either using facial expression recognition or bio sensing) might provide the means for less obtrusive research in this area. Automatic assessments of emotions assume even higher importance when seeing that the interpretation of the feeling pleasure and quantification in a scale is highly personal. While some subjects made use of the full scale (0 to 10) others limited themselves to a short range. This might have to do with personality or with other factors. This means that looking at the exact place of the visual analog scale chosen is not a good measure. Instead, in our data analysis we normalized the values to correspond to a deviance from the median. Rocke et al. reported that older adults report low variability rates of positive affect when compared to younger adults[42]. The use of the hip-worn accelerometer can also become obtrusive. This is likely to be overcome rapidly with the consumer oriented lifestyle devices to promote physical activity becoming smaller, and their use reaching a broader population every year. It is of utmost importance to objectively monitor physical activity of the older population instead of using conventional questionnaires, as the objective measurement provides more reliable information[43] and ambulatory monitoring provides vast opportunities in studying daily life[15].

To the best of our knowledge, our exploratory study is innovative for the variety of data gathered, and the combination of methods used to gather information during the course of one month among the older population. From each participant, we obtained health related information, lifestyle behaviors, emotional- and context-information for a period of approximately 30 days. Furthermore, we made use of three distinct data acquisition methods: conventional standardized questionnaires, on-body sensing and experience sampling. These factors combined provide very valuable knowledge, because, contrarily to most of the studies developed in the past, our data was acquired in real-time, in the daily life of the participants, instead of using a questionnaire that asks previous experiences. We believe that only in this way one can get an accurate view of the daily behaviors. Further research should be performed by analyzing more distinct categories of the properties of daily environments, instead of dichotomous variables. For example, in terms of social companion, one could look at how the experience of pleasure and physical activity are influenced by the fact that an activity is performed with the partner, relatives or even specific friends. Future research could also look separately at routine and non-routine activities. Bouisson & Swendsen suggest that breaks in the routine improve the wellbeing of the older adults, even the ones who claim that they prefer routine[44].

Our study has limitations. First, although the subjects were told to adapt the measurement period to their own routine, the battery of the phone and the accelerometer limited the measurement period to a maximum of 12 hours. Considering that most subjects would start measuring in the morning, the evening period was not considered in our studies. Assuming that in the evening period, people are more likely to do relaxation activities within the home environment, this means that people spend more time at home than reported. Secondly, the visual analogue scale was experienced as being difficult to use. For future studies, we suggest the use of Likert scales instead of visual analogue scales. Still regarding the outcome variable, in this study we were only interested in investigating the experience of positive emotions. To avoid complicating the study, we only looked at the valence dimension (positive axis “Pleasant”) and did not look at different experiences of the arousal, or activation dimension. We recommend researchers to look at the several discrete emotions corresponding to different arousals, from deactivation to activation, following the circumplex models of emotion[38,39]. Regarding the data analysis there are two points for discussion. First, we reduced the granularity of the data grouping variables into dichotomous variables. Although this grouping provides already very interesting results, further analysis should be performed with the original categories. Second, in the calculation of the physical activity related to a daily activity, we considered a time window of 10 minutes centered in the moment of answering the question. This is likely to be arguable, however, our sensitivity analysis with several lengths and time shifts did not show any significant difference. Finally, there is clear the issue of the small sample size. However, as stated in our objectives, we were aiming at getting deep insight in within person analysis, and that objective was met. Further studies should be performed with a larger sample and look at possible predictors of pleasure and physical activity, such as depression or years after retirement.

Conclusions

Our exploratory study suggests that daily activities and their environments do have an impact on the experience of pleasure, physical activity, and relation between physical activity and pleasure, with significant differences between subjects. We also see that older adults are willing to use wearables for periods of one month. Further research should verify if tailored interventions for promotion of physical activity based on the preferences and enjoyment of the individuals do increase adherence. Based on this exploratory study, the use of sensors and experience sampling seems a promising addition to the conventional questionnaires to investigate the relation between physical activity and positive emotions and the mediator effect of the daily activities.

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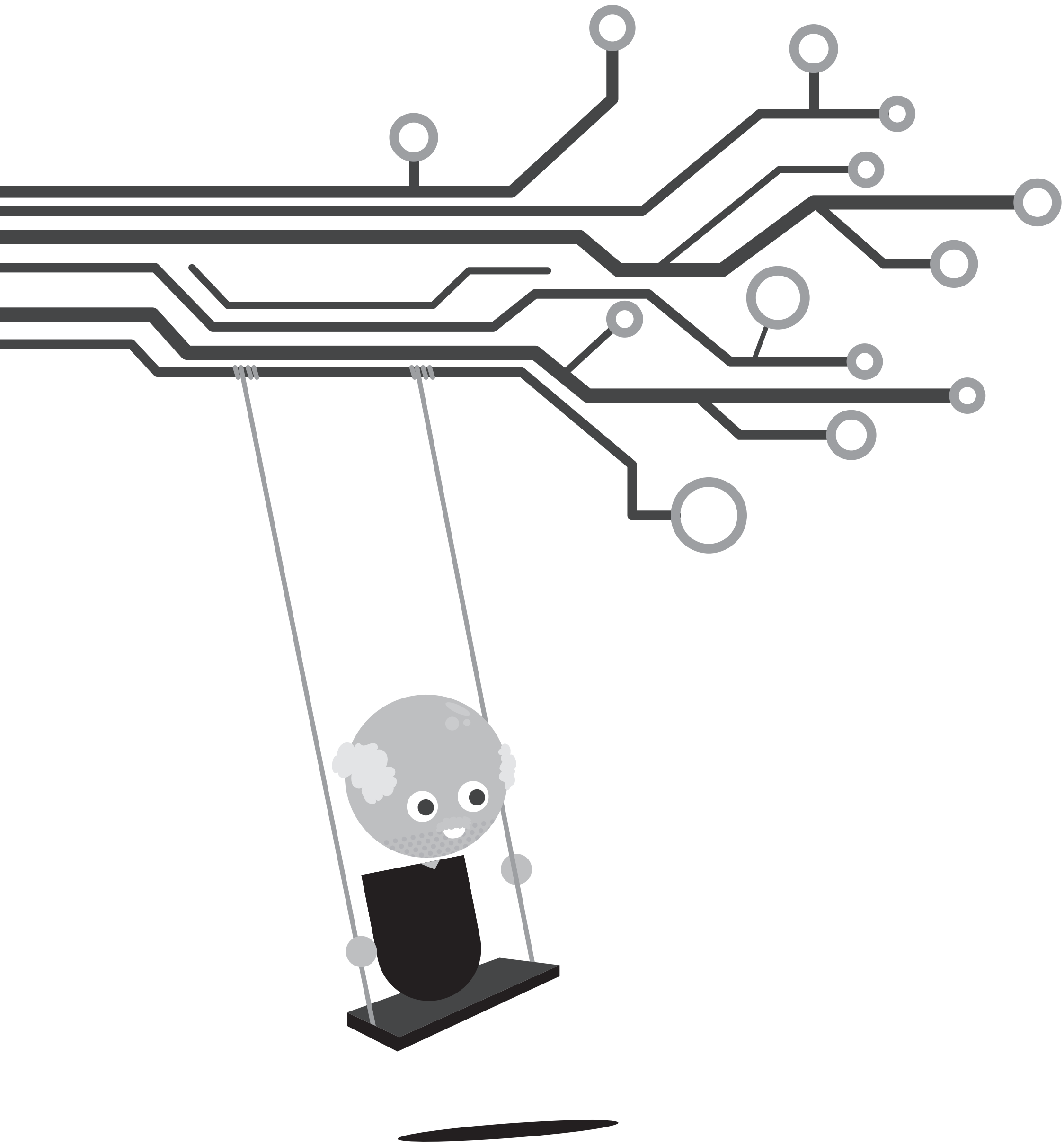

Chapter 4

Wishes and expectations towards technology to support ageing in place

Submitted for publication

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Abstract

Background and objectives: Aging in place demands a holistic perspective of health management. Most qualitative research is performed having the development of one product in mind, without an open mindset. The objective of this study was to investigate, from the perspective of older adults, the needs and wishes of technology to be used in daily life supporting aging in place focus on four domains: nutrition, physical function, cognitive function and wellbeing.

Research Design and Methods: Semi-structured interviews were performed with twelve community-dwelling older adults addressing four themes: (1) current practices in health management, (2) attitudes towards using technology to support health management, (3) wishes from technology, and (4) change in attitudes after actual use of technology. The fourth point was investigated after participants have used technology to monitor physical activity, nutrition and wellbeing for one month. All data collected was analyzed using inductive thematic analysis.

Results: Participants were active in self-managing their health and foresaw an added-value on using technology to support them in everyday life, namely, to support adoption of healthier behaviors. However, attitudes and wishes differed considerably per health domain. Interviewees emphasized that they would preferably use technology that feels as designed for them, as in for their health condition and age. Some fears from technology mentioned were: attention thief, replacement of human touch, and disuse of existing abilities. Our post-interview suggests that attitudes towards technology are prone to change after a short period of use.

Discussion and Implications: Technology to support aging in place must target improvement of health literacy, allow personalization not only in the design but also in the use of the technology, and prevent existing fears of older adults concerning technology. Based on our results, we set a set of recommendations off interest to all those interested in the designing, development and implementation of technology in the support of aging in place.

Introduction

The increase of the life expectancy is one of the factors contributing to the growing proportion of the population aged above 60 years old in the developed countries. However, these extra years are not always perceived as 'healthy years' with the World Health Organization stressing the need to "*add health to years*"[1]. One possible solution is by empowering older adults to self-manage their health and consequently prevent or delay functional decline. Technology can play here a crucial role. In fact, in the last decade we have experienced a growing interest in the research and development of technology for the use of older people. Technology allows for prevention or early detection of functional decline, by providing continuous real-time information on the health status of the older individual, detecting changes over time and promoting healthy behaviors.

Functional decline can result from a sudden event (e.g. a fall resulting in hip fracture) or from a complex interaction between multiple factors combining, among others, lifestyle and presence of chronic diseases. Functional decline can also be a slow process that develops in daily life. Looking at the description from the World Health Organization, functioning comprises mental and physical capacities as well as interactions with the environment that surrounds the individual[2]. In other words, prevention of functional decline requires a holistic approach of health, rather than focusing on one specific health domain. Hence, technology to prevent, detect, or even reverse, functional decline should take a multidimensional perspective of health and should be integrated in the daily life of the older adults.

The adoption rate of information technologies by older adults is growing[3] and, contrary to popular belief, this age group is in general open-minded towards e-Health[4]. However, there are still well-known barriers constraining the adoption and acceptance of technology. Among the critical barriers are privacy concerns, ease of usability for daily use and the belief that the technology is not necessary, i.e. the perception of no need[5].

One way to prevent these barriers is to include the older adults in all phases of development of the new product/service, i.e. participatory design. In fact, the review from Piau et al. reveals that "*inadequate comprehension of user needs*" is a major issue compromising acceptance of technology[6]. Prioritization of needs and wishes of older adults to improve adherence to and acceptance of technology is mentioned not only by the older adults themselves[7,8], but also by several stakeholders involved in the development and deployment of technologies, such as care professionals, technologists and policy makers[9,10]. However, despite the current knowledge on the importance of involving older adults in all phases of research and development, studies investigating the wishes of the older adults regarding technology to prevent functional decline are scarce. Furthermore, most user-centered design studies are performed envisioning the development of a product targeting one or two health domains (e.g. [11,12]), instead of the holistic approach required by the definition of functioning.

In this work, we investigate, through semi-structured interviews, the current practices in self-management and the attitudes as well as the wishes of older adults concerning technology to be used in daily life supporting their health management and preventing functional decline. Given the multidimensional definition of functioning, we take a holistic perspective of health considering each one of the following domains namely: nutrition, cognitive function, physical function and wellbeing.

The literature has shown that the expected effort from using technology can decrease after a short period of use [13,14]. Additionally, older adults perceive that sometimes they need a small nudge to use technology[15]. Consequently, we deploy a case-study in which participants are provided with an example of mobile technology and we investigate whether their attitudes towards technology change after the actual use. Hence, our study addresses four main investigation themes:

1) current practices in health management;
2) attitudes towards using technology in health management;
3) wishes and expectations from technology;
4) attitudes towards using technology in health management after actual use.

This study extends the existent work on understanding the barriers and motivators to use technology among community-dwelling older adults[8,15,16] by looking at technology to support empowerment of older adults in managing their health from the perspective of older adults. With this study, we aim to provide insights to researchers, clinicians and all those interested in developing technology to be used in health management, contributing to the improvement of acceptance and adherence to technology-based interventions to be implemented in daily life of older adults.

Methods

Participants

Twenty-three older adults were recruited from previous participation in the PERSSILAA project (www.perssilaa.eu) and in markets to promote healthy behaviors in the region of Overijssel, the Netherlands. All those interested received information letters via post explaining the research in more detail. Twelve older adults showed interest in participating in the research and were invited for an interview at the premises of Roessingh Research and Development. The research was explained by the interviewers and the participants provided written informed consent. The ethical review board of the University of Twente approved the study. This study did not require approval of the Medical Ethical Review Board, according to European regulations, as all respondents were competent individuals and this study did not involve any interventions or treatments.

Semi-structured interview

An interview scheme was chosen as this method provides freedom and openness to explore the opinion of the participants. The interview started with an introductory session in which the interviewers (N=2) informed the participant that the interview would be audio recorded and it would take approximately one hour. The interview was divided in five main topics/scales: general health management, nutrition, cognition, physical function and wellbeing.

The general health management questions served the purpose to create a context to go further with the other topics by opening the interview. Current practices in health management, attitudes towards monitoring health with technology and wishes from technology were assessed with the following open questions for each one of the health domains addressed: *1 – What are you currently doing to manage your <health domain>?*, *2 – What is your attitude towards monitoring <health domain>?* and *3 – What are your wishes and expectations from technology to monitor <health domain>?*. The wellbeing scale did not have a question regarding current self-management practices.

Actual use of technology

At the end of the interview, participants were borrowed a smartphone, a Fitbit Zip® step counter and a smart scale Withings 30®. The purpose was to let the older adults experience simple technology to monitor three health domains (physical activity, nutrition and wellbeing) using technology. Wellbeing was assessed through a set of questions prompt of the smartphone at the end of each day. The technology was carefully explained to the participants and they were told that they could contact the research team during the study experiment in case any doubts would arise. Participants were asked to use the technology for 4 weeks. At the end of this period, a new interview was performed to assess the experience of the participants and evaluate whether their attitude towards using technology to monitor their health in daily life had changed.

Data analysis

A general health assessment was performed to obtain an overview of the health status of the participants. General frailty was assessed with the Groningen Frailty Indicator[17]. Physical limitations were assessed using the physical functioning scale of the Short Form-36 Health Survey[18], cognitive function with the AD8 Dementia Screening scale[19] and nutritional status with the Mini Nutritional Assessment Scale[20].

The interviews were audio recorded and transcribed verbatim. The transcripts were first categorized using concept-driven approach, considering the three categories from the research questions "current practice", "attitudes towards health management" and "wishes from technology". A more detailed categorization in sub-themes was performed using inductive thematic analysis[21]. An iterative process was taken until eliciting the final codes.

Results

Twelve community-dwelling older adults (aged 65-78) participated in the interviews and 11 concluded the case study. One participant dropped out due privacy concerns. This participant did not answer the questionnaire regarding current health status but gave permission to analyze the data of the interview. Table 1 provides a summary of the demographic characteristics and health status of the participants at the moment of the interview. Seven out of the 12 participants were female and 8 lived with someone else (most cases the partner/spouse). Most participants were robust on the frailty scale and the highest percentage of limitations was found on the physical functioning scale (only 2 out of 11 participants had limitations).

Table 1. Demographic characteristics of the participants (age, gender, living situation and education) and other parameters regarding lifestyle (smoking status) and current health status (general frailty, nutrition, cognitive function and physical function).

Characteristic	
Age (mean, range)	69, 65 – 78
Gender	
Female	7 (58%)
Male	5 (42%)
Living Situation	
Alone	3 (25%)
With someone else	8 (67%)
Missing	1 (8%)
Education	
Elementary School	1 (8%)
High School	3 (25%)
Vocational School	6 (50%)
University	1 (8%)
Missing	1 (8%)
Smoking	
Smoker	2 (17%)
Non-smoker	9 (75%)
Missing	1 (8%)
General Frailty	
Decline	3 (25%)
Robust	7 (58%)
Missing	2 (17%)
Nutrition	
Decline	0
Robust	11 (91%)
Missing	1 (8%)
Cognitive Function	
Decline	1 (8%)
Robust	9 (75%)
Missing	2 (17%)
Physical Function	
Decline	2 (17%)
Robust	9 (75%)
Missing	1 (8%)
BMI (mean, range)	25.3 (17.4 – 36.1)

4

Table2 provides the complete overview of the answers from the participants on current self-management practices, attitude towards monitoring, wishes from technology and actual use of technology per health domain (nutrition, cognitive function, physical function and wellbeing).

Current practices in health management

Eleven out of 12 interviewees mentioned general health practices from the physical domain (e.g. sports), and half of the interviewees mentioned paying attention to eating habits on a daily basis (e.g. avoiding candies). One interviewee referred sleep hygiene (e.g. always sleep 8 hours per night) and another mentioned mental wellbeing (e.g. by performing pleasurable activities).

When asked about the reasons why it is important to keep track of their health, nine participants referred to their current medical situation, often suffering from at least one chronic condition. Secondly, 4 interviewees mentioned that they want to keep doing their daily activities independently. Participants showed to be concerned about the fact that, if they stop doing their normal life, they might not come back to current activity (e.g. *'Because if you start sitting still, you will rust'*, Female 66). Another factor often mentioned was the fast decline or even sudden death of beloved ones in the surroundings of the interviewees and how that affects the self-perception of health. Finally, one interviewee mentioned that, with the amount of information available nowadays, it is imprudent ('silly') if one does not take care of his own health.

When asked about the motivation to keep track of their health, none of the participants referred "to avoid disease". Instead, the functional perspective of health was very present as participants said they want to be healthy to keep doing their daily activities independently.

In general, interviewees were aware that their health status is changing as they get older and want to adopt measures to slow down this process, such as monitoring their current health status and training to improve their general functioning (e.g. *'Health is your biggest treasure!'*, Female 68).

Table 2. Overview of the sub-themes derived from participants statements per overarching theme (*Current practices in health management*, *Attitudes towards technology*, *Wishes from technology* and *Actual use of technology*) and per health domain (*Nutrition*, *Cognitive Function*, *Physical Activity* and *Wellbeing*).

	Nutrition	N	Cognitive Function	N	Physical Function	N	Wellbeing	N
Current practices in health management	Cooking & eating:	11	Cognitive activities		Sports	7	Not applicable	
	Vegetables in every meal	3	Puzzles/crosswords	6	Recreational walking	6		
	Meat or fish in every meal	2	Books/newspapers/ magazines	6	Biking			
	Low fat	2	TV show with cognitive games	3	For commuting	7		
	Small portions	2	Web-based training tool	3	For recreation	5		
	Keep track of eating pattern	2	Volunteer work	2	Households	5		
	Low sugar	1	Computer games	2	Dance	2		
	Low salt	1	Notes/reminders	1	Web-based training tool	2		
	Low carbohydrates	1	Handicrafts	1	Volunteer work	2		
	Diet for long period	1	New languages	1	Walk with the dog	1		
	Drink enough water	1	Do not like puzzles or games	2	Informal caregiver	1		
	Dairy products daily	1	Does not know	2	*Ismakogie* (theory of motion)	1		
	Compensation strategies	1			Compensation strategies	2		
	Not paying attention to nutrition in daily life	1			Meaningful physical activity	2		
Attitudes towards using technology in health management	Recognizes importance of monitoring nutrition	12	Recognizes importance of monitoring cognitive function	12	Do not find important to monitor physical activity	5	Recognizes importance of monitoring wellbeing	8
	Keeps track of daily diet for medical reasons	2	Already monitors and trains cognitive function	3	Would **maybe** use application or website to monitor physical activity	6	Would **not** use application or website to monitor wellbeing	2
	Would **not** use application or website to monitor nutrition	6	Would **maybe** use application or website to monitor or train cognitive function	11			Would **maybe** use application or website to monitor wellbeing	6
	Would **maybe** use application or website to monitor nutrition	5	Is afraid of monitoring cognitive function	3			Do not find important to monitor wellbeing	4
	Would prefer to talk to someone	1						

Wishes and expectations from technology	Self-mentioned		See overview of cognitive function over time		Overview of physical activity throughout the day and week	6	Overview of wellbeing with possibility to make annotations	4
	Healthy recipes	3	Yes	3	Duration and intensity of physical activity	5	Overview of wellbeing through time	1
	Calories/nutritional intake	4	No	3	Personalized monitoring & coaching	4	Graph with physical activity and wellbeing	1
	After suggestion from interviewers		Do not want to share cognitive related information	3	Calories burned	2	Tips on how to improve wellbeing	1
	Healthy recipes		Do not want games	3	Distance		Empathy / sympathy from technology	1
	No	1	Would like to train cognitive function in a fun way	7	Yes	2	Available on smartphone	1
	Calories/nutritional intake		Short and diverse exercises	1	No	2		
	Yes	3	Personalized monitoring & coaching	1	Internal movements of the body	1		
	No	1	Fear of technology as attention theft	1	Separate between PA at home and outside the home	1		
	Health literacy	1			Do not want to see inactive period(s)	1		
	Share own knowledge with others	1			Gamified PA training	1		
	Personalized monitoring & coaching	6			Fear of technology as attention theft	1		
	Fear of technology as attention theft	3						
Attitudes towards using technology in health management after actual use	Weight as the most important feature of the monitoring technology used	3	Not applicable		See an added value on monitoring physical activity in daily life	9	Become more aware after using technology to monitor wellbeing	6
					Find the idea interesting but would not keep monitoring physical activity in daily life	2	See an added value on monitoring wellbeing in daily life	4

Nutrition

Eleven out of 12 interviewees stated the adoption of healthy practices in their daily diet, such as cooking with low salt/sugar/fat/carbohydrates, taking small portions and including vegetables in all warm meals. Only one interviewee mentioned not paying attention to the daily eating and added that he/she only cooks warm meals when accompanied, otherwise eats bread for breakfast, lunch and dinner. From the analysis of the interviews, it became clear that the eating habits are influenced not only by the medical background of the interviewee but also by the medical background of the spouse, as a couple is likely to cook and eat together. It is also noteworthy that the interviewee who would need to take care of daily diet the most (due to overweight) is the only who refers not paying attention to eating habits.

Cognitive function

When asked about the current practices to self-manage cognitive function, most interviewees did not understand the concept. After hints from the interviewers, the interviewees mentioned that, in fact, although unaware that they were training cognition, they kept exercising their cognitive function. Examples of activities mentioned were 'puzzles' (N=6), 'read books and newspapers' (N=6) and 'play computer games' (N=2). Interviewees were aware that their memory was decreasing with age and showed to be concerned about that fact. For those who have relatives or friends who suffer, or have suffered, from conditions as Alzheimer's disease, cognitive decline was perceived as a very sensitive topic to talk about.

Physical function

Interviewees showed to be more aware of healthy behaviors concerning prevention of physical function decline than in any other health domain. Seven out of the 12 interviewees practiced sports at least twice a week. Sports mentioned include tennis, golf, swimming and fitness. Five participants mentioned that keeping doing the households by themselves helps them to feel active. Other physical activities mentioned were dancing, volunteer work and recreational biking or walking. Seven participants mentioned to use the bike for everyday commuting, only preferring the car or bus when the weather is bad. Noteworthy is that one of the interviewees mentioned that most of the daily physical activity comes from his/her role as informal caregiver, considering that he/she needs to take care of everything for the spouse, whenever needed. Two interviewees mentioned to be goal oriented persons, and therefore, could not think of biking, walking or exercising without a meaningful activity. For example, these participants cannot think about going for a walk just for the purpose of walking. Instead, they can walk to the supermarket instead of taking the bicycle. Participants reported that they feel more energetic when they are more active on a daily basis.

The medical background is a strong influence in the three health domains investigated. For example, in the physical function domain, for some participants the medical condition is a motivation to be more active as, for example, diabetic patients know that an active lifestyle helps controlling insulin levels. For other participants, the medical background represents a constraint on becoming active, as for patients with Chronic Obstructive Pulmonary Disease or with cardiovascular diseases.

Compensation strategies were mentioned related to daily diet (nutrition domain) and physical function. For example, one participant said

“[My wife] cooks some special kind of bacon, it’s very nice and spicy, a good feeling; when I eat it, I don’t touch the sweets.” (Male 78)

Attitudes towards using technology in health management

<u>Nutrition</u>

All interviewees recognized that it is important to keep track of the daily diet. However, 6 out of 12 participants claimed that they would not use a website or application to monitor their eating habits. Some participants said that they monitor their food intake by themselves and do not need technology to help with it; others, believe that it would be too time consuming to log everything they eat throughout the day in an app or website. One participant said he/she would prefer to talk to someone about the topic rather than to use technology. Two participants kept a food diary log for a couple of years due to their diabetic condition.

<u>Cognitive function</u>

All participants recognized the importance of keeping good cognitive functioning for performing daily activities independently. None of the participants stated clearly that they would not like to use an application or website to train their cognitive function. Three interviewees stated that they were afraid to get an overview of their cognitive function over time as they would not want to be confronted with a decline.

"Well, I'm actually a bit afraid. […] I'm doing everything to prevent it, but when I get it, I prefer not to be confronted with it." (Female 69)

Reasons for this fear are close cases of dementia (Alzheimer's disease, for example) or their own medical background.

Physical function

When first asked, most interviewees were not open to the idea of monitoring physical activity. After explanation, five out of the 12 participants continued saying that they did not find it important to monitor physical activity with technology, as, according to them, they feel when they are active enough or when they are not. Because of that, they do not need to see the physical activity level in any technology (*"Look, when I'm fit and active, I feel good. Well, and I can feel that myself, I don't need to see that on one of the computers, 'you did this and that…'."*, Female 72). One participant referred that monitoring physical activity with technology would likely make him/her less attentive to the own body. At the end, six participants mentioned that they would maybe use an application or website to monitor their physical activity.

4

Wellbeing

Participants were asked to think specifically of daily wellbeing, as in how they feel on a daily basis. Eight participants found it important to keep track of the wellbeing on a daily basis. Four participants did not see any added value in monitoring wellbeing. One participant refers he does not ever questions him about own wellbeing ("*No, no, no, but that's something like, I have never, you notice that, today I feel a bit better than yesterday. I have never thought about that, because the day starts with fixed routines, and you will see how it ends.", Male 72*). One participant finds the emotional information too personal and would only share it with a specialist. Six participants mentioned that they would at least try the application to monitor wellbeing and two interviewees totally rejected it.

Wishes and expectations from technology

Nutrition

In general interviewees were not aware of possibilities provided by technology. In this way, most of the suggestions came from the interviewers to which the participants provided vague answers, such as "*Maybe that could be interesting*.". After suggestions from the interviewers, three participants said it could be good to obtain an overview of the daily food intake. The opinions of participants diverged regarding the possibility to monitor caloric/nutritional intake and obtain recommendation of healthy recipes. Reasons for not wanting such services concerned the desire to not break old routines of eating.

Nevertheless, some participants expressed by themselves the wish to have access to a website or application to monitor the nutritional or caloric intake. Moreover, four interviewees would wish to receive information, for example on recommendation of healthy recipes, tailored to their medical background and age. One participant would like to share his/her own knowledge on nutrition with other people. One participant would rather talk to someone or follow a course than use technology.

Cognitive Function

The wishes from technology to monitor and train cognitive function are very contradictory. While seven interviewees stated that they would like to train cognitive function in a fun way, three interviewees mentioned clearly that they do not like games and would not want to play them. One participant mentioned that, when existing, exercises should be short and vary over time to remain engaging. Another interviewee referred that the exercises should be tailored to the current cognitive level of the individual. Three participants would like to be able to train their cognitive functioning with technology but would not want to see an overview (e.g. "*I'm just afraid of it, you know? […] Well, because it appeared that, with diabetic people, dementia occurs much more often. And then I think, oh boy… and I'm just hiding that. I am telling you now, but yes, that is a fear that I have.",* Female 68). On the contrary, three interviewees mentioned that they would like to receive feedback on their progress over time. In general, participants recognize the importance of preserving cognitive function at old age: "*Well, I think you should train it one way or the other, and whether that's done with some puzzles, with an app or through something else, I don't care, but it has to happen."* (Male 66)

Physical Activity

Participants expressed more wishes related to monitoring physical activity with technology than to any other health domain. Interviewees would like to see the distribution of physical activity throughout the day in terms of intensity of activity and number of steps (N=6), the distance walked and biked at the end of the day (N=2), and the quantity of calories burnt (N=2). Participants would also like to receive personalized coaching in terms of daily physical activity goals and functional physical exercises tailored to their health, age and gender (N=3). Still in terms of tailoring, one interviewee would like to be able to set his/her own goals. Another participant referred that he/she would likely be motivated by a gamified coaching where he/she could receive points every time the goals were reached. One participant would like to have a distinction between activities performed indoors and outdoors. Finally, one participant would not like to see the amount of time spent inactive as it would probably be too confronting.

Most participants mentioned that they would adapt their behavior to the feedback received and that the most important was to create awareness and answer the question "am I really more/less active than my peers?". As in the other domains, one participant showed concerns that the technology would cause attention theft.

Wellbeing

Interviewees had difficulties to imagine how an application to monitor wellbeing in daily life would look like. After some hints from the interviewers, one participant said he/she would like to compare the wellbeing of different days. Four participants would like to obtain an overview over time to help understanding what influences their wellbeing from day to day. One participant would like to see a figure comparing physical activity and wellbeing, and another would like to receive advice on how to improve the wellbeing. One participant said that to talk about wellbeing he/she had to feel sympathy and empathy from the application, as if it cares. One participant would like to have this application available on a mobile device, and not on a computer.

Attitudes towards using technology in health management after actual use

Participants were given technology to monitor their weight (*nutritional*), physical activity (*physical function*) and positive emotions (*wellbeing*) for a period of four weeks. The interviews performed after this period revealed that all participants were satisfied with using technology to monitor, at least one health domain.

Weight monitoring was the favorite feature for 3 out of 11 participants. These participants said that the fact that the application stored the weight measurements and provided an overview over time was very positive, as it saved time when compared to the conventional procedure of registering the weight with pen and paper. These three participants were those who showed a more positive attitude regarding monitoring of nutrition on a daily basis, as they have already been doing it upon request from their doctors.

Despite the moderate interest regarding the use of technology to monitor physical activity in daily life showed in the first interview (only 6 participants said they would like to use an application in daily life), after using the mobile technology for a period of four weeks, all the participants reported a positive experience. Nine participants mentioned experiencing an added value with this feature and would like to keep using it. The two other participants said that, although the idea is interesting, they would not use the monitoring system in daily life as they know they are more active than the general population of the same age. Eight participants mentioned that they became more active during the four weeks period and five interviewees mentioned that they became more aware of their daily physical activity (*"I find it a piece of art, in fact, that this is possible […] Because it does make you aware of things that you don't really think about.",* Female 67).

The attitudes towards monitoring wellbeing on a daily basis changed less than in the physical activity domain. After using the technology for 4 weeks, only 4 participants foresaw an added value on monitoring wellbeing in their daily life. Nevertheless, 6 participants reported becoming more aware of their own wellbeing after using the technology. The most important reason was that they were invited to reflect on questions that they would not do by themselves. However, as the questions were every day the same, after a short period of time the reflective effect was vanished and most participants reported answering the questions almost automatically. Furthermore, the low interest in monitoring wellbeing after using the technology for one month was influenced by the fact that, contrarily to what happened with weight and physical activity, older adults were not provided any feedback or overview on their answers.

Discussion

This study explored current practices in health management, attitudes towards monitoring health in daily life supported by technology and wishes of technology from the perspective of community-dwelling older adults. Moreover, we investigated whether the attitudes towards technology supporting health management change after actual use in daily life. The older adults in our study were in general engaged in their health management, particularly on the physical domain. Furthermore, the older adults were willing to use technology in daily life to monitor their health and to help them in the adoption of healthier behaviors, as long as they perceive the technology as tailored to their needs. However, the wishes of technology differ per health domain. In the nutritional and physical domains, older adults search for technology that creates awareness about current behaviors and coaches them in the adoption of healthier behaviors. Contrarily, for the cognitive function, older adults look for a training system, but do not want to receive feedback on current status or an overview of changes over time. Furthermore, when developing technology to be used in daily life, not only the wishes should be considered, but also the fears that the older adults state concerning technology, such as the replacement of human contact. Based on the results of our study, in the next paragraphs we provide a set of recommendations for those interested in the developing and implementation of technology-based interventions to prevent functional decline.

Current practices in health management

Although actively engaged in their health management, older adults are not always confident, or even right, about what they believe as being healthy or not. Moreover, older adults wish to obtain meaningful information about *how* and *why* they should change a current behavior. For example, when openly asked about general practices in health management, older adults primarily thought about the physical domain Contrarily, none of the interviewees mentioned cognitive function, as also reported by Menichetti and Graffigna[22]. This means that older adults are themselves not aware of the holistic dimension of functioning, suggested by the World Health Organization[2]. Moreover, in our study, cognitive function was the most difficult health domain to talk about. Older adults did not understand what cognitive function was, or their knowledge was limited to memory related issues. Even though older adults have shown a better understanding about the physical domain, there were still misconceptions. For instance, the idea that being active goes beyond practice of exercise was not present. Interventions should make individuals aware that all daily movements count by promoting an active lifestyle beyond the motivation for physical exercise, as in [23,24]. In the nutritional domain, believes on what is healthy or not are affected by cultural traditions and do not always match what is actually healthy. *All-in-all, improvement of health literacy must be prioritized when aiming to prevent functional decline.*

In our study, older adults tend to adopt a functional perspective of health. This is in line with previous research suggesting that, as people grow old, the conceptualization of being healthy changes from 'disease avoidance' to 'being able to do daily activities independently'[1,25]. Further research should investigate the effectiveness of interventions in which technology supports the individual in reaching personalized goals related to daily activities. As an example, one can think about the goal: "I want to be able to pick up my kids from school". Technology could then support in maintaining or achieving the skills needed from the different health domains to be able to keep doing this activity independently. Therefore, *technology to support prevention of functional decline must go beyond the disease-oriented perspective and focus, instead, on strategies to maintain independence on daily activities.*

Attitudes towards using technology in health management

Older adults were in general positive towards using technology in health management on a daily basis. However, technology should provide this support without interfering with the daily activities and without consuming too much time. This can be achieved with unobtrusive sensing and easy communication between individual and technology. Another general concern mentioned was the fear that, by using technology, older adults would listen less to the signals of their own bodies. In fact, technology can support and increase functioning but it can also diminish capabilities through disuse[7,26]. Technology must then keep challenging older adults to use and improve their abilities, instead of being a simple facilitator. Finally, the interviewees shared the fear that technology would replace human contact, as also reported by Peek et al.[15]. In this case, technology can support communication between older adults in both real and virtual worlds. *Fears related to technology that deserve attention are: (1) technology as attention thief in daily life, (2) technology leading to diminish abilities through disuse and (3) technology as replacement of human contact.*

Older adults wish to perceive the technology as tailored to their own wishes, disabilities and preferences. The World Health Organization identified "diversity in older age" as a challenge when developing policies targeting the promotion of healthy ageing[1]. The same challenge serves for technology. Designers and technology developers should have that into consideration and design modular applications that allow older adults to enable or disable functionalities according to their personal needs and wishes. By doing so, older adults also perceive as being in control over the technology, instead of feeling that they are being controlled by technology. For example, older adults must be given the possibility to decide whether they want to share their information with other people or not. Interventions to support prevention of functional decline should also be tailored in terms of the motivational messages generated (e.g. based on current stage-of-change, from the Transtheoretical model[27]) or in terms of the strategy how the training is provided to the individuals (e.g. gamified training of cognitive function vs. reading of challenging texts). Another possibility is suggested by Menichetti and Graffigna who define three experiential positions regarding health management: locked position, awakening position and climbing position[28]. Technology might play different roles in each one of the experiential positions. In the first it can go more in the health literacy direction, in *the awakening position*, technology might help setting plans as daily tasks, and finally in the *climbing position* technology can support the maintenance of good practices. In conclusion, *one-size-fits-all is not possible in the use of technology to support prevention of functional decline.*

To talk about their health, and in particularly about cognitive function and wellbeing, older adults wish to feel that "the technology cares for them". In fact, exploring wishes of technology to monitor wellbeing in daily life became extremely difficult as most of the older adults participating in this study did not see wellbeing as a component of their health, or as something that can be monitored and trained over time. *Technology should show empathy and sympathy.*

Older adults would like to be given the opportunity to share their knowledge and experience with peers. Other social interactions of interest would be sharing experiences, nudging and congratulating each other. The need of a moderator could be avoided by creating closed groups where information is only accessible by friends. In this way, older adults would like to have an active role not only in the development of the application but also during its use. *Technology should provide the opportunity for older adults to share their own knowledge and experiences with peers.*

The attitudes towards using technology in health management after actual use only changed in one of the three domains addressed. After using technology to monitor physical activity for a period of one month, all participants recognized the value of it, supporting the hypothesis that attitudes towards technology might change after a short period of use, as suggested previously[14,15,29]. Weight measuring in daily life is a procedure that people are already familiar with, as most people already do it on a daily or weekly basis. The advantage of technology is that it stores the results automatically and provides an overview throughout time. Wellbeing was from the beginning the health domain which participants were more skeptical about. This attitude barely changed after the study period. We highly encourage researchers to perform similar studies but start with health literacy aiming to break the prejudice about wellbeing, as there is growing evidence that higher experience of positive emotions is not only associated with better physiological markers of health[30–32] but also with better functioning[33].

Strengths and limitations

This study extends the work of [8,15,16] by taking an holistic perspective of health, without a design of a specific product in mind. The approach taken was: "*Imagine that everything is possible, what would you like to see?*". This is a strength of our study compared to existing literature as it does not limit the mindset of the participants.

The interviews were part of a larger study regarding monitoring of health with mobile technology. The participants in this study, were aware that they would be borrowed a system to monitor physical activity, weight and daily wellbeing on a daily basis. Therefore, they were intrinsically motivated to use technology, otherwise they would have not participated in the study. In this line, the data collected regarding attitudes towards monitoring physical activity might be biased as the participants were a priori interested in monitoring their physical activity, otherwise they would not participate in the study. Our results are particularly relevant for the design and definition of implementation strategies of technology to be used by individuals who are intrinsically motivated to change their behavior.

Most of the interviewees were not aware of possibilities provided by technology and in general needed several hints to come up with suggestions, in agreement with literature reported elsewhere[15,34]. The hints provided might have biased the results on the wishes from technology; not giving hints would not provide any results.

Conclusion

In this study we explore (1) current practices in health management, (2) attitudes towards using technology in health management, (3) wishes of technology and (4) changes in attitudes towards technology after actual use in daily life. Based on interviews with community-dwelling older adults before and after using technology, we conclude that older adults do wish to use technology in daily life to support them in managing their health in the prevention of functional decline, particularly in the nutritional, cognitive and physical domains. Contrarily, wellbeing was not perceived as a health domain or it was not clear how technology could be of any support. Attitudes towards using technology in daily life only changed in the physical domain, but noticeably, with all participants perceiving an added value after use. We summarize the results of our study in a set of recommendations to researchers, clinicians and all those interested in developing and implementing technology based interventions in daily life of older adults to support prevention of functional decline. Further research should investigate whether the proposed strategies improve adherence to interventions deployed in the daily life of older adults.

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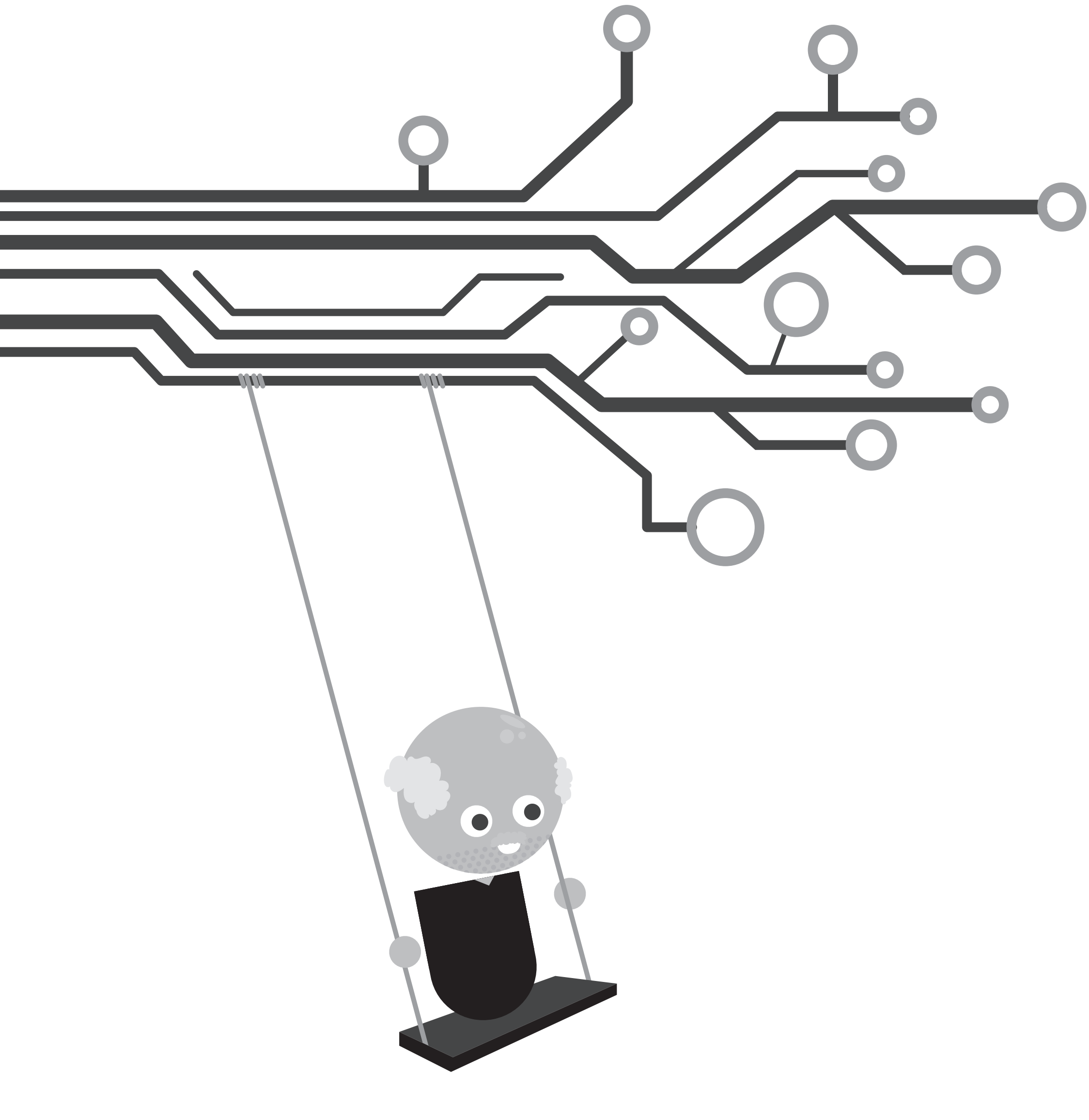

Chapter 5

Mobile Technology to Monitor Physical Activity and Wellbeing in Daily Life: Objective and Subjective Experience of Older Adults

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Abstract

Older adults are not reaching the recommended guidelines for physical activity. There is growing evidence that physical activity and positive emotions reinforce each other. However, the development of interventions leveraging this knowledge faces several challenges, such as the limited knowledge on the assessment of emotional wellbeing in daily life using technology. In this study, we investigate the experience of older adults regarding the use of mobile technology to coach physical activity and monitor emotional wellbeing for one month. Our results show that the participants became more aware of their daily physical activity and perceived an added value in using the technology in daily life. However, only limited added-value was perceived on monitoring positive emotions in daily life in the way we performed it. The most common argument concerned repetitiveness of the questions being asked every day. Moreover, participants also reported that they were not used to think about their emotions, what affected the way they answered the questions regarding their emotional wellbeing. Our results suggest that, to ensure reliability of the data, it is extremely important to hear the experience of the participants after performing studies in daily life.

Introduction

Lack of physical activity and prevalence of physical inactive is a global problem. The World Health Organization points out physical inactivity as the fourth leading cause for global mortality[1]. Despite the overall policies for promotion of physical activity and the well-known benefits for physical and mental health, older adults are still not active. In the literature, the proportion of older adults reaching the recommended guidelines ranges from 2 to 83%, depending on the guidelines and assessment methods chosen[2]. Mobile technology has already provided promising results in promoting physical activity, yet the older population shows low interest in using activity trackers[3]. One reason might be that the market of physical activity trackers often targets a young, active and healthy population. It is therefore important to hear the experiences and opinions of the older adults, when intending to develop interventions to promote physical activity using mobile technology.

One emerging line of research combines promotion of healthy lifestyles with promotion of emotional wellbeing. For example, adapting Frederickson's 'upward spiral theory of lifestyle change' to the promotion of physical activity, being physically active might enhance emotional wellbeing and, in turn, higher experience of emotional wellbeing might motivate people to be more engaged and active[4]. To be confirmed, this theory might open new horizons on interventions promoting physical activity and, furthermore, combining physical and mental health.

Mobile technology allows innovative methods to assess multiple parameters simultaneously. However, there is limited knowledge on the assessment of emotional wellbeing in daily life, especially using mobile technology. Emotional wellbeing concerns positive affective states, or positive emotions[5,6]. Experience sampling, also known as ecological sampling, is a commonly used method in research to assess emotions in daily life[7], and provides the means to assess positive emotions following the requirements proposed by Kanning et al.[8]. Despite its value for research, it has been less explored as a monitoring method, to be used over longer periods of time and create awareness about the own wellbeing.

In this study, we present the results of a one-month study that investigates objective and subjective experiences of community-dwelling older adults regarding physical activity promotion and monitoring of positive emotions in daily life.

This work has two main objectives:

- To investigate how older adults experience promotion of physical activity in their daily life using mobile technology;
- To investigate how older adults experience monitoring positive emotions in their daily life using mobile technology.

As an exploratory study, we also propose to investigate the relation between physical activity and experience of positive emotions per day.

This study is innovative as it provides older adults with technology that is normally more appealing to younger adults, and by investigating both objective and subjective experience of using this technology in daily life. This study focuses on the individual experience, following each participant for the course of one month with an interview at the end of this period to elicit subjective experiences. The results of this study will be used in the development of technology-based interventions to promote physical activity and emotional wellbeing among older adults.

Methods

Participants

Twenty-three older adults were recruited in the PERSSILAA project and in events related to promotion of healthy behaviors. All who were interested received information letters via post explaining the research in more detail and were invited for an interview at the premises of the participating institution. Twelve older adults (7 female) accepted to participate in the study. Technology was explained by two researchers and the participants had time to ask questions. Participants were asked to use the technology at their own pace during four weeks. This study adhered to the guidelines set forth by the Declaration of Helsinki and it was approved by the institutional review board at the participating institution. All participants provided written informed consent.

The average age of the participants was 69 years old (range 65 – 78 years). Three participants lived alone, 8 with someone else and 1 did not want to share this information. This participant dropped out after 5 days due to data privacy concerns. Although authorization was given to use the 5 days of data, we decided to not include the data. According to the frailty assessment from the Groningen Frailty Indicator[9], 3 participants suffered from decline, 7 were robust, and 2 were inconclusive due to missing data. In particular, 2 participants evidenced some physical function decline when assessed with the Short Form-36 Health Survey[10]. Table 1 provides a global overview of the demographics and health related characteristics of the participants.

Table 1. Characteristics of the participants (n=11).

Characteristic	N, range, (%)
Age (mean, range)	69, 65 - 78
Gender	
Female	6 (55%)
Male	5 (45%)
Living Situation	
Alone	3 (27%)
With someone else	8 (73%)
Education	
Elementary School	1 (9%)
High School	3 (27%)
Vocational School	6 (55%)
University	1 (9%)
General Frailty (GFI)	
Decline	3 (27%)
Robust	7 (64%)
Missing	1 (9%)
Physical Function (SF-36)	
Decline	2 (18%)
Robust	9 (82%)
BMI (mean, range)	25.3 (17.4 - 36.1)

Measurements

Physical Activity. Physical activity was monitored using a Fitbit Zip® step counter that can be worn in the pocket to assess number of steps throughout the day. Literature has shown that this step counter provides a valid estimation of the number of steps in both the laboratory[11–14] and free-living[13,15,16] environments with accuracy values ranging between 0.90 and 1 in both conditions.

Feedback on physical activity was provided on the device itself, and also on the screen of the mobile phone, using the Activity Coach application (Figure 1). This application is a re-design of the application developed by Roessingh Research and Development and tested with several clinical populations, such as cancer survivors[17] and patients suffering from chronic pulmonary obstructive disease[18]. In the mobile phone, participants received feedback on the number of steps at that moment, number of steps at the current day per hour and during the last week per day. Participants could also see a representation of how far they were from reaching the daily goal. The daily step goal was set to 7500 steps, following the research of Tudor-Locke and colleagues[19]. Participants were told that this goal could be changed upon request.

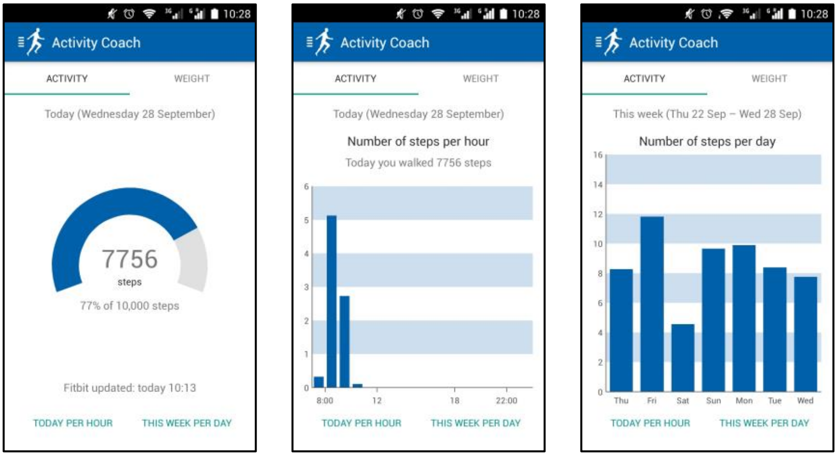

Figure 1. Screenshots of the mobile application showing the current deviation of the daily goal (left), distribution of steps during the day (middle) and during the week (right).

Positive emotions. Emotional wellbeing was operationalized by 6 discrete positive emotions. Participants were asked at the end of every day (at 20:30) to which extent they experienced six discrete positive emotions (*joy*, *amusement*, *awe*, *love/friendliness*, *interest* and *serenity*) and to rate it on a Likert scale from 1 ('not at all') to 7 ('very intense'). The positive emotions asked were taken from the modified Differential Emotions Scale[4]. The emotions were chosen to cover the full arousal, or activation, dimension.

Usability and feasibility. At the end of the 4-week period, participants were invited for a semi-structured interview to share their experience. The objective of this interview was to obtain an extended evaluation of the usability and feasibility of the system. Examples of questions asked were *"Which features of the Activity Coach do you consider as the most important?"* and *"Did you become more aware of your wellbeing by answering the questions daily?"*.

Data Analysis

The interviews were audio recorded and transcribed verbatim. The transcripts were categorized in themes and sub-themes using inductive thematic analysis[20]. An iterative process was taken until eliciting the final codes.

Correlations between physical activity and positive emotions are calculated with bivariate correlation analysis. A composed variable of daily positive emotions was created by summing the results of the 6 emotions. Physical activity was operationalized in 4 discrete variables retrieved directly from the Fitbit classifications: number of steps per day, and number of minutes per day spend in each one of the following activity levels: inactive, lightly active, moderate-to-very active.

Results

Eleven older adults participated in the study on an average of 27 days resulting on a total of 292 days of data collected. The daily average of steps was slightly above 6000 steps, with the daily averages among participants varying from 2989 to 10572 steps per day. Table 2 provides a summary of the combined results from all participants.

Table 2. Descriptive analysis of the parameters assessed regarding physical activity and emotional wellbeing.

Characteristic	Mean (standard deviation), range
Study duration in days (N=292)	27 (1.5), 23 – 28
Physical Activity (N = 273)	
Steps	
Full sample	6316 (3688), 224 – 20158
Variation between subjects	2989 – 10572, (1554 – 5044), 224 – 20158
Distance (km)	4.51 (2.67), 0.15 – 15.51
Sedentary minutes per day	1269 (72), 1037 – 1440
Moderate-to-intense active minutes per day	29 (34), 0 – 215
Daily wellbeing (N = 272)	
Joy	5.53 (0.79), 3 – 7
Awe	5.55 (0.77), 3 – 7
Interest	5.63 (0.72), 3 – 7
Serenity	5.64 (0.90), 2 – 7
Love / Friendliness	5.75 (0.84), 3 – 7
Amusement	5.68 (0.92), 3 – 7
Sum of positive emotions	33.76 (4.34), 19 – 42

Experience of Promotion of Physical Activity in Daily Life

Figure 2 provides an overview of the number of steps per day performed by four participants. Only 1 participant in the study consistently met the daily goal, 5 participants almost never reached the daily goal and the remaining 6 participants reached the goal almost on half of the days. No subject asked to change the goal during the study period. The participant who met the goal every day said that he/she was not interested in increasing the goal due to the accomplishment feeling experienced by seeing that the goal was achieved every day. When asked about the difficulty of the step goal, 4 participants reported that it was too high, as they could not reach the goal in (almost) any day. Three participants found the goal appropriate, as in challenging but achievable, considering that it requires an extra effort to be achieved, as “it comes not by itself”. One participant found the goal very difficult in the beginning but it motivated him/her to become more active, and at the end of the 4 weeks it was actually easy to achieve. Two participants found the goal easy or very easy. Finally, 1 participant said that he/she did not look at the goal during the 4 weeks. Most participants reported that the Activity Coach helped them to become more aware of their physical behavior and helped them to become more active.

“In the beginning I found the daily goal very high, but now it does not look much at all. If you walk 2 kilometers you are almost there. And then if you walk a bit in the house you reach the goal.” (Male, 66 yrs)

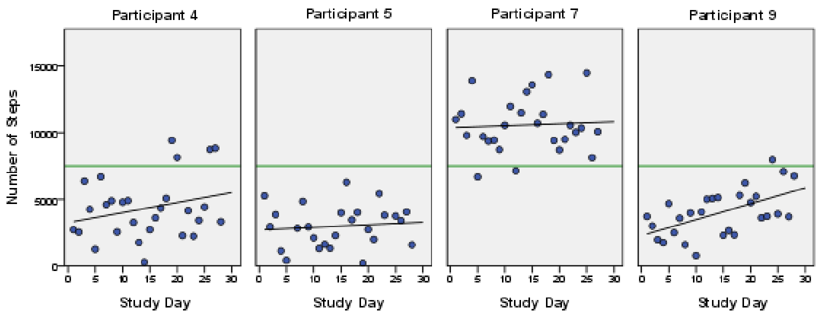

Figure 2: Variation of the number of steps per day for 4 participants. The coloured circles represent the number of steps taken on that day, the black line, the trend on the number of steps during the study. The green line represents the goal set to 7500 steps per day.

When comparing the measured average number of steps of each participant with the sample average, 4 participants are substantially above the average, 2 slightly above (less than 500 steps difference) and 4 participants are below the average. When asked about how the participants perceive their physical activity level compared to their peers, two participants answered that they perceive themselves as more active than average, whereas, in fact, their measured physical activity is below average.

There are also divergences when looking at the comparison between self-perceived and objectively measured change in physical activity during the 4 weeks period, as shown in Table 3. Three participants perceived themselves as becoming more active while in fact this did not happen, while 2 participants said they did not become more active while that data actually shows they did.

Table 3 - Self-perception of physical activity (PA) level compared to peers and objectively measured, as well as self-perception of change in
physical activity during the 4 weeks of study and objectively measured. In grey shadow are represented the cases when the subjective perception and
the measured data coincide.

Participant	Self-perception of PA compared to peers a)	Objectively measured PA compared to peers b)	Self-perception of change in PA	Objectively measured change in PA
1	+	+	-	+
2	+	+	+	-
3	-	-	+	-
4	+	-	+	+
5	/	-	-	/
6	+	++	-	/
7	+	++	-	/
8	+	-	-	+
9	-	-	+	-
10	+	++	+	+
11	+	++	/	/

a) + represents more active than peers, / corresponds to neutral or unclear statements and - corresponds to less active than peers

b) ++ represents more active than peers and quite above the daily goal,
+ more active than peers but average below goal line,
- less active than peers

All participants were satisfied with the possibility to see an overview of the number of steps per day and per week. This overview helped participants becoming more aware of their physical activity encouraging them to become more active.

"*It just motivates you, and I kind of like it to keep track of what you're doing and what you're doing per week and per day, yes I like it very much."* (Female, 70) or "*Yes, one time I was like 'ehm, today I had a little less, so tomorrow I should be moving a little more'*" (Female, 70)

Besides the functionalities currently available, participants would like to see an overview of their steps over longer periods of time (e.g. months or years) and would like to see the distance performed on each day. Participants would also like to see personalized recommendations on how to achieve the desired physical activity level.

Nine participants reported that they see the added value of using technology in daily life for monitoring physical activity. One of the participants bought a step counter for him/herself while participating in the study. Two participants said that, although it was fun to monitor physical activity, they would not do it in everyday life. These were the most active participants.

"I have to admit that, now that I have participated in this study, it is very clear for me how important it is to monitor physical activity." (Female, 73)

Daily Monitoring of Positive Emotions

From the small standard deviations of the ratings of experience of positive emotions in Table 2, it is visible that most of the participants use only 3 values of the Likert's scale providing a very small variability during the study. The reliability of the scale of positive emotions in this sample was acceptable (Cronbach's α = .93).

The opinions of the participants regarding monitoring of emotional wellbeing varied notably. Six participants considered that they became more aware of their wellbeing by answering the questions.

"*You really learn to realize the way you are and the way you work, you start to think about these things a little more, yes.*" (Female, 70)

However, only 4 participants saw an added value on this. Most participants were very critical about answering the wellbeing-related questions. The most referred remarks concerned the repetition of the questions, i.e. every day the same questions, and the fact that no feedback was provided.

"Ok but it is always the same question, then I answer every time the same, 6, 6, 6, 6 and ok that time a 7 because I was really happy, but nothing else…" (Male, 78)

"I mean I would consider a 4 too little, that is not correct. Then I have to choose among the other numbers, I don't stay at the 7, because that would be idiotic, right? No, I wouldn't do it!" (Female, 67)

Also, participants found it difficult to understand how the emotions differ between each other.

"The questions are in fact almost the same. If you are satisfied, then you are also happy more often, this type of thing…" (Female, 72)

One subjected mentioned that he/she would like to see the feedback on positive emotions linked to the feedback on physical activity.

Relation Between Physical Activity and Positive Emotions

The reports of the participants on the experience of monitoring positive emotions in daily life, made us question the reliability of the data collected and, consequently, limit the analysis to correlation analysis, only to grasp a feeling of the data. Table 4 provides the results of the bivariate relation between distinct ways of operationalize physical activity (i.e. steps, distance, and total number of minutes engaged in sedentary, light intensity and moderate to high intense physical activity) and positive emotions (happiness, cheerful, curious, calm, friendly and satisfied, and sum value). The number of steps per day and the distance is significantly associated to the daily ratings of curiosity/interest ($p<0.05$). Furthermore, the number of sedentary minutes is associated to the rating of friendliness ($p<0.05$).

Discussion

In this study we compared the subjective and objective experience of coaching physical activity and monitoring positive emotions in daily life using mobile technology. Older adults see an added value on monitoring physical activity, but not so much in monitoring wellbeing. Moreover, we investigated the relation between physical activity and six discrete positive emotions. Our results suggest that the relation between physical activity and positive emotions is not direct, suggesting that other factors might act as moderators. However, due to the small sample size and considering the criticism concerning the assessment of positive emotions, these results should be taken with caution and we highly encourage further research. In the following sub-sections, the results associated to each one of the objectives are discussed in more detail.

Table 4. Bivariate analysis (Spearman 2-tailed) between several measures of physical activity and positive emotions.

	Joy	Awe	Interest	Serenity	Love	Amusement	Sum Positive Emotions
steps	.056	.099	.141*	-.053	-.099	.025	.020
distance	.049	.095	.138*	-.046	-.090	.028	.021
#minutes inactive	.000	-.056	-.021	.093	.152*	.014	.045
#minutes lightly active	-.001	.041	-.010	-.071	-.111	-.001	-.035
#minutes moderate-to-active	-.010	.017	.057	-.072	-.119	-.035	-.052

*p<0.05.

Experience of Promotion of Physical Activity in Daily Life

In general, the participants were very satisfied with the opportunity to monitor physical activity in daily life and particularly with the tracker chosen. This physical activity tracker is discrete, can be worn in the pocket, has long battery duration and is simple. This fact suggests that, although older adults are often not the target population of the market of physical trackers, after a small nudge to start using the technology, they actually perceive an added value.

The average number of steps of the full sample was approximately 6300 steps/day, with large individual differences. In the present moment there is no commonly accepted guideline for the number of steps older adults should take per day. Literature elsewhere reports similar ranges of steps with healthy older adults ranging from 2000 to 9000 steps/day and special populations 1200 to 8800 steps/day[19]. It is therefore not surprising, that some participants experienced the goal of 7500 steps/day as difficult, while others reached it with no difficulty every day. This large variability in the daily number of steps emphasizes the need for tailored interventions with goals set specifically to each individual. A possible approach to automatically goal-setting is provided in our previous work[21]. The Goal-Setting theory suggests that, to be motivating, goals must be challenging but achievable[22]. This is clearly seen in the subjective experience reported by the participants in the interview. Those who were already very active, and constantly above the daily goal, reported limited added value from the system; on the contrary, those who started below the goal, but close to it, mentioned that the system helped to make them more aware of their lack of physical activity and motivated them to become more active. Similar results are presented by Eisenhauer et al.[23].

During the four weeks of study, several technical issues were reported, on the connectivity between the step counter and the smartphone. Similar technical problems are also reported in literature[24]. Despite these issues, the participants reported a positive experience, perceived the technology as useful, and were comfortable using it. Furthermore, it is difficult to distinguish between inactive time and not worn time. This is particularly difficult in the evenings, as it might be that older adults stop carrying the step counter but keep doing their normal activities.

Daily Monitoring of Emotional Wellbeing

The opinions about monitoring emotional wellbeing diverged. While part of the participants became more aware about their wellbeing, only a few perceived an added value. The strongest criticism was that participants did not receive any feedback on their answers. Some participants also referred that they were not used to reflect on their emotions and do not feel comfortable doing so. Participants perceived wellbeing, or mental health, as something too personal to provide information about to a machine. This is perceived differently than information related to physical health, showing the stigma might still be present when talking about mental health.

Regarding the assessment method, participants perceived the questions as too repetitive. We suggest that, while experience sampling is a promising method to assess emotions, attention should be given when designing the questions. For example, variation in the phrasing should be considered to avoid unreflective answers.

Further research should be performed on the assessment of emotional wellbeing in daily life. One can think of strategies as facial recognition or text mining from the data in social media; however, these methods do not request reflection from the person being assessed, as initially desired in this study. Nevertheless, predictive models of daily emotions are currently being investigated and can open room for interventions in daily life, yet with limited confidence in positive results[25].

Relation Between Physical Activity and Positive Emotions

Our study follows the 3 recommendations of the Kanning and colleagues for within-subject analysis of physical activity and affective states: objective assessment of physical activity, the importance of real time assessment, affective states measured electronically[8]. Despite following these recommendations, we were not able to investigate the dynamics between positive emotions and physical activity, as initially desired. Based on the interviews performed after the study, we considered that the answers given to the daily ratings of positive emotions were not reliable. In any case, our preliminary analysis suggests that there is some evidence to confirm a relation between positive emotions and physical activity, dependent on the operationalization of the outcome. We recommend further research investigating the context of the activities. Another suggestion is to perform studies for longer periods of time and extract only the data points in which the experience of positive emotions deviates from the mode value.

Conclusion

Our study suggests that older adults are willing to monitor their physical activity in daily life and that the technology helps them becoming more aware of their current activity level. On the contrary, older adults perceive limited added value of monitoring emotional wellbeing in daily life – in this study operationalized as experience of positive emotions – mostly due to the repetitiveness of the questions. The interviews performed with the participants at the end of the study revealed low reliability on the data collected on the wellbeing. For this reason, a thorough analysis on the relation between physical activity and positive emotions was not performed.

Further research needs to be performed in the mobile assessment of emotional wellbeing before being able to look at the relations with other factors. The interviews performed after using technology were extremely important to let us make sense of the data collected. We would like to alert researchers using mobile assessment of emotions to question the reliability of their data when repeating the same questions for a long period of time.

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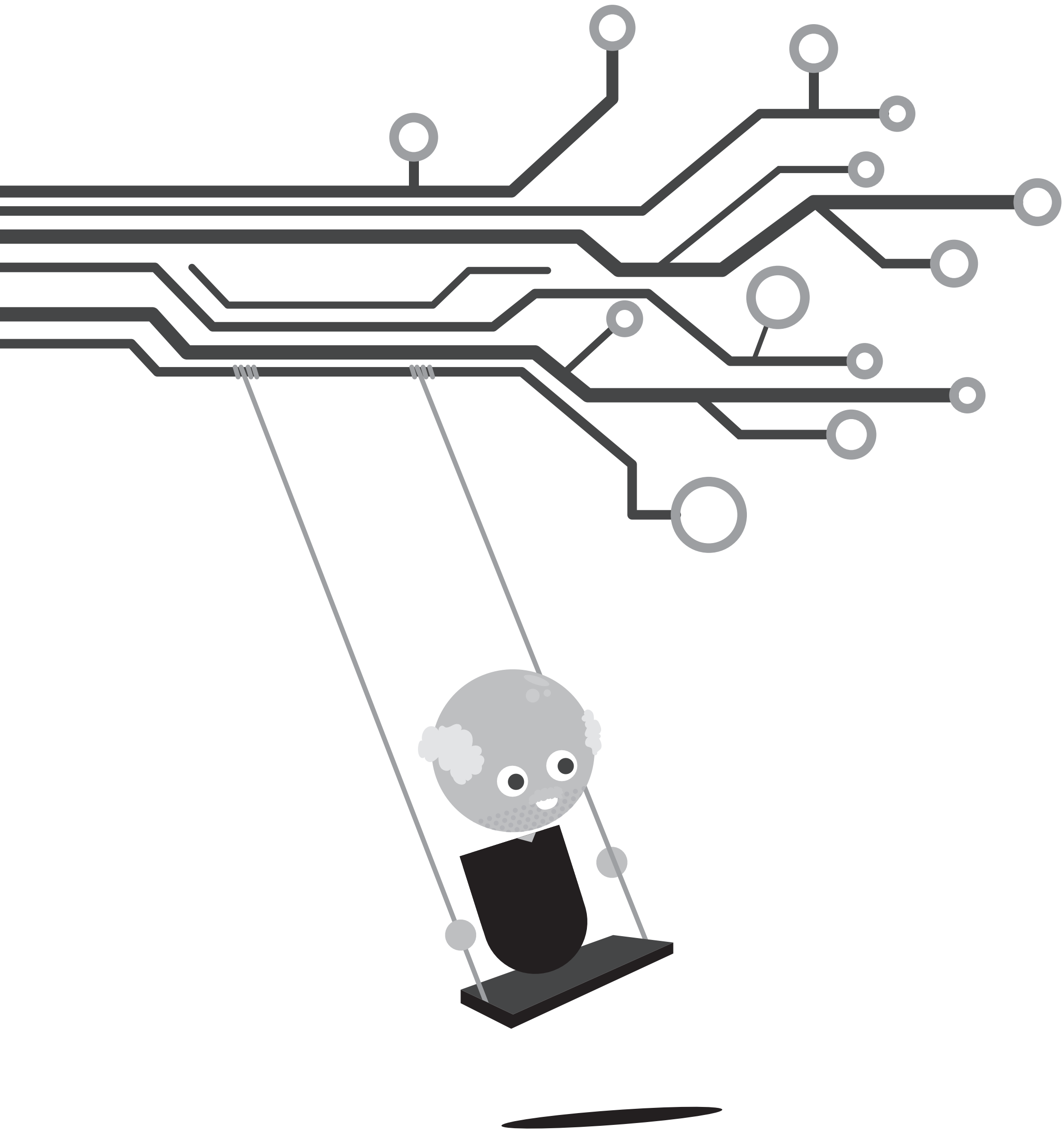

Chapter 6

Persuasive Technology to Support Active and Healthy Ageing: an Exploration of Past, Present, and Future Methodologies

Submitted for publication

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Abstract

The age of the population worldwide is rapidly increasing, bringing social and economic challenges. Persuasive technology aims to encourage and sustain behavior change, supporting healthy lifestyles, leading to independent living for as long as possible, thereby decreasing demand on traditional healthcare services. The promotion and support of healthy aging is no longer a challenge concerning only healthcare professionals, but instead has become a field in which innovation is being driven by experts from various disciplines, such as psychology, computer science and biomedical engineering. In order to be embedded in the everyday lives of the older adults, these technologies must be persuasive and unobtrusive. In this manuscript, we present an overview of the history and state-of-the-art of technologies that support Active and Healthy Ageing in daily life, focusing on physical activity and emotional wellbeing. Additionally, we provide a glimpse into the future on how novel methodologies can accelerate innovation in this field. From a technology perspective, the support of Healthy Ageing in daily life requires (1) measurement of current behavior (*sensing*), (2) analysis of the data gathered to derive meaningful information (*reasoning*), (3) support the individual in the adoption or maintenance of a behavior (*coaching*), and (4) tools or interfaces that provide the information to the individual to stimulate the desired behavior (*applications*). Based on the lessons learned from our earlier work on this subject and the study on the state-of-the-art performed here, we provide recommendations for future innovations of technology to support Active and Healthy Ageing.

Introduction

The promotion and support of healthy ageing is no longer a challenge concerning only healthcare professionals. It is expected that, due to the inversion of the demographic pyramid, by 2020, one in four individuals in the Netherlands should work in healthcare to cover all needs – an unrealistic prospect. In 2002, the World Health Organization (WHO) highlighted the importance of a multidisciplinary effort by defining Active Ageing as "*the process of optimizing opportunities for health, participation and security to enhance quality of life as people age*"[1]. Thirteen years later, the World Report on Ageing and Health introduces Healthy Ageing as "*the process of developing and maintaining the functional ability that enables wellbeing in older age*"[2]. While the definition of Active Ageing targets policy makers, Healthy Ageing, as presented by the WHO, places the individual as an active participant in managing his own health, focusing on prevention and the importance of healthy lifestyles. Healthy Ageing translates to the need for resilience in old age, i.e. the ability to cope with situations of adversity caused, for example, by health-related impairments. Healthy ageing compiles a functional perspective on health, far beyond avoidance of disease, in which personal factors (intrinsic capacity and functional ability), lifestyle behaviors (e.g. physical activity and nutrition) and environmental factors (e.g. age-friendly infrastructures) play crucial roles.

In 2005, Buettner identified global areas where, statistically, people live the longest – the so-called *Blue Zones*[3]. When searching for the common elements that make these five regions unique, Buettner identified a set of lifestyle and environmental factors[4]. One of the elements was "moving freely", i.e. having an active lifestyle, with no need for running marathons or going to the gym. This is a differentiating factor of these regions as literature suggests that, in general, 2-83% of the older adults reach the recommended levels of physical activity, depending on the guidelines and assessment methods chosen[5]. When talking about physical activity promotion, people often think about exercise, or complete changes in their daily life, but that does not need to be the case. Leisure time physical activity, transportation, household chores and even game playing are mentioned in the guidelines for physical activity as an important way to get the recommended daily activity[6]. Furthermore, when incorporated in the daily lives, these activities support individuals in being engaged in community activities, another common factor associated to longevity in the identified Blue Zones, and a key determinant in several theories of Successful Ageing[7,8]. Therefore, one approach to support Active and Healthy Ageing is by encouraging and motivating individuals to be engaged in activities that are pleasurable and contribute to daily physical activity, thereby contributing to both physical and emotional wellbeing.

While some individuals can achieve this active lifestyle by themselves, others seem to need an external drive. Changing behavior is difficult and technology can assist through several strategies, such as creating awareness about a current behavior or providing motivation to engage in healthier behaviors. Persuasive technology refers to technology designed to change attitudes or behaviors[9–11] and can thus be of great importance in supporting Active and Healthy Ageing. Although a large body of literature on the topic of persuasive technology exists, developing successful tools to support a wide variety of older adult users in their everyday lives remains to be a challenge. From a technology perspective, tools or interventions that support an active lifestyle require (1) measurement of relevant parameters related to daily behavior and context (*sensing*), (2) analysis of the data gathered to derive meaningful information (*reasoning*), (3) defining, selecting and personalizing of coaching strategies to support adoption or maintenance of a behavior (*coaching*), and (4) tools or user interfaces that provide the information to the individual to stimulate the desired behavior (*applications*[¥1]). In this work we will discuss the design process of support for Active and Healthy Ageing according to these four domains illustrated in Figure 1.

In our analysis of support for Active and Healthy Ageing we pay extra attention to the multidisciplinary nature of the field, and the various types of required expertise. For such interventions to be successfully designed and implemented, we need multidisciplinary efforts from all stakeholders involved in designing and delivering care, including software developers, designers, engineers, caregivers, policy makers, and social assistants[12]. For example, using techniques from Computer Science, such

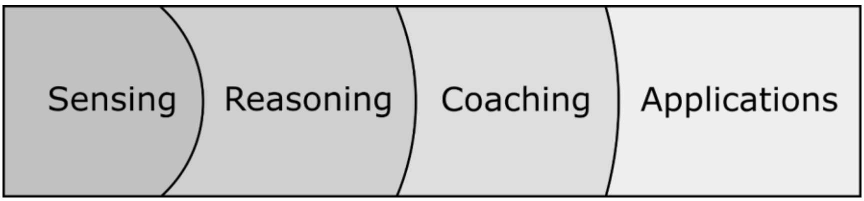

Figure 1. Technology components required in the support of Healthy Ageing in the daily lives of older adults.

[¥1] We will use the term *applications* from now on as a grouping term for any type of tools, interventions, mobile or web apps that *apply* the methodologies described in this work.

as machine learning and pattern recognition, we can create artificial intelligent systems able to process and reason on the data collected, defining short- and long-term patterns, detecting deviations from these patterns and alerting the user(s) when appropriate. Furthermore, self-learning systems can adapt to the users and their environments. As another example, the field of Psychology provides us with the behavior change theories and the way in which we can make use of those theories to support the individual achieving the desired behavior. Similarly, the field of Human Computer Interaction provides the expertise to deal with the challenges of making technological systems useful and understandable by the human. The list of expertise's and knowledge fields is far from completed with these three examples, but we would like to highlight the multidisciplinary efforts that need to be combined to develop technology-based interventions to support behavior change, beyond the healthcare domain.

In this manuscript, we review the past and current state-of-the-art of the technology components to support of Active and Healthy Ageing in daily life, focusing on physical activity and emotional wellbeing. Furthermore, based on the results of this review combined with the lessons learned from our previous studies, we provide future design recommendations. As a glimpse into the future, the manuscript finishes with two scenarios that combine the lessons learnt into tangible examples of how technology in active and healthy ageing can assist the older adult of tomorrow.

Sensing

In many ways, "sensing" is the first step in the chain of concepts involved in the development of technology for supporting healthy ageing. Sensing concerns the collection of information from any source with or without direct involvement of the user himself. The dictionary definition of a sensor is "*a device which detects or measures a physical property and records, indicates, or otherwise responds to it*"[13], but in our view a sensor does not need to be a *device*. Sensor devices can be placed on the body of the user (e.g. step counters), or in the environment (e.g. cameras); but, in our broader definition, sensing can also mean requesting direct information from the user (e.g. through questionnaires).

Sensing in supporting healthy ageing includes two areas: sensing of the *body*, and sensing of the *mind*. To provide support, we need to know about the individual's physical behavior (body), as well as his emotional wellbeing and his attitudes towards health in general (mind). These are very diverse areas of sensing that each require their own diverse expertise. For example, biomedical engineering expertise is needed for the sensing of physical parameters, psychology for the mental wellbeing and measuring of attitudes, and various fields of expertise of computer science to cover the hardware and programming of sensors. Furthermore, we are looking at strategies to promote healthy ageing in daily life. This means that the sensing must fit the daily routine of the individual to avoid being burdensome and to promote the use for long periods of times.

Physical Activity

The need for physical activity in daily life was already acknowledged in the early beginnings of the 19th century, for example thorough physical education among the youngsters[14,15]. The empirical studies on physical activity during the first half of the twentieth century focused mostly on physical activity at work[16] and within the context of university or school sports programs[17–19]. The work of Jeremy Morris and colleagues is pioneering in relating physical activity to cardiovascular function and one of the drivers for the research on the benefits of physical activity on health in general. Morris, named by The Financial Times as *"the man who invented exercise"*[20], from his cohort study held between 1947-1972 with more than 30.000 male motor-drivers, noticed that those participants whose occupation required high physical activity had lower rates of coronary heart disease than their peers with more sedentary occupations[21]. Later, Morris and colleagues widened the scope of the work to the study of other occupations concluding that the incidence of coronary disease was higher in those with sedentary occupations in general[22]. The cohort study of Jeremy Morris and the Tecumseh community health study in 1965[23] are among the first large epidemiological studies reported. The first half of the 20th century also introduces the notion that not all physical activity is the same and that one should clearly look at the different levels of intensity[16,24]. When aiming at sensing in daily life, the study from Jackson and Kelly is a pioneering in its investigation of the relation between self-reported physical activities in daily life and blood sugar levels among youngsters[24].

The second half of the 20th century saw an expansion of the research on the benefits of physical activity on health. Several meta-analysis studies have reviewed the work done during this period on the benefits of physical activity on physical and mental health of the ageing population[25]. Most of this work is performed in large populations using self-reported questionnaires as the sensing strategy. Due to these efforts, there are currently more than 80 validated questionnaires for the assessment of physical activity[26]. Large populations can be reached easily with questionnaires allowing large epidemiological studies on physical activity[27]. However, assessment of physical activity is relevant not only for epidemiological studies, but also to evaluate effectiveness of interventions promoting physical activity. Such interventions require repeated assessments of physical activity over time to detect changes in patterns and to design individual plans for promotion of physical activity[28]. Questionnaires can fulfil this task but they lack objectivity and accuracy as they rely on the recall ability of the respondents[29,30]. Van Poppel and colleagues investigated the measurement properties of 85 questionnaires and concluded that only a few had sufficient construct validity when correlated to objective measurement of physical activity[31]. In fact, large differences were found between self-reported and objectively measured levels of physical activity among older adults[32] and adults in general[33]. Furthermore, their repetitive use can be bothersome to the individual, often leading to drop out. Therefore, more objective, and less obtrusive, ways of sensing physical activity in daily life were needed.

The placement of sensors on the body to measure parameters related to physical activity over time goes back as far as the beginning of the 1980s, when Polar launched their first wireless wearable heart rate portable monitor focused on improvement of sports performance[34]. However, this was a niche product related to sports physiology, not a matter of public health. It was also in this decade that the first accelerometer-based physical activity monitor was adopted by researchers[35]. During these early years, accelerometer-based research appeared to be of interest of a certain niche of researchers and presented concerns related to the accuracy of the devices[36]. However, this situation rapidly changed. One of the first steps was to adopt a common definition of physical activity. The definition proposed by Caspersen and colleagues is still the preferred one and states that physical activity is *"any bodily movement produced by skeletal muscle that results in energy expenditure"* [37]. This definition does not limit the notion of physical activity to structured exercise, but instead considers any movement done in daily life. In terms of ambulant sensing of energy expenditure, the doubly labeled water technique[38,39] remains the Gold standard; however, this method is too expensive to be applied in large scale studies or in studies targeting daily life use[40]. Therefore, the desired situation is to use an accelerometer that is validated using the doubly labeled water technique[41].

The interest on objective measurement of physical activity in daily life for several consecutive days seems to have appeared in the beginning of the 2000s[42]. A big improvement compared to early accelerometers was the ability to obtain real-time data[43]. It is in the beginning of the millennium that the terms *wearables* and *ubiquitous computing* appear connected to physical activity[44]. Since then, technology changed at an incredible rate bringing the most diverse opportunities and challenges to sensing physical activity with wearable devices.

Not only the technology was available, but there was also the recognition of a need from public health initiatives to promote physical activity among people of all ages. Physical inactivity is now identified as the fourth leading risk factor for global mortality and one of the modifiable risk factors for chronic diseases[6]. For the ageing population, physical activity provides innumerous benefits, for example, for the prevention of functional decline and maintenance of independence[45,46]. Furthermore, the inversion in the demographic pyramid and consequent increased costs associated to the management of chronic diseases, started a trend in healthcare to go from curative to preventive healthcare, as well as to make the individual responsible and pro-active in the management of his or her own health. This involves collection of data in daily life, to evaluate patterns and detect domains that require intervention.

The devices used in the laboratory setting for measurement of physical activity are often big, uncomfortable to use, expensive, and not appealing to long term use in daily life. The 2010s marked the advent of a new market of consumer available physical activity sensing devices, often smaller, cheaper, more comfortable and therefore suitable for continuous use for long periods of time. Companies such as Fitbit, Jawbone, WiThings and Misfit promise a revolution in physical activity tracking, mostly focused on the young, healthy consumer. Due to their various advantages, more and more research is being performed with these devices. They allow us to leave the lab and better evaluate activities during daily living but also come with drawbacks. The validity and reliability of these commercial sensors has been evaluated in systematic reviews, suggesting that consumer based wearables provide high validity of steps in laboratory studies and variable correlation in daily life studies (cross correlation ranging from 0.36 to 0.86). However, validity and reliability of measures of energy expenditure was much lower[47]. Another concern relates to the fact that none of these devices allows direct handling of the data. This means that the data is not directly accessible to the researcher, but, instead, stored in servers located most of the times in other continents. To overcome possible privacy concerns, data storage must comply to the regional (e.g. European) and country-specific guidelines. For example, in the Netherlands, data storage and processing must adhere to the Dutch Personal Data Protection Act[48]. This issue can be solved allowing open access to devices at a reasonable price, with the data being provided directly to researchers, complying with privacy guidelines. Another concern related to these devices is the fact that their algorithms are a black-box. For example, we do not know the algorithm to categorize bouts of physical activity according to their intensity (e.g. inactive, light activity, moderate activity and vigorous activity), bringing uncertainties for clinical assessment when looking at distribution of bouts of activity throughout the day or week. Finally, a risk when performing studies in daily life with wearable devices, is that we do not know if the person was actually using the sensor or not, although this issue could be solved by incorporating other sensors, such as those measuring skin temperature[49]. Despite their flaws, commercial devices are worth considering for behavior change interventions due to their practicality and the fact that they are able to be used for longer periods of time[50], being suitable for the support of Active and Healthy Ageing in daily life.

Commercial devices to track and promote physical activity often target a young, healthy population. This is understandably an effective marketing strategy but it does not mean that older adults are not willing to use physical activity trackers in daily life. On the contrary, in our earlier studies, we have found that older adults are curious about the technology and willing to adopt it in their daily lives when focused on their needs and preferences[51]. It does not make sense to say that all older adults avoid technology. Some of the participants in our studies ended up buying physical activity trackers themselves. However, one should think that older adults might be more susceptible to stigmatization than the younger generations. While younger people might be very proudly wearing the latest gadget on the market, older adults might be afraid that other people might think that they are using a medical device (with all its negative connotations). When asked in several meetings and focus groups, older adults repeatedly answered that they would prefer a discrete tracker that could be worn on the pocket. There is a market for physical activity trackers among older adults if producers take into consideration the issues of discreteness. Furthermore, based on our interviews, older adults do want to monitor their physical activity. When asked about current practices in self-managing their health, physical activity is generally the first topic they mention. For the ageing population, it is very important to be active as this ensures that they can maintain their independence. Having the strength and endurance to do the shopping independently, or to pick up the grandchildren from school, are goals often mentioned. Also, after using a wearable associated with a mobile application that collects and shows the data for a period of four weeks, most of the older adults in the study perceived an added value and reported that it helped them becoming more aware of their daily activity[51].

The future of sensing devices looks promising. The continuous evolvement of technology brings innumerous possibilities to the field of physical activity sensing, and devices are not limited to wrist bands or waist-worn devices. Technology provides diverse possibilities for wirelessly sensing physical activity both in the home as well as in the working environment[52]. The methods most often used to identify the location where physical activity is performed are global positioning system (GPS) sensors, wearable cameras and radio frequency identification[53]. The trackers as we currently know can also change completely. Smart textiles[54], pills, in-ear devices and smart tattoos, or even implantable sensors might revolutionize the way we monitor our health, including physical activity.

Almost everyone these days carries a super computer in their pocket. Although not really considered a wearable sensor, the mobile phone also provides the possibility to monitor physical activity in- and outdoors. The drawback is that, as it is not attached to the body, people might forget to carry it around all the time, namely in the home environment where they are more relaxed. Nevertheless, the computational power of the smartphones enables real-time activity recognition. Within the laboratory setting, smartphone-based applications were already demonstrated to be able to accurately quantify sit-to-stand movements in healthy older adults[55].

There are many different tools and techniques for sensing physical activity, summarized in Table 1, each with its own complex interactions of advantages and drawbacks. The message is that when designing an application for supporting Active and Healthy ageing, it is important to be aware of these properties, and to be aware of the different individual preferences of the individual user.

Table 1. Sensing methods and tools for physical activity assessment.

Method	Sensing tool
Self-reported	Questionnaires
	Experience Sampling
Wearable sensing	Wristbands/Watch
	Smartphone
	Waist band
	Necklace/Ring
	Smart Textile
Global Contextual	GPS
	Smart cities: Internet-of-Things
Local Contextual / Indoor location	Radio Frequency Identification
	Integrated circuit tags
	Ultrasonic
Implantable sensing	Chips

Throughout this manuscript, we consider persuasive technologies in the Active and Healthy Ageing, focusing on daily activities that contribute to physical and emotional wellbeing. In this way, it is important to know the context in which the activity is taking place, as well as the feelings, mood and experiences induced in the individuals. One strategy to do so is through the experience sampling method, which will be discussed in the next section.

Emotional Wellbeing

Subjective wellbeing concerns the presence of positive affect, absence of negative affect, and a cognitive appraisal of satisfaction with life in general[56,57]. Emotional wellbeing is identified as the emotional component of subjective wellbeing[58]. It concerns the experience of pleasurable engagement with the environment, eliciting feelings, such as happiness and serenity[56,59,60]. As positive emotions concern feelings experienced at a certain moment, they are prone to influences from the environment and context of the individual[59,61].

Subjective, and more particular, emotional wellbeing has been studied for many decades[56,62,63]. In 1984, Diener reviewed measurements of subjective wellbeing, identifying 17 different assessment tools, including single- and multiple-item scales[57]. In 2013 the Organisation for Economic Co-operation and Development (OECD) released the OECD Guidelines on Measuring Subjective Wellbeing[64]. While these guidelines intend to guide the surveys on large populations, they are not suitable for assessment of emotions and feeling associated to a specific activity or situation, as it is the aim of this methodological review.

Diary log methods are very commonly used. For example, in the Day Reconstruction Method[65] participants are asked to start by sequencing the episodes of the previous day, report on the context of each episode (e.g. time, location and companion) and the respective emotions associated to each activity. Although initially applied within the field of Psychology, this method is now used in various fields, such as economy[66] and marketing[67]. Using the Day Reconstruction Method, White and Dolan looked at the pleasure and reward domain of daily activities among adults[68]. Outdoor activities were the most pleasurable, opposing to work activities. However, work activities were the most rewarding. On the other hand, relaxing and watching TV were placed in the positive axis of pleasure but experienced as being the least rewarding. Online versions of this method are to be found, such as in the Happiness Pointer[69] (in original:

G*eluksWijzer*) which objective is to make the participants aware of what makes their happy or constrains their happiness.

The Experience Sampling Method (ESM), also known as Ecological Momentary Assessment, was introduced in 1987 and concerns the assessment of feelings or activities at the current moment that they happen[70]. ESM gained a lot of interest more recently, with the spread of smartphones and mobile technology in general. ESM provides several advantages over methods such as the Day Reconstruction Method. The most often mentioned is that it reduces the recall bias as individuals are asked what they are doing at the current moment. Secondly, it consists of short questions designed to avoid disturbing the individual, and allowing collection of data for long periods of time.

In our own research we have been using ESM to assess wellbeing and daily activities. For example, in one of our studies we combine accelerometry for the assessment of physical activity and ESM in the assessment of activities, context and experience in order to investigate the relation between physical activity and pleasure in the daily lives of older adults[71]. In this study the participants were asked to report several times a day what activity they were doing, with whom, where and how much pleasure they were experiencing while performing that activity. Additionally, the participants were asked whether they have been performing any other activities since their last report, referred to here as “extra activities”. Despite the advantages mentioned earlier, in our study we identified several drawbacks from ESM. For example, the moment when the person answers the question is chosen by oneself and it is almost always interrupting the current activity of the person. This is particularly important when assessing feelings as the person can become annoyed only because of the interruption. The interruption of routine becomes even more relevant when using ESM to obtain information regarding the context of physical activities. It is unlikely that the individual will stop a jogging session or a tennis game to answer the questions on the smartphone. Probably, the person will finish the game and then answer the question. In this way, the answer “playing tennis” to the question “what are you doing now?” is strictly speaking no longer true. The person *was* playing tennis, now he/she is answering to a question on the phone. So, if we look at the physical activity of the person at the moment of the answer, or closely before it, it is unlikely to correspond to the physical activity of the person while performing the activity, in this case, playing tennis. The obtrusiveness of ESM is also seen by the fact that, in our studies, participants were more likely to report “extra activities” when alone than when with other people. From the 1.693 ‘extra activities’ reported in one study, 1.261 (74%)

events were reported when alone. This indicates the importance of the timing. A solution might be using context sensitive ESM whenever possible, and avoid situations when the person is in the middle of an activity, unless, when that activity is exactly the situation of research. Towards this end, in 2003 Intille introduced the concept of context-aware experience sampling[72] and it had been further developed for several purposes. For example, Mehrota et al. propose a method that finds the opportune moments to ask questions based on prediction models, aligned to the lifestyle of the participant[73]. Another possible improvement to ESM would be a way to guarantee that the interruptions are short enough not to disturb the activity at all. To do so, smartwatches might be a good media as suggested by Intille[74]. Finally, one can think of automatic recognition of activities through analysis of accelerometer data combined with contextual information, such as location, to reduce obtrusiveness.

Another issue concerning ESM relates to the repetitiveness of the questions that may lead to familiarization. One of the advantages most often mentioned regarding ESM is the fact that it reduces memory recall bias. However, repeating always the same questions for a period of time might lead to familiarization as reported by [51,75] suggesting that through repetitiveness, people can give impulsive answers because “they already know the question”. All-in-all, burdensome inquiries can lead participants to answer falsely, do not answer at all, or even drop out of the study[76], compromising the quality of the research.

Based on many discussions with experts from all over the world in various scientific settings, there seems to be a “fear” of using ESM with the older population. We did not encounter any specific problem here. We do not think that all older adults have low technology affinity, only that there is a higher variability of technology skills when compared to a younger population. Throughout our research we have encountered participants who owned a mobile phone, as well as those that have never used a smartphone before. At least in one case, a participant mentioned that the motivation to participate in the research was to learn how to use a smartphone. Also, in the case of this participant that never used a smartphone, she did not have any problem using the technology; a positive example that speaks against the “fear” of using ESM with older adults.

Physical activity and emotional wellbeing are two different concepts to be measured. Physical activity can be understood as a physiological measure that can be measured with sensors, i.e. translated to an objective measure (in this case acceleration). As an example: an acceleration of 1 m/s^2 means the same for all individuals in all parts of the globe. Contrarily, measures of wellbeing bring several challenges in its interpretation. In line with the criticism towards self-reported physical activity, self-reported measures of wellbeing are subject to personal interpretation. When asked on a scale from 1 (*not at all*) to 7 (*totally*) how happy people felt during the day for a period of one month, some people may report a score of 7 when they have experienced a reasonably nice day, while others may reserve such higher range scores for special occasions exclusively. This makes comparison between individuals extremely difficult. This is also susceptible to cultural differences (e.g. is it ok to talk about happiness?) and personality. Talking about emotions is not easy for everyone. Some people seem to have a shield; they do not want to, and they are not interested in talking about emotions. Unobtrusive ways of emotion detection – such as facial emotional recognition or brain computer interfaces – open ways to assess emotions in people that do not want to talk about it. However, create awareness is often one of the first steps on behavior change, as we will see in Section “Coaching”. The pro’s and the con’s should then be considered in order to take the decision that will best support the individual to achieve the desired behavior. For example, while some individuals might benefit from being asked about wellbeing directly, others might prefer an assessment without implicit interaction.

Recent technology developments have also enabled improvement in the automatic recognition of emotions leading to the field of Affective Computing, and highlighting the multidisciplinary work between Psychology and Computer Science. Affective Computing refers to the detection of emotions mostly based on visual and/or audio signal analysis. Predominantly facial expressions are used to detect emotions, but also body language. Especially in the domain of data mining, promising research is emerging on automatic detection of mood. Emotion detection through environmental sensing is also possible. For example, the EQ-Radio claims to detect emotions as happiness, sadness or anger with 87% accuracy using reflections on the human body emitted by a wireless router to detect heartbeat and breath[77]. Emotion tracking is also emerging as a field in wearable technology[78]. These devices base their emotion recognition on physiological parameters, such as skin conductance, heat rate and skin temperature. Once again, our mobile phones allow for the collection of all types of data. Furthermore, our environments are getting smarter and smarter with smart homes connected to smart hospitals, smart roads, etc. We live in smart cities. By connecting everything (internet-of-things), knowledge from computer science can enter in place and actually make sense of the data.

The more we know about the individual user, the better we can tailor interventions to reduce obtrusiveness and to gather information about context and emotional experience throughout the day. Ideally, sensing may be totally unobtrusive to the user, but with the technology currently available, we are forced to make smart decisions about which tools to use for which applications. Combining various sensing methods may improve the accuracy of available knowledge in a further processing step. This processing of sensing data, or *reasoning*, to acquire meaningful, semantically rich information about the user and his environment will be discussed next.

Reasoning

To promote pleasurable activities in daily life, and subsequently increase physical and mental wellbeing of the older population, we need to combine information from the individual and his/her context. Through sensing we can collect real-time data in daily life. However, most of the times the data collected is meaningless in its raw, or unprocessed, form. Reasoning concerns the fusion of data sensed by multiple sources to obtain meaningful information for the users, to detect short- and long-term patterns, as well as deviations from those patterns. By doing that, coaching can be provided in (near) real-time, to meet the context of the user at that moment and to adapt to changes in, for example, the behavior of the user. The computational power of ordinary technology used in daily life allows real-time feedback and coaching. Also, the eminent field of Internet-of-Things supported by the upcoming 5G networks, give the means for communication between devices and continuous information about the user and his context. The challenge is to make sense of the data and model it in a meaningful way, so that the user that will ultimately be supported in achieving the desirable behavior change.

Data gathered in daily life is not obtained in a controlled setting; it is noisy and incomplete, and as such we can rarely control if the data we are collecting is exactly what we think it is. The advent of less obtrusive sensing is allowing more and more studies to be performed in daily life. Conventional analytical methods have difficulties dealing with this type of data and there are several groups dealing with adaptations to that fact. The book *Intensive Longitudinal Methods: an Introduction to Diary and Experience Sampling Research* from Bolger & Laurenceau provides valuable information on intensive longitudinal studies, i.e. studies "*with enough repeated measurements to model a distinct change process for each individual*", and it focuses mainly on multilevel analysis of the data[79]. Multilevel modeling is appropriate for the analysis of hierarchically structured data in which there might be a lack of independence among observations[80]. Data collected in daily life meets this description, as it is often structured in at least two levels (e.g. observations nested within subjects) or multiple levels (e.g. observations nested in days, which are nested within weeks, and finally nested in subjects). The predictors associated to a level can be used to predict variation in another level. For example, multilevel analysis can be used to investigate the association between psychological functioning (a subject-level characteristic) with variability of affect (an observation-level variable)[81]. In multilevel regression analysis, when observations are nested within subjects, the variation of the slopes and the intercepts is then the variation between- and within-subjects, respectively. Such methods allow us to look for general effectiveness of an intervention, for example, but also to the differential effectiveness, i.e. “who benefits from the intervention?”[82]. Multilevel modeling brings the flexibility of having different sample sizes in each level. This means that there can be X observations for individual A and Y observations for individual B. This is particularly important in studies in daily life as it is unlikely that all subjects have the same number of observations, making the analysis unsuitable for repeated measures analysis of variance (ANOVA).

To give some examples, in the field of physical activity, multi-level analysis has been used to analyze associations between predictors (e.g. demographic and environmental factors) with the time spent in moderate and vigorous physical activity intensity separately on weekdays and on weekends[83]. Using multi-level analysis, Corder and colleagues showed that, among a sample of 2,064 children, that those with more parental logistic support were less likely to decrease their physical activity on the weekends during a one-year study, while peer support was more important during the weekdays. Multilevel analysis has also been used to investigate the relationships between affect and physical activity. For example, in a study with 62 university students aged between 19 and 30 years old, increase in physical activity was associated with positive and energetic feelings[84]. In this case, women felt significantly better (positive valence) after increasing their activity levels, when compared to man.

In our previous studies, we have investigated the influence of daily activities on the relation between physical activity and pleasure among older adults with multilevel analysis[71]. Our results suggest that the type of daily activity moderates the relation between physical activity and pleasure. In this case, it was not possible to analyze the variation between subjects (random slopes) – most likely due to the small sample size.

However, we lost a lot of the granularity of the data by taking this approach. In multilevel regression analysis, the predictors must be dichotomized. In our study, participants were asked through ESM to choose their current activity from a list of more than 20 activities on a smartphone, every hour for a period of one month. However, when analyzing the data, we simply distinguish between the basic activities of daily living (e.g. eating and caring for yourself) and leisure activities (e.g. relaxation and doing sports). Also, we have asked whether or not the activities were performed in the presence of others, and if so, with whom. In our analysis, we only looked at activities performed alone or with someone else but it would have been important to look at different companions, such as friends or grandchildren. Despite the flexibility given by multilevel modeling, this method still presents some challenges regarding, for example, categorical predictors. This type of variables can always be transformed into binary variables, leaving one out as reference, but this is not desired when a variable can assume a large number of values. Furthermore, this is a method suitable for ad-hoc analysis (i.e. after the data is collected) and is not suitable for implementing in real-time. These analytical methods, although not suitable to be used in real-time, give us the tools to understand behavior and create profiles.

A new trend is to bring techniques from the field of machine learning to conventional statistical tools. One example is the analysis and interpretation of human behavior as a neural network. In this network, each symptom (or variable of interest) is represented by a node. The weights of the connections between nodes and the changes to these weights over time, provide an indication of the relations and dynamics of the system. Bringmann and colleagues analyze personal neural networks with multilevel vector regression models to investigate clinical longitudinal data[85]. The authors used this method to show that worrying plays a more central position on the network for people who score high on neuroticism than on people who score low. This personalized network analysis is being used in the field of psychopathology[86], for example in the prediction of depression. In this analysis, the dynamics of a personal network can be analyzed to detect proximity from a tipping point, by increased chaos and connections in the person's network[87].

A similar approach can be taken to analyze the dynamics of healthy lifestyles. For example, in a study to monitor and understand craving behavior, researchers investigated the contexts of healthy and unhealthy eating, in which a smartphone app is used to ask participants about their activities, location, companion and emotional status approximately eight times a day[88]. Furthermore, participants were asked to report everything they ate as well as craving for healthy and unhealthy food. The behavior of obese and non-obese participants was then modeled with population networks to investigate which factors are influencing the craving behavior for each one of the sample populations separately. First, the network of the obese sample showed a much denser structure (i.e. more significant connections between nodes) than the network of the healthy-weight sample. Looking at specific nodes, negative emotions, such as sadness and boredom, predicted unhealthy eating on the obese sample and unhealthy eating on the healthy-weighted people. Additionally, this method allows for individual analysis of behavior giving the opportunity to look at the network of each specific individual and, therefore, implement personalized interventions. Finally, by treating the networks as graphs, this method provides the possibility to analyze the centrality of the networks (i.e. outdegree, indegree and betweeness values), seeing which nodes play the more important roles in the networks and, therefore, deserve more attention.

To the best of our knowledge, the personal network analysis has not been investigated in the domain of Active Ageing. It would be interesting to look at the dynamics of healthy behaviors especially in the older population, modeling physical and mental health and see the relations between different parameters. This approach could for example be used to understand within-person differences in the influence of contexts in the promotion of physical activity.

To generate meaningful information to the users, behavior change systems can incorporate expert-knowledge, i.e. pre-defined knowledge from the user (e.g. age, gender, health status), user-knowledge (e.g. preferences) and data-driven features (e.g. from the data collected over a month it is seen that the user moves more on Saturday’s than in any other day of the week). For example, Sprint and colleagues combine knowledge-based and data-driven features to perform unsupervised detection of changes in physical activity over time[89]. The analysis of long term patterns is a challenge that emerged with the amount of data that is possible to collect nowadays with wearable devices, environmental sensing and personal devices, such as the smartphone. The coming years will likely bring exciting developments in this field, with large amount of information from the individual and his environment being collected by different sources, and new and more effective algorithms, supported by smaller and unobtrusive devices with large computational power.

While conventional statistical analysis gives us the possibility to analyze which intervention works for whom, (near) real-time data mining allows us to adapt the interventions to the current status of the user and his context. In this way, when a new user starts the intervention, he can be given the intervention that has shown most effective results on people alike, and the intervention can be further tailored in real-time. Similarly, to the field of sensing, also in what concerns reasoning techniques, we need higher transparency and communication between researchers and companies to meet the ultimate goal of promoting health and wellbeing.

Initiatives such as the Open Science Framework[90] are likely to help in spreading knowledge and implementations of algorithms in a transparent manner. Looking at initiatives such as Google's DeepMind[91] and IBM's Watson[92], artificial intelligence within the computer science field is bringing new horizons to behavior change support systems. Although smart reasoning can bring a wealth of meaningful information regarding the user, his context, and his behaviors, the next crucial step is to turn this information into meaningful actions to promote behavior change: *coaching*.

Coaching

Persuading someone to change a behavior is not easy. Psychologists have investigated the reasons and moderators that lead humans to break established patterns of action since long ago. Work from as far back as the beginning of the 1930s showed that, within the sports of Northeastern University in USA, improvement in physical fitness was more dependent on the instructor/coach than on the sport itself[18]. These results suggest that an external agent, in this case a human coach, can play a crucial role in the motivation of the individual to reach a desired behavior change. Furthermore, individual characteristics and the environment can be motivators or inhibitors of adopting new behaviors. In terms of support of Active Ageing, we encounter the challenge of persuading an older adult user to break a lifestyle pattern that may have been established over the course of many years. It is therefore of utmost importance to look at theories of persuasive technology and behavior change, and identify how these theories can be implemented in technology to improve the effectiveness of interventions.

The Social Cognitive Theory remains one of the most generally used theories in the promotion of healthy behaviors. Self-efficacy, one of its constructs, is defined as the belief in one's capability to organize and execute the courses of action required to produce given attainments[93]. If the individual has low self-efficacy, i.e. if s/he does not perceive himself as capable of adopting the new behavior, it is unlikely that the individual will be motivated to change current behavior. Therefore, technology interventions promoting healthy behaviors must ensure the user that he/she has the personal resources necessary to act in the desired manner. To do so, it is important to set not only a long term goal, but also short-term goals that are challenging but achievable, in accordance to the Goal Setting Theory[94]. In fact, setting appropriate goals is a key determinant of the success of any persuasive technology. Several reviews have shown the importance of goal-setting in behavior change interventions promoting, e.g. healthy eating[95], physical activity[96], and supporting self-management of chronic conditions, such as diabetes[97]. Looking at physical activity promotion, personalized goals are particularly relevant in the older population due to the heterogeneity of this group, as it is likely that older adults experience some degree of disability[51,98]. Therefore, a daily physical activity goal should be set according to the current behavior of the individual. We have worked on an approach to automatically set daily physical activity goals adjusted to the routine of the individual[99]. In this self-adaptive goal setting, the system analyses the routine of the user, and set incremental challenging but achievable daily goals, that require small steps to reach the ultimate desired goal. The ultimate goal, as well as how the user should ideally distribute his/her activity over the day, can be set by a healthcare professional or based on the guideline that matches the user profile.

The Transtheoretical Model coined by Prochaska and DiClemente in 1983, suggests that a behavioral change process, whether it means recovering from problematic/addictive behaviors or adopting a new healthy behavior, involves movement through a series of five discrete stages: pre-contemplation, contemplation, preparation, action and maintenance[100]. Each one of these discrete stages is called a *stage-of-change*. In the early stages of this model – pre-contemplation and contemplation – the main strategies consist of creating awareness about the current behavior (without being aware, there is no perception of any need to change) and educate about the advantages of the desired behavior. When moving through the several stages, an individual should re-evaluate the goals to keep appropriate goals that are specific, challenging and achievable that continuously adapt to the current behavior of the individual[94]. Setting goals that are too difficult for the user to achieve can lead to frustration and drop-out. Commitment to take actions is also very important, as considered in the strategy of implementation intentions, which states that an individual is more likely to take an action if he/she has previously committed to perform that action[101].

It is also necessary to take into consideration the reasons why an individual takes an action. The Self-Determination Theory defines two types of motivation: extrinsic and intrinsic motivation. While extrinsic motivation refers to "*the performance of an activity in order to attain some separable outcome*" (think of monetary reward), the intrinsic motivation "*refers to doing an activity for the inherent satisfaction of the activity itself*"[102]. Experiencing pleasure or enjoyment while performing an action, is a motivator to repeat that action. Translating this to behavior change promotion, by learning what the user enjoys doing and adapting the coaching strategy accordingly, we are likely to increase the adherence to the interventions as the individual is more likely to comply with the advice. This strategy is a core component of the approach of promoting pleasurable activities in daily life to achieve Active and Healthy Ageing. The Self-Determination Theory is not the only theory referring to the driven effect of positive emotions in the promotion of healthy behaviors. Building upon the Broaden-and-Build Theory, which states that positive emotions broaden individuals' momentary thought-action responses and support in building a variety of resilience resources[59], Frederickson has introduced the 'upward spiral theory of lifestyle changes'[103]. According to this offshoot of the Broaden-and-Build Theory, individuals experiencing positive emotions are more likely to be open to new activities, and consequently initialize, new behaviors; these new activities, and behaviors support building of personal resources which enhance health and feelings of fulfilment and accomplishment for adopting the healthy behaviors, producing experiences of positive emotions, and creating an upward spiral. Furthermore, incorporating Berridge's perspectives on a difference between *liking* (i.e. the same concept of pleasure as used in the Self-Determination Theory) and *wanting* (similar to a drug addict that 'wants' to take a drug even when he does not experience pleasure with that action anymore)[104,105], Frederickson suggests that there is an inner layer of the spiral, in which positive emotions, including those that go beyond pleasure, can be non-conscious motivators for sustainable decisions to maintain healthy lifestyles. The results of our systematic review on the relation between positive emotions and independence in performing activities of daily living match this bi-directional relation with longitudinal studies suggesting that those with higher levels of positive emotions at baseline are more likely to have better functioning at follow-up[106]. An hypothesis is given by Cooper and colleagues, who suggest that when older adults are faced with a decline in functioning, those with higher levels of positive characteristics are likely better at building a variety of personal, social and environmental resources to counteract that decline and keep their independence[107]. Building resilience resources is particularly relevant in the older populations, as with age, people are more likely to encounter adversity on the health domain (e.g. functional decline) and in terms of life-changing events (e.g. death of relative).

Unobtrusive technology facilitates learning what individuals do and experience in daily life, and apply the behavior change theories mentioned above. In fact, a meta-analysis from Fanning and colleagues shows that indeed technology-based interventions targeting promotion of physical activity are more effective when relying on behavior models[108]. Oinas-Kukkonen defined behavior change systems as "*information systems designed to form, alter or reinforce attitudes, behaviors or an act of complying without using deception, coercion or inducements*"[109]. Technology-based interventions to promote Healthy and Active Ageing fall into this definition. New behavioral models are also being designed having technology-based interventions in mind. One example, is Fogg's Behavior Model which suggests that new behaviors result from a combination of motivation, ability and triggers[110]. This means that an individual must be motivated and have the skills (ability) to perform a new behavior. The trigger given by the behavior change system must meet the motivation and ability of the individual at any given moment. Fogg defines three types of triggers: *spark* (when a person lacks motivation), facilitator (when a person is motivated but lacks ability) and signal (as a simple reminder when a person is highly motivated and has high ability). Even those who are intrinsically motivated to adopt a certain behavior, experience ups and downs in their motivation. Triggers in the path of the individual remind and highlight why the change in behavior is desired and, for example, why this is a good moment to take an action. This work resulted in Fogg's "Behavior Grid" which specifies 15 types of behavior, in a 3x5 matrix, where the first dimension concerns the duration of the intended behaviors (one time event, specific duration event, or permanent change) and the other dimension concerns, what the authors call, "Flavour" (new vs. familiar behavior, encourage vs. discourage vs. stop behavior)[111].

Each individual is unique, and dynamic, in a sense that a strategy that works for one, might not work for another, and even what previously motivated an individual in the beginning of the intervention might not motivate the same individual at a later point in time. Persuasive technology can benefit from what is nowadays called *personalized health*: each person has an individually 'tailored' plan, like a tailor fitting a suit. This means that we can tailor the interventions and the communication to the user. Since each individual is different, it is widely believed that tailoring, or personalization, helps increasing the adherence, and effectiveness, of technology promoting behavior change[112]. Hawkins et al. defined tailoring as "*any of a number of methods for creating* *communications individualized for their receivers, with the expectation that this individualization will lead to larger intended effects of these communications*"[113].

A framework to provide tailored communication to individuals is given by op den Akker et al., and identifies four properties that can be tailored to each particular instance of communication: timing (*when is the communication provided?*), intention (*what is the goal of the communication?*), content (*what is stated in the communication?*) and representation (*how is the communication presented to the user?*)[114]. Each one of these components can be tailored in at least one of the tailoring concepts identified in previous work: feedback, inter-human interaction, adaptation, user targeting, goal setting, context awareness and self-learning[96]. In the following paragraphs we provide a set of examples in how to tailor, or personalize, each one of the properties of communication.

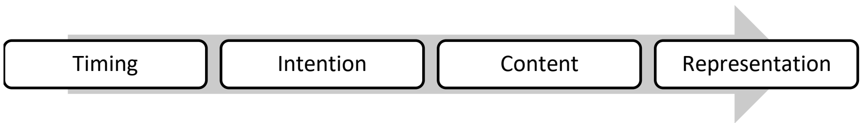

Figure 2. Concepts for personalization of motivational messages. Adapted from op den Akker et al.[114].

Timing property corresponds to *when* the communication is delivered. The communication can be user-initiated, i.e. the user intentionally requests information from the system. For example, we can think of the user intentionally seeing how far he is from reaching the physical activity goal or requesting information about activities in his/her surroundings. Secondly, the communication can be system-initiated. In this case, the system decides when the communication with the user should be initiated. Tailoring the timing to individual users can occur through five distinct concepts: goal-setting (e.g. encouraging as a user is approaching his goal), adaptation (e.g. adjusting the frequency of nudging based on the user's stage of change), context-awareness (e.g. timing a message based on the user's location), self-learning (e.g. learning which moments are effective for reminders) and user-targeting (e.g. using a personal calendar to decide which moments better not to disturb). Without the proper strategy the timing of communication can be very wrong, as for example a system should not initiate interaction with the user when he/she is participating in a religious event, except if in an emergency situation.

Intention corresponds to the aim of the communication and it is always associated to a goal. Intentions might contemplate the motivation to increase certain behaviors (e.g. social activity and physical activity), decrease/cessation of a behavior (e.g. smoking and unhealthy cravings) or neutral (e.g. reinforcing the user that he is doing fine). Noteworthy is that, even when it comes to promotion of a certain behavior, as in physical activity, there might be moments when the system must discourage the user to engage in that behavior. For example, the system might discourage the user to do intense strength trainings two days in a row. When the intention of the communication is established, we can move to the content.

Content corresponds to the actual information that is given in a communication. The content of the message can consist of feedback (i.e. information about the status of the user), argument (i.e. a reason why the user should perform a behavior or action), and a follow-up which, in turn, can be a suggestion of an activity or a reinforcement. Suggestion of activities or behavior can be based on the lifestyle of the individual or on the context of the individual at a certain moment. For example, looking at suggesting activities to increase physical activity, in our interviews about current practices and attitudes towards technology to coach physical activity, we identified that there are people who are intrinsically motivated to be physically active by the pleasure it brings to them, while others need to be engaged in a meaningful activity in which they can clearly perceive an outcome. Those in the second group are not intrinsically motivated to run as this activity does not provide any perceived "outcome". Contrarily, gardening or doing groceries is rewarding as it provides a clear outcome and is stimulating to be physically active. Interventions to perform physical activity should take this into consideration as gardening a backyard can be qualified as a strength and flexibility training. Choi and colleagues propose a list with sports and activities to be performed at home with the equivalent number of steps[115]. The Metabolic Equivalent of Task can also serve as indication of the physical activity associated to different daily activities[116]. The promotion of physical activity can then be performed via proxy, i.e. motivating people to engage in activities of contexts which are likely to induce physical activity, but are not related to exercising. For example, in our work we saw that people are more active when they are outside or with other people[117]. Therefore, instead of saying directly to go for a walk, the technology might recommend being with other people.

Representation, the last property of a communication, is the way the message is represented to the user. This can be visual, e.g. through images or natural language, audio or haptic. The representation of a communication can be personalized, for example, to the context of the user. For instance, when the user is at home he might receive audio messages in the sound system, saying that there will be a 15 minutes' window of sun in this stormy day, while when the user is at work, the same message should be given as a text on a device to decrease obtrusiveness. Several feedback and coaching modalities will be discussed in the next sub-section.

In this section, we have seen that behavior change systems must build on theories from Psychology to support each individual user in reaching the desired objectives. Although tailoring is extremely important, there is a risk of reducing the level of control given to the user of the technology. Our earlier studies showed that control is important and thus technology developers must not forget to put the user in control, whenever the physical and cognitive capabilities allow it[51]. An outcome of all our user studies was that, users do want to feel in control of the technology, and not the other way around. This means, that technology should support the user, but should not replace functions, with the fear that it will lead to underuse[12]. Furthermore, in accordance to the tailoring models, and based on our interviews, individuals want to feel that the system was designed for them having into account their personal demographics (e.g. age and gender), health status (e.g. chronic diseases) and lifestyle (e.g. preferences). The field of Computer Science provides the tools to personalize an intervention to each specific user and to adapt to changes of the individual or the environment over time. Furthermore, data mining techniques can help identifying the most suitable intervention for a user from his profile based on previous work to avoid the cold-start problem (i.e. lack of detailed information of a user in the beginning of an intervention). A promising initiative is The Human Behavior Change Project[118] which aims to synthesize evidence about behavior change, by systematically organizing and analyzing previous research and generate new insights about behavior change.

In the previous sections we addressed the gathering of relevant user and context data, processing of this data into meaningful information and the application of the right coaching strategies to turn this data into behavior change support. In the next section we look at the various tools that incorporate all of the previous parts in order to come to a tangible feedback and coaching tool.

Applications

Sensing technologies, reasoning algorithms and coaching strategies are vital building blocks, but must in the end be embedded in valuable tools and applications that provide information to the individual on how to reach Active and Healthy Ageing. We refer to *Applications*, as the interfaces that allow the system to communicate to the user. Recent decades have experienced a growth in the applications available to support behavior change. However, most applications for older adults target monitoring and detection of behavior (e.g. recognition of activities of daily living and fall detection), and not on interventions for prevention and promotion of health and wellbeing. Nevertheless, there is an overall growing interest on the development of applications focused on prevention, as can be seen for example by the European Union efforts by setting up more than twenty-five million euros for the development of innovative projects on "*Personalized coaching for wellbeing and care of people as they age*"[119]. In this section, we will provide some examples of projects we have worked on as well as emerging and promising tools, mostly focused on support of Active and Healthy Ageing but also referring to more general behavior change interventions.

With the increased adoption of mobile phones, several interventions made use of SMS messaging to promote behavior change, such as smoke cessation[120] or encouraging physical activity (e.g. [121–124]). However, when associated to the older population, SMS messages are often used as alerts to the caregivers (e.g. [125,126]), instead of prompting the older adult to achieve a certain behavior. Smartphones enabled a new way of intervention delivery. They allow real-time computation of data, and delivery of information or prompts to the user in engaging interfaces, for example in the promotion of healthy eating[127] or physical and cognitive activity[128]. Some of these systems, made it to consumer products, such as the Gociety tool, a solution consisting on a smartphone application, activity tracker and a mobile application for caregivers that supports the individual in maintaining independence and achieving an active lifestyle[129].

Another ubiquitous screen-based tool to deliver interventions is the personal computer. An example of a web-based platform to promote Active and Healthy Ageing was developed in the European FP7 project PERSSILAA[130]. In PERSSILAA, a multidisciplinary and international consortium developed, implemented and evaluated a novel service model to screen for and prevent frailty among community-dwelling older adults. Older adults were given tools to screen, monitor and train their health, in a multi-domain approach focused on the domains of nutrition, cognitive and physical functioning. Through online screening instruments, older adults could see if they were at risk in any of the health domains mentioned. Based on the screening result, older adults would be directed to the general practitioner or be invited to use a set of training tools. Autonomous training was given through remotely available health literacy programs, as well as personalized training schemes to improve physical and cognitive function. Older adults could train at home, at their own pace, or come to pre-defined locations in their neighborhoods to train together. Monitoring of everyday functioning and detection of changes over time was made possible by a set of unobtrusive and ambulant monitoring tools, easily integrated in one’s daily routine. A wearable step counter and an associated smartphone application allowed coaching of physical activity, a smart scale connected to the same application enabled the monitoring of the user’s weight[51]. On a web-portal, a short-questionnaire monitored eating habits and a short cognitive training from the Neuropersonal Trainer allowed monitoring of cognitive function. The screening, training and monitoring tools were combined in a gamification layer, shown to the user in a form of the desert island shown in Figure 3, in which the achievements in daily life were rewarded by in-game pieces of a puzzle that eventually allowed the main character to escape the island. The service model was designed to meet the healthcare services, needs and technology affinity of communities in Italy and the Netherlands by participatory design including all relevant stakeholders[131]. During the project the PERSSILAA service model was implemented in Italy (Campania) and the Netherlands (Overijssel), counting for an involvement of more than 7.000 older adults. In general, in the Netherlands the older population that was more familiar with technology started using the web-platform immediately. Contrarily, in Italy, the project had to accommodate extra tasks to make older adults acquainted with technology to ensure their proper use of the tools and keep people engaged in the health promotion.

Figure 3. Desert Island designed to enhance motivation and adherence to the PERSSILAA services.

The area of Smart-Homes is another technology that is increasingly being used to support Active Ageing and independent living. The European Funded FP7 project eWALL is an example of a smart home environment designed and developed having in mind the needs of older adults with chronic diseases or suffering from age-related impairments[132]. eWALL combines wearables and environmental sensing to infer the health status of the user at any moment, and supports the user in achieving a healthy lifestyle by providing feedback and coaching on a large touch screen, as shown in Figure 4. Short- and long-term behavior patterns were analyzed to support older adults reaching their desired levels of activity or sleep. In the proof-of-concept studies performed in the Netherlands, Austria, Denmark and Italy, the sleep and the physical activity applications were among the most liked applications. Wellbeing advertisements were provided mimicking the advertisements received on television, applying the constructs of social marketing to healthcare[133]. A virtual agent, a friendly robot called Robin, builds on the personalized communication framework described in the previous section to support the users reaching the desired behaviors.

Figure 4. eWall main screen (*left*) and complete cabinet (*right*).

Virtual agents, or more specifically embodied conversational agents, can support managing the agenda of the older users[134] or react in real-time to the performance of physical exercises[135], for both users with high, but also lower levels of health literacy[136]. These personal assistants, can be all-knowing, supporting the users in all components of their lives. Systems as Amazon's Alexa[137], Apple's Siri[138], and Google Now[139] are promising tools that may be used to support active lifestyles, also among older adults. Personal assistants can be embodied, either using virtual agents displayed through an interface or on the upcoming field of holograms. For example, the Japanese company Vinclu Inc. recently announced the launch of Azuma Hikari[140], a female embodied hologram that assists individuals in their lives. In its released version, Vinclu Inc. targets a young and technology savvy audience, but it is easy to imagine the potential also to older populations. The difference here is that Azuma

Hikari has a personality and preferences (for example, she likes doughnuts and hates insects) and supports her 'master' in all tasks of daily life, such as reminding of meetings or switching on the heating before the user arrives home. There are many factors involved in the design of an effective virtual coach. Whenever a coach is in place, it is perhaps most important to talk about credibility and empathy. The former refers to the credibility of who is providing the message. Whatever the media of the agent, it is very important that they show empathy. Designers can learn from the video-game industry or cartoons (e.g. Pixar Studios that have a long track record of bringing to life empathic virtual characters) how to design empathetic systems. As one of the participants in our studies said "*I want to feel that the technology cares for me*", especially when targeting mental health. It is very important that the technology supports, and does not replace, human contact whenever possible[141]. Systems can use one single virtual agent or a group of agents to provide holistic care and better simulate the real life world[142].

Virtual agents can be presented on a screen or in any other interface, such as a robot. Similarly, robots can serve as the embodiment of physical training tools (e.g. [143,144]). In geriatric care, these assistants might also fight loneliness, a very problematic condition of the ageing population. An example is the seal-like PARO therapeutic robot resembling a pet that needs to be taken care of, used in clinical (e.g. [145]) and non-clinical populations[146]. Also, there is a great interest in robots to be companions, or even to perform the role of butler. Daily interaction with robots can be performed to support activities of daily living[147] or improve mental wellbeing (e.g. [148]). This drive does not come only anymore from the healthcare demands, but also from the consumer perspective, as the case of the Zenbo[149] robot, presented in October 2016 by Asus.

Still inside the home environment, we can think of how objects of everyday life can be used in the support of Active and Healthy Ageing. One example already in place is to transform the typical photo frames available in every house to be smart displays to promote healthy behaviors (e.g. [150,151]). An art installation in the house whose change in the leaves in the trees is a metaphor for the physical activity; a statue which position reflects the wellbeing of the person; promotion of behavior related to the function of the object, as in for example, the fridge supporting in healthy eating; there are many creative opportunities of bringing supportive technology into the lives of people that are not fully explored and exploited.

The final technological tool we want to talk about is virtual reality. Non-immersive virtual reality has been used among older adults for example to engage walking on a treadmill or stationary cycling. Compared to other web-based technologies, immersive virtual reality provides the sense of presence bringing people together. In the terms of Active and Healthy Ageing, virtual reality can help improve mental wellbeing by providing new means of entertainment and connectedness, especially for those living in remote areas. To reduce the burden of loneliness, one can think about the appeal of sharing experiences with virtual reality, in which the receiver can perceive himself as part of the event, such as a birthday or seeing the new family car.

Regardless of the specific feedback and coaching tool, those involved in the development and implementation of technology to support Active Ageing must think that the tool is in support of the user, and has his best interests in mind. Also, technology should be designed with the user to ensure its adoption into the life of those users[152]. Virtual Reality, Robotics, and even Virtual Agents presented on more commonplace displays are all emerging fields that radically change the interaction between user and application. Although *early adopters* may completely embrace these upcoming, futuristic technologies, the true potential value in the field of Active and Healthy Ageing comes from designing applications that combine unobtrusive sensing, smart reasoning, adopting personalized coaching strategies and combining it all in friendly and natural user interaction concepts that provide pleasant added-value to the life of the older adults.

Scenario

In the previous sections, we have looked at the four components of technologies to support Healthy Ageing in the daily life: sensing, reasoning, coaching and applications with four main messages:

- *Sensing* must be as unobtrusive as possible, and embedded in the life of the individuals.
- *Reasoning* processes must continuously learn about the behavior of the individual, ideally fusing data from several sources to obtain a (close to) complete overview of the lifestyle of the individual, and provide meaningful information about that behavior over time.
- The *coaching* strategies must fit the individual and his/her context at all times.

- There is no one-size-fits-all for *applications*; there must be several options that satisfy the needs and preferences of the users themselves.

In this section we will integrate these four main messages in two short stories. As we have seen in the previous sections, design and implementation of technology based interventions to support Active and Healthy Ageing must consist of a multidisciplinary team, including expertise of, for example, computer science, psychology and biomedical engineering and healthcare professionals. Users must also be involved at all phases to guarantee that the designed technology meets the needs of the users.

Communication difficulties are likely to arise in such multidisciplinary teams. For example, while “implementation” can mean development for a technician, it can also mean embedded in healthcare practices, when talking to stakeholders with a medical background. A scenario based approach is often used to solve these communication difficulties by making clear in a common language which are the agents or actors, often called *personas*, with specific activities and goals. Scenarios are of great utility for understanding requirements, discuss systems’ properties, the behavior of the individuals interacting with the system, and the interaction context[153,154]. In the early stages of the design process, the scenario can be written from a user-centered perspective following the methodology of PACT (People, Activities, Context and Technologies)[155].

In the remaining part of this section we introduce two personas, Maria and Bob, representing the older adults in two very different situations. Maria is cosmopolitan and an early-adopter of technology, while Bob has lower technology affinity and is more “careful” when it comes to accepting changes. The aim of these scenarios is to show how technology can support Maria and Bob in achieving Healthy Ageing, fitting their routines and being designed for their needs and preferences. Elements of sensing, reasoning and coaching are presented as part of several applications.

Scenario 1: The urban life

Maria is a 69 years old pensioner who lives in one of the most vibrant neighborhoods of Amsterdam. Throughout her life, she has worked in several multinational companies, travelled around the world for business meetings and for holiday trips with her family. Her transition to retirement was not easy mostly due to the sudden lack of a daily structure and a lack of sense of purpose.

Maria is divorced for 20 years. Her marriage resulted in two children, Peter and Simon, each one of them living in a different continent. She cannot blame them for their desire to live abroad, as throughout their childhood Maria made sure that they experienced different cultures. They talk to each other frequently but do not meet each other physically that often. Through her life, Maria has gathered a close group of friends that make sure she does not feel alone. Especially after a hip fracture resulting from a fall, Maria felt that her friends were there to support her and help her with all aspects of her life. But that does not mean that Maria does not feel lonely in the comfort of her house.

To counteract that loneliness, two years ago Maria "hired" Grace. After interviewing more than 10 virtual assistants, Maria decided to choose Grace as her personal assistant. And Maria hasn't regretted it for a moment; Grace is knowledgeable but humble, kind but assertive whenever necessary, and most of all, she does not treat Maria as an old lady. Contrarily, during the first months assisting Maria, Grace has *learned* to push the boundaries, challenging Maria to be active, not only physically and cognitively, but also by staying engaged in the community. To do so, Grace *includes* a module that reasons on the physiological data collected from the microchip implanted under Maria's skin to continually infer on daily behavior and on the health status of Maria at all time.

"*Good morning Grace! Which advices do you have for me today?*". Grace informs Maria that the humidity of the air finally dropped and it is a pleasant day to go for a long walk in the park after the humid days, that are characteristics of the Dutch weather. "*Today there will be a molecular cooking festival at the Vondelpark, why not look at it?*" Maria says that she does not feel adventurous to try new food and asks for a new advice. Grace *perceives* that Maria needs an activity to cheer her up and suggests an open-air exhibition of a new modern artist. This exhibition is close by Veronica's house, a friend and former colleague of Maria. "*That sounds like a plan! Veronica is one of those persons that can always uplift one's mood!*".

Maria has just returned from the exhibition. The door of the building opens automatically recognizing Maria. The same with the door of her house. When Maria arrives home, Grace informs her that she received a video from Peter. The video starts and the walls of the living room are transformed to accommodate the 360° movie. Maria's grandchildren are playing underwater with colored fishes. "*How beautiful is it!*". Maria prepares herself to rest when Grace takes over "*Hey beauty! Not so easy… you still haven't reached your activity goal! Your friend Natasha is in the swimming* *pool, why don't you join her?*. "*Swimming?! Please don't! I really do not feel like swimming. What else do you have for me?*". This time Grace suggests the indoor cycling and, with Maria's permission, the living room is transformed into a Tour de France landscape. Maria joins a group of 10 other people in the virtual environment. "*Hello Robert! How are you feeling today?*" Maria uses this moment to chit-chat with her friends. How good is it now that I do not have to wear any of those physical activity trackers from 10 years ago! That is so outdated!

After dinner, when Maria's 6 o'clock favorite show finishes, Grace interrupts Maria's thoughts saying "*I see you are not in your best mood… Does that have to do with your lecture tomorrow morning?*". "*Right to the point, as always…*", thinks Maria. Tomorrow Maria will say goodbye to a group of students she has been following for the last six months. Following a suggestion from Grace, Maria gives lectures on business development to remote communities in South America twice a week. Through her virtual representation, Maria is perceived as being physically in the classroom; she can teach to the whole classroom and also go from table to table to give 1-to-1 assistance to her students. This was a changing point in her retirement. She feels again that her life is meaningful and she is very happy. But it is always difficult to say goodbye.

In the meanwhile, Grace has become more of a friend than a personal assistant. Grace is everywhere, at home, on the streets, on vacations. Grace takes care of everything that concerns Maria's life, she cares for Maria. Sometimes even too much, from Maria's perspective. Now and then Maria feels that she needs a break and sends Grace on vacations. Although Maria knows that Grace will always be there whenever she calls her.

Scenario 2: The rural life

Bob is a 72-year-old proud countryside man who has worked on agriculture his whole life. He lives with his wife Elsa, 5 goats and a couple of chickens in a modest farm. In his village are now only 10 permanent inhabitants and he is one of the youngest; all others come and go on the weekends and vacations. Bob is known for being serious, he grew up not talking about feelings and that is how he feels comfortable.

Five years ago, Bob was encouraged by his GP to obtain an intelligent Band-Aid. He would not dare to swallow one of those small machines that control everything in your body. Having a micro device inside your body? Can you imagine that? No way!

The GP tried to convince him to get one, apparently, it is a way to get an overview of his vital signs, especially important after the heart attack he suffered 3 years ago. Bob managed to reach a compromise with his GP, and got himself an intelligent Band-Aid. Super easy, simply stuck to his belly. Washable, reusable, and the best of it?, the GP, wife and daughter stopped bugging him. Another great feature is that he does not have to remember taking his medication anymore, the Band-Aid releases the medication automatically.

Bob looks at the patch and it is yellow! He knows what it means; not enough physical activity for today. "*Oh well, let's see if someone in the village needs my help*". Bob sees on the display of the community that George, who lives a couple hundred meters away, needs help extracting honey. Bob gives indication that he is on his way to help George. Two hours later, and with all honeycombs empty, Bob's Band-Aid is glowing green and Bob is finally able to continue reading his new thriller book.

"*Hi dad!*", Bob got startled! "*Dad, I am here!!*", Bob can hear the voice of Rita, his daughter, but where is it coming from? "*Dad, next to the kitchen door!*", "*Ah there she is!*" Bob can see Rita in full size. "*She looks a mess!*", Bob thinks without saying anything; life has taught him not to give this type of comments to a woman. "*Sorry Pat, I am still getting used to this… thing!*". Rita tells Bob about her plans to visit on the weekend and the conversation is interrupted by Mariana, Rita's daughter, who wants to show grandpa her new 3D drawings. "*Hey Mariana! Will you send grandpa a kiss?*" The lamp in the corner of the room changes color, and so does Bob's mood; Mariana has that effect on him. His thoughts are interrupted by Rita's voice "*Dad I know you are eating more than you should! You know that that is not good for you!*". *"How does she know? Oh yes, that *stupid* fridge…"* Bob answers that he has been very busy taking care of the animals and that it increases his appetite, although he knows that this excuse will not work, as Rita can see an overview of his physical activity. But Rita decides to not provide any further comments. Elsa has finished cooking dinner and Bob says goodbye to daughter and granddaughter.

After dinner Bob plays Sudoku in his digital paper book. "*These games are getting more and more difficult*"; Bob tries his best to finish the puzzle's as fast as possible as he does not want to decrease in the village ranking. Bob gets an extra bonus puzzle but he feels too tired to do it, he cannot concentrate for so long anymore. All challenges of the day are finished, time to go to bed.

Bob wakes up and it is still dark outside. He can see Rita in his bedroom, what only happens in emergency situations. "*Dad what's going on? I saw that you had an* *episode of arrhythmia! Are you ok? Do you want me to call Dr. Woods?*" Apparently, Bob's heart rate is irregular below expected for his condition. In the early morning, Bob communicates with his GP via the hologram communication system. In the next day Bob will receive an extra dose of his medication.

Despite the initial concerns and reluctance, Bob is now happy to admit that the pieces of technology in his environment connect him to the community and his family, and that the monitoring brings him peace of mind, and for those who care for him.

Conclusion

In this article, we looked at the past, present and emerging solutions of the four components of technology to support Active and Healthy Ageing – sensing, reasoning, coaching and applications – that are needed to bring the experience to the users. The advances in technology in the last decades have resulted in smaller and less obtrusive sensing devices that are suitable for use in daily life, efficient algorithms able to deal with complex and large datasets, personal coaches that follow us everywhere all the time, as well as new exciting means of interaction. We have looked at sensing from the perspective of measuring daily physical activity behavior as well as of measuring emotional wellbeing, and discussed the various methods available together with their advantages and drawbacks. In terms of physical activity, although accurate and affordable sensing devices are ubiquitously available, these are not necessarily designed with an older adult population in mind. When aiming to obtain information about the user's emotional state, one must consider whether the user is willing to be confronted with his/her emotional state. By asking directly, users are forced to think about and put their emotions on the table. In this case, less obtrusive methods, such as facial recognition or automatic analysis of the user's expressions on social media may be preferable over the more traditional tools, such as ESM, except when the intervention aims exactly at creating awareness about one's emotions. In both cases, the choice of sensing device or tool must be taken carefully, taking into account the different properties that are relevant to the individual user. When, for example, a common tool like ESM is used, special attention should be given to the interpretation of the results. Measuring any type of behavior or human attribute in daily life is challenging, due to missing and noisy date; conventional statistical methods have difficulty in dealing with this type of data. Advanced data mining and machine learning methods, such as personal networks, are emerging as promising tools to continuously learn about the individual's behavior and its changes over time. A proper understanding of daily life data is an important prerequisite for effective interventions in Active and Healthy Ageing, but the data must be used in a fitting decision-making process, or coaching strategy. From the field of psychology and persuasive system design a host of different methods and strategies have emerged over the past decades. For any coaching strategy, personalization is an important factor that needs to be taken into account into the design of the system. Many different strategies for tailoring the communication to the individual user exist, and are most often straightforward to implement. The implementation of smart sensing, reasoning and coaching techniques into an application that can add value to the lives of the users can happen in many different ways. Mobile applications, web sites, virtual reality worlds, or even personal robotic, or holographic companions are some of the embodiments that a coaching service can take. We have shown a small number of examples of such applications, with the most important conclusion that, to be effective, the individual's needs and preferences must be the foremost driver for any design and implementation decision.

To guarantee the success of interventions promoting Active and Healthy Ageing, stakeholders must work together combining expertise from different fields. Moreover, the advent of Internet-of-Things, 5G Networks, and the idea that all devices are connected will bring new opportunities inside and outside the home environment. Mobile cloud computing also ensures that all information is available all the time, everywhere. Also, with new smart devices, reasoning on large amount of data is available at any moment and time. There is also the question of the technology affinity. The idea that older adults are technology avoiders is not always correct, and besides this is at *worst* a temporary concern as in the developed countries the next generation(s) of 65+ did already grow up with technology in their lives. Although technology continuous to develop at an even faster pace, the expectation is that the ability to adapt to new technologies is increasing with current and future generations as well. Predicting what the future of technology in the support of healthcare will bring is threading on thin ice. However, the combination of unobtrusive sensing techniques, ever more effective reasoning, coaching strategies combined with persuasive technology and applications designed for real users, we might be one step closer to true personalized medicine. We look at a bright future in which technology supports the Maria's and Bob's of the world in being active and engaged in their communities, not only being part of, but a structural pillar of their communities, for as long as possible.

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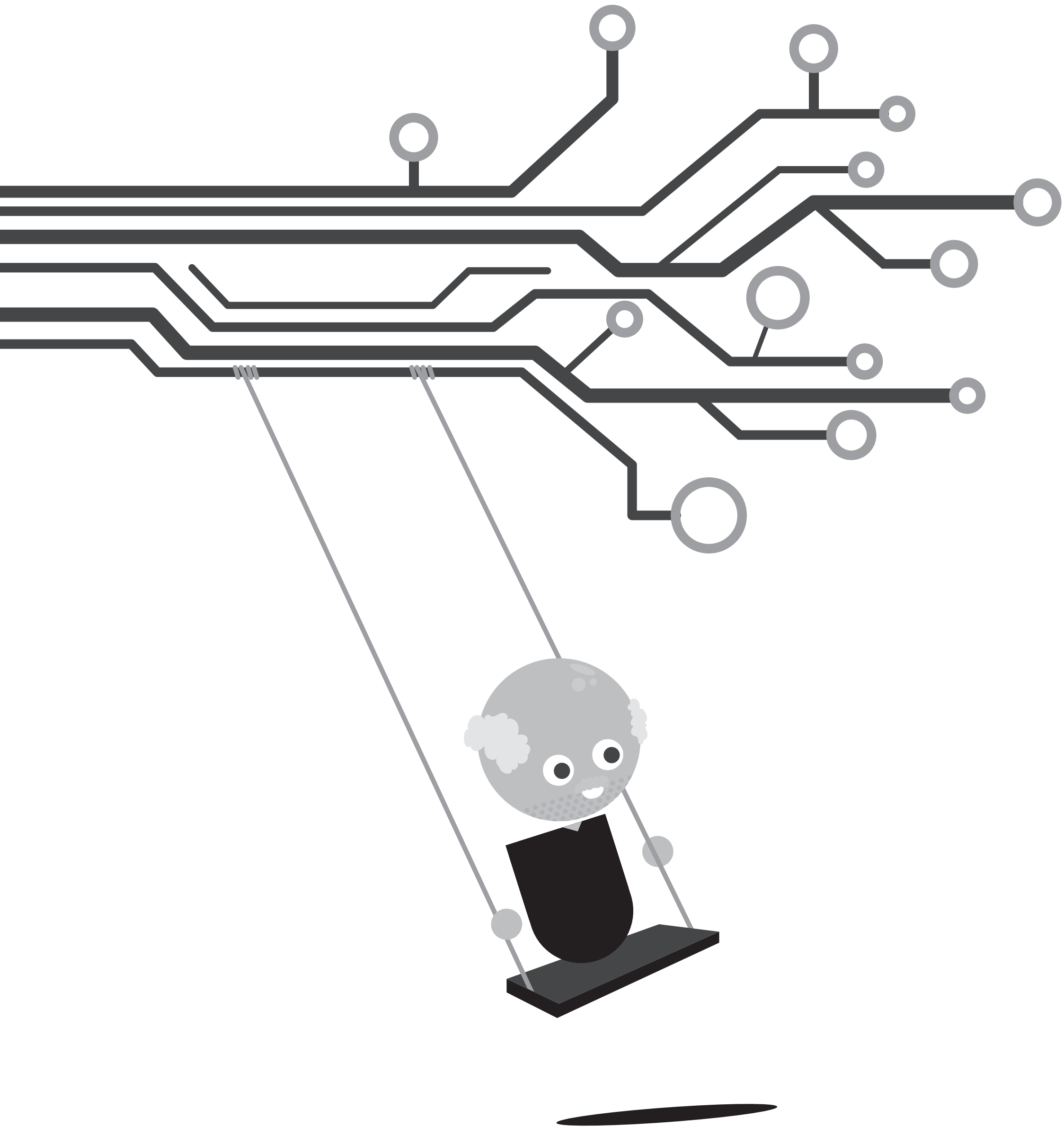

Chapter 7

General discussion

The aim of this thesis was to explore how technology can be utilized for promoting physical activity and emotional wellbeing in daily life to support Active and Healthy Ageing. More specifically, the focus of this Thesis was on the intersection between the topics of Active & Healthy Ageing, physical activity and emotional wellbeing (shaded areas in Figure 1), which we denominate *Active & Pleasant Ageing*.

In this section, we will discuss our findings from the perspective of the three objectives defined in the Introduction. Moreover, we will address how to achieve a higher level of adoption of technology in current healthcare and in society, extending the discussion on how technology can support Active and Healthy Ageing initialized in Chapter 6. We finalize with general conclusions and afterthought.

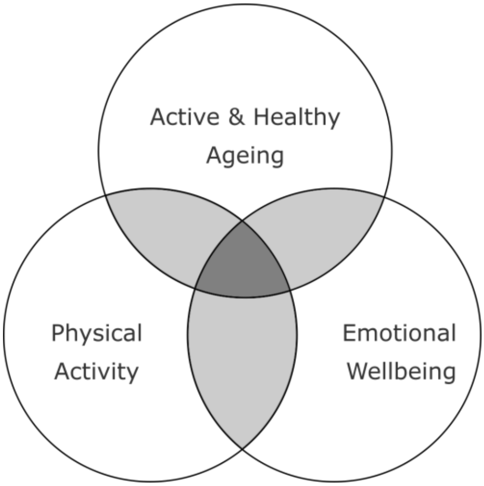

Figure 1 - Core elements of this PhD Thesis on Active and Pleasant Ageing.

Positive emotions do relate to functional ability of older adults living independently

This Thesis, at its core, has a positive perspective on ageing. Older age is a period often portrayed with negative connotations such as 'decline', 'loneliness' and 'vulnerability'. But that does not need to be the case. In fact, from the beginning of our research, we have continuously replaced the image of the grandmother sitting at the window staring at a past, with the image of the same grandmother actively engaged in the community and enthusiastic about the following day. The concepts of Active and Healthy Ageing fit this perspective of supporting older adults being engaged in their communities and maintaining functional abilities that enable wellbeing in older age. In this line, our first objective was to investigate how changes in the emotional wellbeing, operationalized as the experience of positive emotions in daily life, predict or follow changes in the functional abilities.

Our systematic review of the literature showed that, indeed, there is evidence supporting a relation between functional ability and positive emotions, although the direction of the relation remains unclear (**Chapter 2**). We found that positive emotions showed positive correlation with being able to perform activities of daily living independently. These findings are in line with the theories of positive psychology advocating that people who experience positive emotions might adopt protective behaviors that delay functional decline and ultimately prevent illness[1]. This also supports the scientific evidence that positive emotions increase resilience[2,3], i.e. the ability to cope in moments of adversity and stress[4]. As people age, the occurrence of adverse life events is more likely (e.g. decease of a close relative, acute health problems). This means that the experience of positive emotions, might enhance the ability to adopt strategies to cope in moments of adversity at a later age[5].

Our review clearly showed that, contrarily to other dimensions of wellbeing such as psychological wellbeing, the number of longitudinal studies looking at both emotional wellbeing and functional abilities of the older adults is still small. Such studies might advance our knowledge on the contribution of emotional wellbeing to trajectories of ageing. More importantly, this knowledge can then be translated into strategies to better support Active and Healthy Ageing. In **Chapter 6** we have explored several methods that enable monitoring of (positive) emotions for long periods of time requiring direct input of the user (e.g. Experience Sampling Method) and/or recurring to artificial intelligence methods (e.g. emotion inference from social networks' use). Regarding monitoring of functional abilities and detection of decline, ongoing developments in home- and wearable sensing are likely to advance recognition of daily activities inside and outside the home environment. In fact, we suggest a line of research investigating whether similar methods can be used in the prediction or early detection of functional decline. Literature suggests that intrinsic motivation is influenced by interest, competence and effort[6]. Therefore, we hypothesize that before individuals stop doing their normal daily activities, there is likely a period when individuals are still doing the activities but experience them as troublesome or painful. By facilitating monitoring of daily activities as well as respective enjoyment, we might be able to detect functional decline before loss of independence occurs. In the Netherlands, standardized periodic health assessments are not part of the primary care pathways and most older adults only visit the General Practitioner when symptoms or complaints emerge. Because of this, possible critical situations are more likely to be identified only when loss of independence has already occurred.

Positive emotions and physical activity in the daily life of older adults

Within this Thesis we introduced the ideas of Positive Psychology in the promotion of physical activity among older adults. The initial plan of this PhD trajectory[7] was to develop a recommendation system to support older adults becoming more active in their daily lives, aspiring to bring fun and enjoyment to the daily life and fighting the barriers to engage in physical activity found in literature, such as lack of interest[8–10], lack of time and not enjoying the activities[10]. The logical first step was to investigate activities, and context of activities (i.e. social and physical context) that involve movement (physical activity) and are enjoyable/fun to the individual.

From our observational study in daily life we see that older adults were more active outside the house, and less active when in the company of others (Chapter 3). However, post-hoc into the type of companionship (i.e. being with *friends*, *children*, *family*, *partner*, *colleagues*, *others,* or *alone*), showed that older adults were in fact more active when being with friends than alone[11]. Furthermore, in our study we observed that exercise-related activities contribute the most to overall levels of physical activity (as expected) and are also rated high on pleasure. Household activities have an important contribution to the daily physical activity of older adults, in line with the activities suggested to meet the guidelines for physical activity[12]. However, we found in our study that these activities were not perceived to be pleasurable at all. In fact, household activities were rated the lowest average level of pleasure of all reported activities. Noteworthy is also that *going out* is the most pleasurable type of activity, highlighting the importance of keeping active within the social community. Although *going out* activities per se were associated with low physical activity (e.g. cinema, theater or going out for dinner), they always involve commuting, which is a type of activity that can contribute to the physical activity in daily life. Based on these findings, technology can be designed to support older adults in becoming more active by learning the routines and preferences of the older adults and nudging individuals to engage in the activities that are more pleasurable (and ideally require some healthy travel time). One can say that if people like to do something, they will not need reminders but, in fact, most people need nudges. Individuals know what they like to do but sometimes they just temporarily forget, or create some mental barriers to do it. In the scenarios in Chapter 6, based on the model from op den Akker et al.[13], we explored how these nudges, or motivational messages, can be personalized to the user in the promotion of an active and pleasant lifestyle. Furthermore, technology can support in identifying and bringing together people with the same interests. In fact, promoting active and pleasant ageing can also play a role in facilitating engagement of the older adults in the society. In the words of Robert Waldinger, current director of the Harvard Study of Adult Development, which has been following participants for more than 75 years, "*The clearest message that we get from this 75-year study is this: Good relationships keep us happier and healthier. Period.*"[14].

In our interviews presented in Chapter 4 we investigated the reasons why older adults find it important to be active. The participants provided reasons related to preservation of functional ability (e.g. to be there for the grandchildren), physical and cognitive health (e.g. to support self-management of chronic diseases), social interaction (e.g. to keep social life) and wellbeing (e.g. to feel good). For further policies and interventions, this means that the goal of the interventions should be aligned with the goals of the older adults and not in terms of physiological parameters (e.g. walk 1000 steps a day), nor disease-avoidance oriented (e.g. control blood pressure). For future interventions supporting Active and Healthy Ageing, we recommend setting meaningful goals for the individual (e.g. be able to walk to my friend's house who lives 500 meters away from me) to enhance intrinsic motivation.

Promoting physical activity is one thing, discouraging sedentary behavior is another. We have seen that the older adults participating in the interviews presented in Chapter 4 see *being active* as the most importance practice to take care of their health. Interestingly, when asked about physical activity, older adults would immediately think of structured exercise, and do not think of the consequences of prolonged periods of sedentary behavior. Sedentary behavior is characterized by little physical movement and low energy expenditure, including activities as watching TV and using the computer. Under the moto "*sitting is the new smoking*", the guidelines for physical activity also often include a section dedicated to discouragement of sedentary behavior[15,16], but curiously often not specific for the older adults group[16], likely to the lack of studies developed on the topic until the moment of the release of the latest guidelines[17]. A recommended line of research would be to analyze the relation between emotions and sedentary behavior using similar methods. We already had the opportunity to take a glimpse at that topic from the dataset gathered in the study presented in Chapter 3. We have seen that watching TV is one of the most reported activities, but not pleasurable. Moreover, according to a study exploring the context of sedentary behavior among older adults, most sedentary time is spent at home and in the afternoon[18]. Further research on this topic is highly recommended to design strategies to promote physical activity and reduce sedentary behavior, contributing to active and pleasant ageing.

Technology in the support of Active and Healthy Ageing

Older adults are often seen as the most difficult target group to design technology for. Among the scientific community it is often heard that even deploying studies that include ambulatory assessment might be slightly frightening within the current older generation. However, it does not need to be the case. In the Netherlands, the 75+ is the group of internet users that is growing the most, with more than 50% of the 65-75 years old owning a smartphone and almost 30% of the 75+[19]. In fact, throughout our studies we have encountered older adults whose motivation to participate in the study was to learn how to use a smartphone, but we have also encountered those who complained about how outdated the (3 years old) research phones were. In Chapter 4 we can see that older adults have a positive attitude towards technology to support managing their health as long as this technology is integrated in daily life (not a burden), targeted to personal needs and preferences, empathetic and not replacing existing human contact. We have also seen in Chapter 5 that this attitude remains positive or improves, after using technology to promote physical activity for a period of 4 weeks.

In Chapter 6 we have discussed in detail how technology can support active and pleasant ageing. To actually contribute to Active and Healthy Ageing, technology with a high readiness level needs to be adopted in society. There are several challenges associated with the adoption of technology; for example, how the end users, in this case older adults, get access and start using the technology.

One possible scenario is by *self-initiative* of the older adult, in the sense that the technology is commercially available and can be acquired by everyone, for example, in a department store. This is the case of our persona “Maria”, introduced in Chapter 6. The time is optimal as consumer technology targeting promotion of physical activity has expanded immensely in the last years, resulting in reliable, comfortable and even fashionable physical activity trackers. However, people buying these devices or using healthy lifestyle applications represent a specific part of the population as they are already motivated to change, are often high-educated and healthier than non-users[20,21]. Another problem with commercially available devices is that approximately

50% of the users stop using them after a few months[22]. The option presented in the next paragraph can help solving the economic burden and lack of long-term commitment.

The integration of technology to support active and pleasant ageing in *primary and secondary care* is another option to reach the older adults. This assumes a healthcare path much more dedicated to prevention than to treatment, focusing on an active role of the older adult. Such service or system would also require some sort of collaboration with the health insurance companies, for example using a plan of discounts as (extrinsic) motivation to motivate healthy behaviors. This is already the case in the Netherlands with some insurers providing discounts in premium health packages as a compensation for engaging in physical activity. In addition, in order to have a full and optimal integration of prevention with care settings, the information gathered by the technology can and should be used in clinical settings. As pointed out earlier, by reasoning on information gathered during continuous monitoring, technology allows for automatic detection of deviations from patterns of behavior or detection of critical situations, alerting the healthcare professional whenever appropriate, facilitating an immediate response and preventing worsening of the situation. Moreover, summary reports of the data can be automatically generated and shown upon request before a patient consult. By having a factual, clearly presented overview of the patient's information at hand, the actual consult can be used more efficiently to discuss treatment instead of reviewing the patient's past performance. In this way, we are likely to reach a more efficient and high-quality care, fully targeted to the individual. Furthermore, by showing to the users (both *primary* – the patient, and *secondary* – the professional) the benefit of technology, we might solve the commitment issue and avoid the drop out after the novelty effect typical of the commercially available devices.

In the PERSSILAA project we worked in the direction of this second option. Older adults were invited by healthcare professionals for a health screening, and based on the results were guided to the appropriate training plan. Apart from the first contact by the professional, the support during the intervention was mostly given by members of the community. By doing so, we learned how crucial the support of the community can be to the adoption of technology for active and healthy ageing. In Italy, a strongly religious community, the support for technology was provided in groups after the church service, focusing first on improving technology skills of the community members, followed by introduction of the telemedicine services. On the other hand, in the Netherlands there was no, or a sporadic, need to improve the technology skills, and thus, older adults were given the telemedicine services after short training sessions, with support being given whenever necessary by a group of volunteers. Despite the different strategies, these are two success cases on how technology can be implemented using the support of the community. If not considered, lack of support or inadequate infrastructure might encumber the deployment of technology-based interventions. For example, the study presented in Chapter 4 was designed to be performed in the Netherlands and in Italy but it ended up taking place only in the Netherlands as it was not feasible in Italy since only a few older adults had Wi-Fi in their houses, among other similar reasons.

Community-based interventions, with or without health-related purposes, allow for interaction between older adults (e.g. by joining the same intervention or by taking a volunteer/assistant role, as in the PERSSILAA project), but also between generations. In fact, the intergenerational digital gap can be a facilitator to bring together the older and younger generations. The "*Cyber seniors – connecting generations*"[23] is a documentary portraying an initiative in which a group of teenagers challenged and supported older adults in a retirement home setting up YouTube channels. This initiative was such a great success that a complete kit was made available online for those who want to start initiatives targeting the intergenerational digital gap. In the same way, technology allows older adults to continue being engaged in activities such as teaching, even in situations constrained by physical health or limitations of the immediate environment. A well-known case is the "*Speaking Exchange*" project[24] that allowed American older adults living in retirement homes teaching English to Brazilian children by video conferencing.

Successful implementation of technology-based interventions to promote active and healthy ageing requires a combined effort from several stakeholders. For example, designers need to collaborate with the end users to understand their needs, policy makers must find strategies that ensure that the products developed reach the end user, and the communities need to support the older adults in using the technology.

Wider context

An active and pleasant life is not only important as primary intervention for the ageing population. Physical inactivity is estimated to be the cause of, on average, 9% of premature mortality worldwide[25]. Additionally, an active lifestyle is very important in the self-management of chronic diseases, such as chronic obstructive pulmonary disease[26,27] and as secondary prevention. Therefore, the concepts discussed in this

Thesis to encourage an active and pleasant life supported by technology can be extended to other populations. For example, a potential strategy to promote an active and pleasant lifestyle among children with asthma is to include gaming related activities. Children like playing, that is beyond doubt. By incorporating gaming elements, we are likely to increase compliance to interventions promoting daily physical activity. That is the hypothesis in the AIRplay project[28], a national Dutch project. In the AIRplay project, we are integrating an interactive playground placed at a community location (e.g. hospital, neighborhood center or school) with a mobile system that monitors and promotes physical activity in daily life based on personal goal-setting. We hypothesize that by including strategies such as feedback, social interaction and game features as rewards and competition, children get intrinsically motivated to be active in their daily life, and therefore support the self-management of their asthma.

Conclusion

This Thesis has generated valuable knowledge on how technology can support active and healthy ageing in the daily life of community-dwelling older adults. We have explored the intersection between three topics: *Active and Healthy Ageing*, *Physical Activity* and *Emotional Wellbeing*. By systematically reviewing the literature, we learnt that there is evidence suggesting a bi-directional influence of positive emotions on functional abilities – considered one of the key determinants of Healthy Ageing. In our longitudinal study, we have observed the contribution of outdoor activities and social relationships to the daily physical activity of older adults. Additionally, our results indicated that, when engaged in leisure activities, more physical activity is associated with higher experience of positive emotions (in this case pleasure), but not when engaged in basic activities of daily living (e.g. commuting or eating). We have also learnt that older adults are willing to use technology to support their health management when they feel that the technology is designed to fit their needs. However, the expectations and attitudes towards technology vary in the different health domains. For example, while older adults want to receive feedback in terms of physical activity or eating habits, they are more conscious about feedback on the cognitive domain. Finally, we have reviewed the past and glimpsed at the future of ambulatory technology to promote Active and Healthy Ageing and concluded that technology requires unobtrusive sensing, more intelligent reasoning and innovative ways to coach in the daily life of older adults.

Afterthought

Enabling wellbeing in old age and support of functional independence is a core priority for policy makers and researchers worldwide. In the past 4 years, a greater interest has been given to the topic of wellbeing in older age. However, I believe there is still a long path to change our look at ageing. We often look at ageing as a "problem", searching for solutions on how to deal with the burden associated. However, the change in the demographic pyramid can, and should, be seen as an opportunity. An opportunity for societies to reinvent themselves. An older population provides the wisdom, experience and knowledge accumulated of a lifetime. Furthermore, often free of work obligations, older adults are likely to have the time to share their knowledge and experiences. An ageing population has an incomparable impact on the intellectual capital of a society, with older adults contributing to human and relational capital. The challenge is in defining strategies for older adults to apply their value. "Fortunately, we have technology", says the engineer.

As a Biomedical Engineer, my strongest professional ambition is to contribute to the development of technology that positively impacts the life of the population. I strongly believe that the research performed in this PhD contributes to that aim and I will keep pursuing this mission throughout my professional life. To quote myself:

> *"We look at a bright future in which technology supports the Maria's and Bob's of the world in being active and engaged in their communities, not only being part of, but a structural pillar of their communities, for as long as possible."* (Chapter 6)

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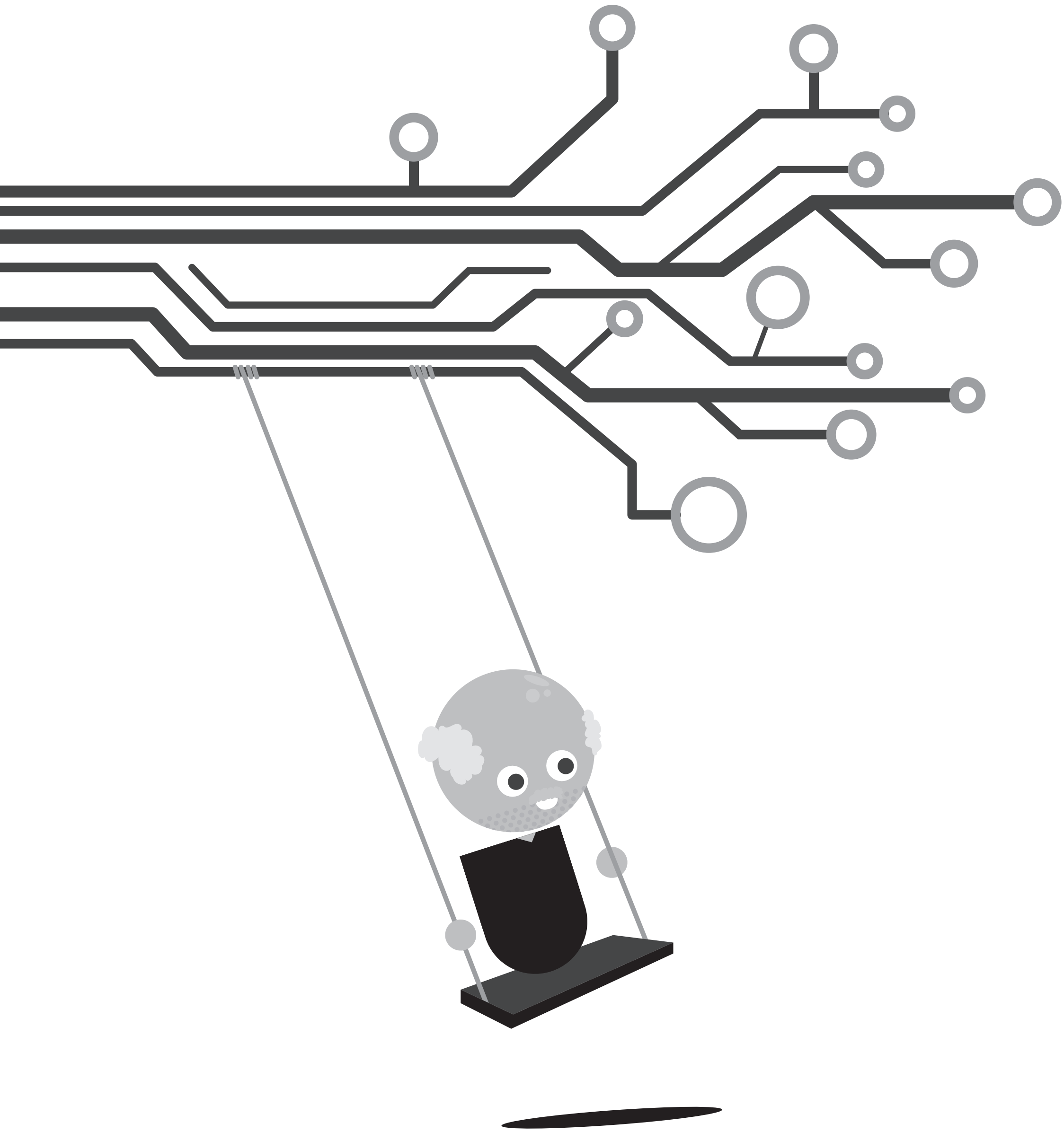

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Summary

The proportion of the global population aged above 60 years old is growing more rapidly than any other age group creating several socio-economic challenges. Finding strategies to preserve functional independence for as long as possible is a priority to reduce the burden on the healthcare sector and enhance quality-of-life for the older population. In 2015, the World Health Organization defined Healthy Ageing as "*the process of developing and maintaining the functional ability that enables wellbeing in older age*". As such, Healthy Ageing places the individuals as active participants in managing their own health, focusing on the importance of healthy behaviors as strategies to preserve functional ability in older age. Telemedicine systems and services – often interchangeably referred to as telehealth or eHealth systems – concern the use of ICT in the prevention, diagnosis and/or treatment of diseases from a distance. For Active and Healthy Ageing, telemedicine services can provide support in monitoring, diagnosis and treatment in several life domains, such as physical and mental health, mobility, social connectedness, everyday activities and leisure.

The main aim of this Thesis is to explore how technology can be utilized in the support of Active and Healthy Ageing in daily life, by promoting physical activity and emotional wellbeing in everyday life.

In **Chapter 1** we introduce the research on *Active and Pleasant Ageing*, which gives title to this PhD Thesis, as emerging in the overlapping area between three topics: Active & Healthy Ageing, physical activity and emotional wellbeing. The first topic was already introduced: Active & Healthy Ageing. The second topic is *physical activity*, one of the focal points in strategies to support Active & Healthy Ageing. Physical activity, referred in this work as the total of voluntary movement produced by skeletal muscles during everyday functioning, has well-established benefits for physical health and to preserve functional independence. Despite the well-known benefits of an active lifestyle for physical health, most older adults do not reach the recommended activity levels. When asked about the barriers to engage in regular physical activity, older adults mention poor health, but also provide reasons such as lack of interest, lack of time and not enjoying the activities. Within this Thesis, we look at approaches to promote physical activity in the daily lives of older adults to support Active and Pleasant Ageing. The third topic is *emotional wellbeing*, and concerns the presence of positive emotions (e.g. joy and calmness), the absence of negative emotions (e.g. sadness and anger), and satisfaction with life. Positive emotions are influenced by daily contexts and situations and are thus prone to fluctuations in daily life.

In **Chapter 2** we present the results of a systematic review of the literature on the relation between positive emotions and functional ability of older adults living independently, including only empirical studies. There is solid evidence that being physically active plays an important role in the prevention of functional decline. But how do positive emotions contribute to the preservation, or decline, of these functional abilities? The results of the systematic review presented in this chapter suggest that there is evidence supporting a relation between functional ability and the intensity and frequency of experience of positive emotions, although the direction of this relation remains unclear. Particularly, there is some, but limited, evidence suggesting that more frequent experience of positive emotions relates to better functional status and to delay of functional decline. A cohesive conclusion could not be drawn from our review due to the limited number of studies meeting the inclusion criteria, as well as disparities among design methods and sample populations. Nevertheless, the results presented are in line with theories of positive psychology suggesting that frequent experience of positive emotions supports a variety of resilience resources, such as environmental mastery and social support, which might enhance the ability to adopt strategies to cope in moments of adversity at later age. In conclusion, the review of empirical studies, combined with the theoretical models, suggest that emotional wellbeing has positive implications on the functional abilities of the older adults, and in this way, should be addressed when defining strategies for the support of Active and Healthy Ageing.

In **Chapter 3** we present the results of a longitudinal study that investigates the social and physical context of daily physical activity (e.g. location, social companionship and type of activity) and corresponding pleasure in the daily life of older adults. Using an intensive longitudinal study design with ambulatory assessment, consisting of continuous monitoring of physical activity with an accelerometer and repeated measurements in a smartphone application to assess daily activities and their contexts, we observed the contribution of outdoor activities and social relations to the daily physical activity of older adults. Our results indicate that, when engaged in leisure activities, more physical activity is associated with higher experience of positive emotions (in this case pleasure), but not when engaged in basic activities of daily living (e.g. commuting or eating). The results of our study support the hypothesis that identification and promotion of pleasurable activities, i.e. daily activities that contribute simultaneously for to both daily physical activity and emotional wellbeing of the older adults, might be a good strategy to support Active and Healthy Ageing.

In the next step, we investigated how older adults experience health technology in their daily life and what their expectations are before and after use. This study was divided into two parts. In the first part, we investigated current practices in managing health in daily life, attitudes towards using technology and expectations from technology, by performing semi-structured interviews with twelve older adults. This study analyzed four health domains: physical function, cognitive function, nutrition and wellbeing. The results presented in Chapter 4 suggest that the level of engagement of older adults in self-managing their health depends on various factors, such as medical history of themselves or close relatives. Furthermore, we see that older adults have a positive attitude towards technology to support managing their health, as long as this technology is integrated in daily life, targeted to personal needs and preferences, empathetic and not replacing existing human contact. To sum up, the older adults participating in the study recognize the potential added value of technology to support the self-management of their health as well as achieving and maintaining healthy behaviors, ultimately supporting Active and Healthy Ageing.

In a second part of the study, after assessing expectations of technology, we provided the same older adults with a short intervention – consisting of goal-setting and feedback – to coach physical activity and monitor emotional wellbeing in daily life. The data collected through step counters and experience sampling method was analyzed, and compared to the data acquired through semi-structured interviews, in order to investigate how older adults perceived the use of health technology in daily life for a period of 4 weeks. The results of this study, reported in Chapter 5, suggest that the attitude towards technology remains positive, or improves, after using technology to promote physical activity. However, most participants did not experience an added value of monitoring positive emotions in daily life. At the end of this chapter, we discuss the reasons underlining the dissatisfaction of the older adults with monitoring of emotional well-being, in particular, in relation to various challenges associated to research with ambulatory assessment.

Chapter 6 presents an overview of the literature on technology aiming to support Active and Healthy Ageing, focusing on four components – *sensing*, *reasoning*, *coaching* and *applications* – with physical activity and emotional wellbeing as core parameters. For each one of these components we explore the past and state-of-the-art, incorporating the lessons learned from the literature study and empirical studies. The chapter ends by providing a glimpse at future trends on the field of technologies supporting Active and Healthy Ageing.

Finally, in **Chapter 7** we discuss the results of the research and look at several challenges and opportunities associated with the adoption of technology. Furthermore, we discuss how the lessons learnt in this Thesis can be applied in a wider context, for example, supporting self-management of chronic diseases.

Samenvatting

Het deel van de wereldbevolking ouder dan 60 jaar groeit sneller dan elke andere leeftijdsgroep, waardoor er verschillende sociaaleconomische uitdagingen ontstaan. Het vinden van strategieën om de functionele onafhankelijkheid zo lang mogelijk te bewaren is een prioriteit om de lasten voor de zorgsector te verminderen en de kwaliteit van leven van de ouderen te verbeteren. In 2015 definieerde de Wereldgezondheidsorganisatie 'Gezond ouder worden' als "*het proces van ontwikkelen en behouden van het functionele vermogen dat welzijn op oudere leeftijd mogelijk maakt*". Gezond ouder worden geeft het individu een actieve rol voor zijn of haar eigen gezondheid, waarbij de nadruk ligt op het belang van gezond gedrag als strategie om functionele vermogens op oudere leeftijd te behouden. eHealth toepassingen – systemen die gebruik maken van informatie en communicatietechnologieën bij de preventie, diagnose en/of behandeling van ziekten op afstand – zijn veelbelovend voor de ondersteuning van oudere volwassenen bij het bereiken en in stand houden van gezond gedrag.

Het doel van dit Proefschrift is om te onderzoeken hoe technologie kan worden gebruikt bij het ondersteunen van Actief en Gezond ouder worden in het dagelijks leven. In het bijzonder wordt gekeken naar het bevorderen van fysieke activiteit en emotioneel welbevinden in het dagelijks leven.

In **Hoofdstuk 1** introduceren we het onderzoek naar Actief en Plezierig Ouder Worden, dat titel geeft aan dit Proefschrift. We onderscheiden hierin drie overlappende thema's: Actief & Gezond ouder worden, fysieke activiteit en emotioneel welbevinden. Het eerste thema werd al geïntroduceerd: Actief & Gezond ouder worden. Het tweede thema is fysieke activiteit, een van de speerpunten in strategieën ter ondersteuning van gezond ouder worden. In dit proefschrift bedoelen we met fysieke activiteit alle vormen van vrijwillige beweging die tijdens het dagelijks functioneren door het spierskeletsysteem wordt voortgebracht. Fysiek actief zijn heeft voordelen voor de lichamelijke gezondheid en is van belang voor behoud van functionele onafhankelijkheid. Ondanks de bekende voordelen van een actieve levensstijl voor de gezondheid, bereiken de meeste oudere volwassenen niet de aanbevolen hoeveelheden activiteit. Wanneer gevraagd over de barrières voor regelmatig bewegen, wijzen ouderen op een slechte gezondheid, maar geven ze ook redenen als gebrek aan interesse, tijd en dat ze weinig plezier beleven aan het doen van de activiteiten. Binnen dit Proefschrift onderzoeken we op welke manier we

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lichaamsbeweging in het dagelijks leven van ouderen kunnen bevorderen om zo actief en plezierig ouder worden te ondersteunen. Het derde thema, emotioneel welbevinden, betreft de aanwezigheid van positieve emoties (bijv. vreugde en kalmte), de afwezigheid van negatieve emoties (bijv. verdriet en woede), en tevredenheid met het leven. Positieve emoties worden beïnvloed door dagelijkse contexten en situaties en zijn daardoor gevoelig voor schommelingen in het dagelijks leven. Aangezien we op zoek zijn naar strategieën die actief en gezond ouder worden in het dagelijks leven ondersteunen, is emotioneel welbevinden – en vooral positieve emoties – het derde hoofdthema van dit Proefschrift.

In **Hoofdstuk 2** presenteren we de resultaten van een systematisch literatuuronderzoek over de relatie tussen positieve emoties en het functionele vermogen van ouderen die zelfstandig wonen. Er zijn sterke aanwijzingen dat fysieke activiteit een belangrijke rol speelt bij het voorkomen van functionele achteruitgang. Maar hoe dragen positieve emoties bij aan het behoud of de afname van deze functionele vermogens? De resultaten van het literatuuronderzoek in dit hoofdstuk laten aanwijzingen zien voor een verband tussen functioneel vermogen en positieve emoties, hoewel de richting van deze relatie onduidelijk blijft. Er zijn enkele, maar beperkte, aanwijzingen dat een frequentere ervaring met positieve emoties gerelateerd is aan een beter functioneren en vertraging van de afname van functionele vermogens. Een volledige conclusie kan niet worden getrokken vanwege het beperkte aantal studies dat voldoet aan de inclusiecriteria en de verschillen in onderzoeksmethoden en steekproefpopulaties. Toch zijn de gepresenteerde resultaten in lijn met de theorieën van positieve psychologie die suggereren dat frequente ervaring van positieve emoties bijdraagt aan veerkracht om momenten van tegenspoed op latere leeftijd het hoofd te bieden. Samenvattend ondersteunen deze bevindingen, in combinatie met de theoretische modellen, dat emotioneel welbevinden positieve gevolgen heeft voor de functionele capaciteiten van oudere volwassenen. Dit biedt tevens aangrijpingspunten voor het ontwikkelen van strategieën ter ondersteuning van actief en gezond ouder worden.

In **Hoofdstuk 3** presenteren we de resultaten van een longitudinaal onderzoek naar de sociale en fysieke context van dagelijkse fysieke activiteit (bijv. locatie, sociaal gezelschap en soort activiteit) en het bijbehorende plezier in het dagelijks leven van oudere volwassenen. Met behulp van een intensief longitudinaal onderzoeksdesign met ambulante beoordeling hebben we de bijdrage van buitenactiviteiten en sociale relaties aan de dagelijkse activiteit van oudere volwassenen aangetoond. Daarnaast geven onze resultaten aan dat bij vrijetijdsactiviteiten meer fysieke activiteit gepaard gaat met een meer intensief ervaring van positieve emoties (in dit geval plezier), maar dat dit niet het geval is voor dagelijkse bezigheden (bijv. reizen of eten). De resultaten van onze studie ondersteunen de hypothese dat het identificeren en bevorderen van plezierige activiteiten – d. w. z. dagelijkse activiteiten die tegelijkertijd bijdragen aan de dagelijkse lichamelijke activiteit en het emotionele welbevinden van de ouderen – een goede strategie kan zijn om actief en gezond ouder worden te ondersteunen.

In de volgende stap onderzochten we hoe oudere volwassenen gezondheidstechnologie ervaren in hun dagelijks leven en wat hun verwachtingen zijn. Deze studie is verdeeld in twee delen. In het eerste deel onderzochten we hun huidige manier van gezondheidsmanagement in het dagelijks leven, de houding ten opzichte van het gebruik van technologie en de verwachtingen van technologie, door semigestructureerde interviews met twaalf oudere volwassenen. Deze studie ging in op vier gezondheidsdomeinen: fysieke functie, cognitieve functie, voeding en welbevinden. De resultaten uit **Hoofdstuk 4** suggereren dat de mate van betrokkenheid van ouderen bij zelfsturing van hun gezondheid afhankelijk is van verschillende factoren, zoals de eigen medische voorgeschiedenis of naaste verwanten. Verder zien we dat ouderen een positieve houding hebben ten opzichte van technologie om hun gezondheid te ondersteunen, zolang deze technologie maar geïntegreerd is in het dagelijks leven (geen belasting), gericht op persoonlijke behoeften en voorkeuren, empathisch is en niet in de plaats komt van bestaand menselijk contact. Kortom, de ouderen die deelnemen aan de studie erkennen de potentiële toegevoegde waarde van technologie om het zelfmanagement van hun gezondheid te ondersteunen en om gezond gedrag te bereiken en te behouden, en uiteindelijk Actief en Gezond ouder Worden te ondersteunen.

In het tweede deel van de studie, na het beoordelen van de verwachtingen van de technologie, hebben dezelfde oudere volwassenen meegedaan aan een korte interventie, waarin doelen gesteld werden voor actief gedrag en waarin feedback op gedrag gegeven werd om zo fysieke activiteit en emotioneel welbevinden te monitoren en coachen in het dagelijks leven. De gegevens in het experiment zijn verzameld door middel van stappentellers en *experience sampling methoden*, en werden geanalyseerd en vergeleken met de ervaringen van de proefpersonen, gerapporteerd via semigestructureerde interviews. De resultaten van deze studie, gerapporteerd in **Hoofdstuk 5**, suggereren dat de houding ten opzichte van technologie positief blijft of zelfs-verbetert na het gebruik van technologie om fysieke activiteit gedurende een periode van 4 weken te bevorderen. De meeste deelnemers ervaarden echter geen toegevoegde waarde van het monitoren van positieve emoties in het dagelijks leven. Aan het eind van hoofdstuk 5 bespreken we de redenen voor de ontevredenheid van oudere volwassenen over het monitoren van emotioneel welbevinden, in het bijzonder met betrekking tot verschillende uitdagingen in verband met onderzoek met ambulante evaluatie.

In **Hoofdstuk 6** kijken we naar vier componenten van technologie die Actief en Gezond ouder worden stimuleren met fysieke activiteit en emotioneel welbevinden als centrale parameters. De vier component zijn: meten, redeneren, coachen en applicaties. Voor elk van deze componenten kijken we naar het verleden en de stand van de techniek, waarbij we de lessen uit het literatuuronderzoek en empirische studies meenemen. In het hoofdstuk wordt uiteindelijk een toekomst beeld geschetst waarin technologieën ter ondersteuning van actief en gezond ouder worden een prominente rol in ons dagelijks leven spelen.

Ten slotte, in **Hoofdstuk 7**, bespreken we de resultaten van het onderzoek en kijken we naar een aantal uitdagingen en kansen die verbonden zijn aan de toepassing van technologie. Verder bespreken we hoe de lessen die hieruit getrokken zijn in dit Proefschrift in een bredere context kunnen worden toegepast, bijvoorbeeld door het ondersteunen van zelfmanagement van chronische ziekten.

Resumo

A população mundial com idade acima dos 60 anos tem vindo a crescer mais rapidamente do que qualquer outra faixa etária, criando vários desafios socioeconómicos. Encontrar estratégias para preservar a independência funcional da população idosa por tanto tempo quanto possível, é uma prioridade para reduzir a carga sobre o sector da saúde e melhorar a qualidade de vida da população idosa. Em 2015, a Organização Mundial de Saúde (OMS) definiu *Envelhecimento Saudável* como "o processo de desenvolvimento e manutenção da capacidade funcional que permite o bem-estar em idade avançada". Com esta definição, Envelhecimento Saudável coloca o individuo como um participante ativo na gestão da sua própria saúde (autogestão da saúde), com foco na importância dos comportamentos saudáveis como estratégicas essenciais para preservar a capacidade funcional em idade avançada. Neste contexto, a capacidade funcional deve ser entendida como o conjunto dos atributos relacionados com a saúde que permitem que os indivíduos sejam ou façam o que valorizam. Os serviços de telemedicina ou *eHealth* – i.e. a utilização de Tecnologias da Informação e da Comunicação na prevenção, diagnóstico e/ou tratamento de doenças à distância – são promissores no apoio que podem proporcionar a idosos, designadamente na adoção e manutenção de comportamentos saudáveis. O objetivo desta Dissertação é explorar o potencial representado pela tecnologia no apoio ao Envelhecimento Ativo e Saudável no quotidiano do individuo idoso, focando na promoção de atividade física e bem-estar emocional no dia-a-dia.

No **Capítulo 1** apresentamos a investigação em *Envelhecimento Ativo e Agradável*, que dá título a esta Dissertação, emergindo como área de sobreposição de três temas: Envelhecimento Ativo e Saudável, atividade física e bem-estar emocional. O primeiro tema, *Envelhecimento Ativo e Saudável*, foi já introduzido. O segundo tema, *atividade física*, é um dos comportamentos mais importante nas estratégias de apoio ao Envelhecimento Saudável. A atividade física, referida nesta investigação como o total de movimento voluntário produzido por músculos esqueléticos durante o dia-a-dia, tem benefícios comprovados para a saúde física e preservação da capacidade funcional dos idosos. Apesar dos conhecidos benefícios de um estilo de vida ativo para a saúde, uma grande parte da população idosa não atinge os níveis de atividade recomendados. Quando questionados sobre as barreiras que impedem o envolvimento em atividade física, os idosos referem, com frequência, as limitações de saúde, a falta de interesse, a falta de tempo, ou o desagrado do esforço requerido

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para o exercício. Nesta Dissertação, investigamos abordagens para promover a atividade física no dia-a-dia da população idosa, apoiando, desta forma, o Envelhecimento Ativo e Saudável. O terceiro tema desta Dissertação é o *bem-estar emocional*, e refere-se à presença de emoções positivas (por exemplo, felicidade e calma), à ausência de emoções negativas (por exemplo, tristeza e angustia) e satisfação com a vida. As emoções positivas são influenciadas pelo contexto físico e social do individuo e, como tal, suscetíveis de flutuações no dia-a-dia. Tendo em conta que o nosso interesse é investigar estratégias que possam apoiar o Envelhecimento Ativo e Saudável no dia-a-dia, o bem-estar emocional – e em particular a experiência de emoções positivas – constitui o terceiro tópico central desta Dissertação.

No **Capítulo 2** apresentamos os resultados de uma revisão sistemática da literatura sobre a relação entre emoções positivas e a capacidade funcional de idosos que vivam de forma independente, considerando apenas estudos empíricos (longitudinais ou transversais). Estudos científicos demonstram que um estilo de vida ativo tem implicações positivas na preservação da capacidade funcional. Mas qual é a influência das emoções positivas na preservação ou declínio dessa capacidade funcional? Os resultados da revisão da literatura apresentados neste capítulo sugerem evidência que sustenta uma relação entre a capacidade funcional e a intensidade e frequência da experiência de emoções positivas, embora a direção desta relação não esteja definida. Em particular, há evidência, embora limitada, que a experiência mais frequente de emoções positivas está associada a uma melhor capacidade funcional e retardamento do declínio funcional. A revisão da literatura apresentada não permite uma conclusão integrada devido ao número limitado de estudos que atendem os critérios de inclusão, bem como as disparidades entre os métodos de recolha de dados e amostras populacionais. No entanto, os resultados apresentados estão de acordo com as teorias da psicologia positiva que sugerem que a experiência frequente de emoções positivas suporta uma variedade de recursos de resiliência, como a análise do ambiente e a procura de apoio social, que melhoram a capacidade de adotar estratégias favoráveis, em momentos de adversidade, característicos de uma idade avançada. Em síntese, a revisão dos estudos empíricos, alinhados com estudos teóricos, sugere que há evidência no sentido de que o bem-estar emocional tem implicações positivas para a capacidade funcional dos idosos, e assim sendo, deve ser tido em consideração em estratégias para o apoio do Envelhecimento Ativo e Saudável.

No **Capítulo 3** apresentamos os resultados de um estudo longitudinal que investiga o contexto físico e social da atividade física (por exemplo, localização, interação social

e tipo de atividade), e o prazer associado, no dia-a-dia dos idosos. Através de um estudo longitudinal intensivo – repetidos momentos de medição ao longo do dia para investigar as atividades do dia-a-dia foram combinados com o uso contínuo de um acelerómetro para monitorizar a atividade física – verificámos a importância das atividades realizadas fora de casa e das relações sociais na atividade física diária. Além disso, os nossos resultados indicam que atividades de lazer, intensificam tanto a atividade física como a experiência de emoções positivas (neste caso prazer). Esta relação não se verifica quando os idosos estão ocupados com atividades básicas do dia-a-dia (e.g. transporte e atividades de cuidado pessoal). Os resultados do estudo apoiam a hipótese de que uma estratégia para o apoio de Envelhecimento Ativo e Saudável possa passar por identificação e promoção de atividades diárias que contribuam simultaneamente para a atividade física e bem-estar emocional dos idosos.

Tendo em vista o objetivo inicial de investigar possíveis utilizações de tecnologia para apoiar o Envelhecimento Ativo e Saudável no dia-a-dia, nesta Dissertação investigamos também quais as atitudes e expectativas dos idosos relativamente a tecnologia que suporta monitorização da saúde. Este estudo foi dividido em duas partes. Numa primeira parte, através de extensivas entrevistas semiestruturadas, investigámos as práticas atuais na autogestão da saúde no dia-a-dia, assim como as atitudes em relação ao uso de tecnologia no apoio ao Envelhecimento Ativo e Saudável. Este estudo analisou quatro domínios da saúde: aptidão física, aptidão cognitiva, nutrição e bem-estar. Os resultados apresentados no **Capítulo 4** sugerem que o grau de envolvimento dos idosos na gestão da própria saúde depende de vários fatores, entre eles o historial médico de si mesmos e de parentes próximos. Além disso, verificamos que os idosos têm uma atitude positiva em relação ao uso de tecnologia no dia-a-dia para ajudar na autogestão da saúde, desde que essa tecnologia esteja adaptada às suas necessidades e preferências do dia-a-dia, seja empática e não substitua o contacto humano. Concluindo, os idosos entrevistados reconhecem o potencial valor do uso de tecnologia para a autogestão da saúde e motivação de comportamentos saudáveis que os apoie no Envelhecimento Ativo e Saudável.

Na segunda parte do estudo, os mesmos idosos que participaram nas entrevistas apresentadas no Capítulo 4, receberam uma pequena intervenção – consistindo na definição de objetivos e feedback – para promover a atividade física diária e monitorizar o bem-estar emocional. Os dados recolhidos através de um contador de passos e de questões repetidas numa aplicação de telemóvel, foram analisados e

combinados com os dados adquiridos através de novas entrevistas semiestruturadas, de forma a investigar como os participantes experienciaram o uso de tecnologia no dia-a-dia durante 4 semanas. Os resultados deste estudo, apresentados no **Capítulo 5**, sugerem que as atitudes relativas à tecnologia permaneceram positivas, ou melhoram, após o período do estudo. Os participantes mostraram-se satisfeitos com a monitorização da atividade física, mas não tão positivos relativamente à monitorização do bem-estar emocional. Desta forma, ainda no capítulo 5, discutimos a insatisfação dos idosos relativamente à monitorização do bem-estar emocional, nomeadamente aqueles causados por diversos desafios inerentes ao uso de sistemas de monitorização ambulatória na investigação de comportamentos do dia-a-dia.

O **Capítulo 6** apresenta uma revisão da literatura referente a tecnologia utilizada no apoio ao Envelhecimento Ativo e Saudável, com destaque para a promoção da atividade física e bem-estar emocional, focando-se em 4 componentes: monitorização, análise, estratégias de motivação e aplicações. Para cada uma destas componentes, analisamos o passado e o estado-da-arte, integrando também as lições aprendidas nos estudos desenvolvidos ao longo desta dissertação. O capítulo é finalizado com um olhar às tendências futuras relativas à tecnologia no apoio ao Envelhecimento Ativo e Saudável.

Finalmente, no **Capítulo 7**, discutimos os resultados da nossa investigação e abordamos vários desafios associados à adoção da tecnologia (por exemplo, como é que o idoso tem conhecimento das tecnologias disponíveis). Adicionalmente, discutimos como as lições aprendidas nesta Dissertação podem ser aplicadas a um contexto mais abrangente, como o apoio à autogestão de doenças crónicas.

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Sitting in a café in Enschede writing the Acknowledgements section of my PhD thesis, feels a bit… *bizar*. Since November 2013, I learned a new language, I got married, I acquired dual citizenship, or better saying, I found myself having two homes 3000 km apart from each other. This means a lot of traveling and a permanently split, not broken, heart. In the meanwhile, it seems I also became an independent researcher. This path would not have been possible without the support of many people. As separating work from private life is clearly not one of my most developed skills, in the following paragraphs I attempt to express my gratefulness in both domains.

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With all this tiring work and education, one needs distraction. And that is exactly what I got from the Bolwerk crew. Thank you everyone for all the shared moments in the last years! In the distracting domain, thank you to the *Enschede Resistance*, Amina, Katrin and Stefan. Girls, thank you for being always there for me and supporting me no matter what, sharing dark chocolate or a bottle of wine. Stefan, thank you for giving me weekly moments of fun and leisure throughout these years. Thank you for all the *flowers* that helped me released the frustrations with Squash but also with work at the end of the day.

Enschede introduced me to another group of people that I will be eternally grateful for, my ERASMUS family. Ksenija, Nicolo, Felix, Quentin and Roland, thank you in all languages! Thank you for the reunions in IT, DE, BE, PT, NL and FR. Every time we meet each other it feels that we were never apart. Ksenija, my minion, I admire you more than I can put into words. Thank you for being a constant inspiration in my life.

After six years living abroad, there are not a lot of friendships that survive. But those that do so, I keep as my most precious treasures. Thank you all! In particular, Gonçalo, thank you for being my safe harbour and my warrior, at all times. Ri and Raquel, thank you for being by my side for more than 20 years, sharing the best and most difficult moments. This year we gained a star that brings us even closer, wherever we are.

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This Thesis is dedicated to Rita Marques Almeida.
(24-01-1990, 24-05-2017)

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Curriculum vitae

Miriam Cabrita was born in Lisbon, Portugal, in December 1990. In 2008, she started the Biomedical Engineering studies at the Faculty of Science and Technology, Universidade Nova de Lisboa, Portugal. In the summer of 2011 she moved to Enschede, the Netherlands, within the ERASMUS exchange program, where she pursued the first year of the Master in Biomedical Engineering at the University of Twente. During this year in Enschede, Miriam became interested in telemedicine services, and as a result she performed her master thesis research at Roessingh Research and Development, also in Enschede, on the development of personalized strategies to motivate physical activity with a mobile application.

Immediately after receiving her Master's degree, in October 2013, Miriam started her PhD research at Roessingh Research and Development and at the University of Twente. Miriam has been involved in several international and national projects, including PERSSILAA (FP7-ICT), eWALL (FP7-ICT), VIREP (Euregio) and AIRplay (Pioneers in Healthcare). This thesis presents part of her research within the PERSSILAA project. Since 2013, Miriam is actively involved in education at the University of Twente, as a tutor, lecturer or supervisor, mostly within Creative Technology, Psychology and Health Sciences studies.

Currently, Miriam is employed as a researcher at Roessingh Research and Development where she is investigating motivational strategies to promote physical behavior among the older population and those with chronic diseases. Since 2017 Miriam is a member of the board of directors of the International Society for Measurement of Physical Behavior.

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