AFFECTING FALL RISK IN OLDER ADULTS
-
THE ROLE OF NOVEL TECHNOLOGY-BASED EXERCISE INTERVENTIONS

A thesis submitted to attain the degree of
DOCTOR OF SCIENCES of ETH ZURICH
(Dr. sc. ETH Zurich)

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2015
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1 Prologue

The discussion about the relevance of physical exercise for healthy aging is not groundbreaking. Nevertheless, it is a continual issue of extreme importance, challenging researchers, clinicians and policy makers to develop strategies that promote healthy aging. One of the major opportunities to extend years of active independent life is to be physically active on a regular basis [1-3]. Aging is characterized by a gradual reduction in the ability to perform activities of daily life. Walking, as one of its core activities, not surprisingly often shows significant changes during aging, since walking requires efficient circulatory, heart, lung, nervous, and musculoskeletal systems [4], systems that are vulnerable during general aging. Decreased walking ability is a specific precipitating cause for falls in older adults [5].

Walking has long been viewed as an automatic process, and falls have, therefore, mainly been considered as being a result of motor deficits [6]. With this assumption it is not surprising that most fall prevention programs in the past focused on the training of physical functions. Since muscle weakness, gait and balance deficits are among the most important risk factors for falling [7-10], physical training, and especially strength and balance training with the aim to enhance walking function and, consequently, to prevent falls [11] remain indispensable. However, the automatism of gait only holds true for walking conditions under which no deviations from learned programs are required [12]. In reality, where walking often has to be performed in challenging environments, an infinite number of possible obstacles require instantaneous adaptation of the program for safe navigation.

Older adults fall, even when their physical functions are intact [13, 14]. The fact that people with cognitive deficits fall about twice as frequently compared to cognitively intact people [9] gives strong reason to assume that walking partly depends on cognitive functions. Walking, and, in general, almost all activities of daily life, require both sensorimotor processes and higher level cognitive functions [15]. These findings support the understanding that walking is a complex task requiring a high number of attentional resources. To deal with the additional cognitive requirements of walking under attention-demanding circumstances, motor training alone seems insufficient. Evidence is growing that physical and cognitive exercises should be combined, aiming to help older adults to move safer and maintain independence [16, 17]. Recent literature suggests that the impact of sensorimotor impairments on falls is in part moderated by executive functions (EF), i.e. that these functions play an important role in falls prevention.
One of the scientific challenges that researchers face today is to design, test, and implement structured interventions that are capable of enhancing physical and cognitive functioning in older adults, delay onset of cognitive or motor disorders, and, through this, reduce falls. Despite the increasing wealth of knowledge regarding the relationship between physical and cognitive training and health we have become an increasingly sedentary society. Older adults often face strong barriers to exercise and, through this, to increase their physical activity level. They are confronted by a lack of motivation to keep exercising regularly and for a longer period, which partly results from a combination of poor health, fear of falling, and insufficient knowledge about the health protecting factors [18-22]. Motivating people is a complex issue, and depends on factors such as perceived chance of success and perceived importance of the goal [18, 19]. These factors, however, can potentially be influenced. Independently living people living in regions with poorly designed neighborhoods and communities which are perceived as being unsafe are reluctant to leave their home. Problems in reaching a training center (e.g. because of living in rural or remote areas) can make it hard for older adults to maintain or increase their level of physical activity [23]. Especially for these people an effective home-based intervention at regular intervals may offer great benefits [24, 25]. Thus, despite the fact that exercise has widely been accepted as beneficial for health, successful implementation of exercise interventions presents a major challenge for many older people [26].

This doctoral thesis presents the results of a cognitive-motor training intervention performed in 14 homes-for-the-aged with a large enough sample size to draw meaningful conclusions about how dual task costs of gait is effected by the type of training. The topic of combining cognitive and motor interventions needs for more studies with larger sample sizes [17, 27] to elucidate possible causal relations. Furthermore, studies are needed that link the cognitive training component to prospective falls [17, 28]. This thesis also addresses the development and implementation of innovative intervention programs for independently living older adults aiming to reduce falls. New technologies, in this case a tablet-based application containing a training program, may present a capable method to motivate older adults to become active and perform a targeted training program in their homes.

To optimally plan, develop and implement interventions, it is important to understand the factors determining the performance of daily life activities. Therefore, the next part briefly summarizes changes during the aging process, emphasizing its link to walking ability and falls.

1.1 Aging process and its relationship to walking and falls

At about the age of twenty, the human body increases the reserves and functional capacity of its systems to their maximum potential [29]. From this point, it loses about 10% of its functions per decade, resulting in an approximate 30% loss of functional capacity at the age of 60 [30]. There
seems to be a similarity between the changes during the aging process and those that happen due to disuse of various body parts [1]. Physiological changes associated with aging or disuse are, amongst others, a decrease in exercise and work capacity, muscle strength, tissue elasticity, motor coordination, and neural reaction time [1]. One of the most remarkable changes is the loss of muscle mass, and its almost full replacement by fat mass [31]. Muscle mass already starts to decline at the age of 30, and continues to decline by 10% - 15% per decade [32].

Walking requires a relatively high number of attentional resources – and these resources are expected to be limited in elderly [15]. In combination with sensory and motor deficits occurring during natural aging, the limitation is especially pronounced in older adults. To cope with situations in which a cognitive and a motor task must be performed simultaneously – e.g. in situations where attention has to be divided - becomes difficult. Divided attention, one component of executive functions, and some aspects of selective attention seem to be especially impaired in the aging process [33, 34]. As a result of the competing interference between two or more tasks, walking often deteriorates [35, 36]. Characteristics of an older person’s walking pattern are, amongst others, slower walking speed, shorter stride length, increased stride-to-stride variability, longer step time, double support time and step initiation time [37-39]. Several of these factors in a way relate to the central nervous system. High variability, expressed as an unsteady and inconsistent walking pattern, for example, associates with executive functions [40-43], functions that are prone to the aging process [6, 44, 45]. Furthermore, a loss of efficiency in mechanisms of the central nervous system appears to cause falling during gait initiation [46].

1.2 Falls and their consequences

A decrease in walking ability frequently results in disability and falls, which in turn leads to a loss of independence in activities of daily living [47], institutionalization, and death [48, 49]. A loss of independence in older adults increases health care costs [50-52] and, not least because of this, to minimize falls is a common concern. A third of people aged 65 and older fall, and even half of those aged 85 and more, whereby 10% results in serious injury [53, 54], which reinforces the importance of intervention programs aiming to reach a meaningful reduction of falls. A review including 32 studies calculating fall-related health care costs demonstrated costs between 0.85% and 1.5% of the total health care expenditures [55]. The impact of hip fracture, for example, is serious in terms of mortality, morbidity, and costs [56, 57], and 9 of 10 hip fractures are caused by a fall [58]. Estimates reveal that between 2000 and 2020, the absolute number of osteoporotic hip fractures in the Swiss population will rise by 36%, which relates, in combination with vertebral and distal forearm fractures, to an expected increase of 33% in direct medical inpatient costs yearly [59].
Although the aging process often causes physical and mental suffering, negative changes have an individual character. Most of them can be influenced by individual behavior. The aging process is dynamic, not static. Relevant changes can be prevented, or at least contained, by cognitive and motor exercises.

1.3 Contribute to shaping the aging process

Even when the biological clock keeps ticking, it is well known that intervention programs can minimize negative changes related to the aging process [30] – provided the programs are implemented and performed correctly.

Exercise affecting physical & mental health

The evidence that sedentary people lose a relatively large fraction of their muscle mass during aging [1] confirms that avoiding physical inactivity, in general, is an obvious aim for interventions [60]. Physical activity, in general, has been shown to inversely relate to several diseases, e.g. type II diabetes mellitus, osteoporosis, colon and breast cancer, and has the potential to positively influence body composition, physical- and cognitive functioning, and cardiovascular- and psychological health [30, 60-65]. Structured exercise training is recommended to postpone frailty and vulnerability [66, 67] and to minimize several chronic degenerative diseases that result from an inactive lifestyle [60, 68]. Physical activity associates with increased life expectancy [69], and diminishes the probability of a fall [70, 71].

The most efficient way to prevent age-related changes of the body composition, including the decrease in skeletal muscle mass, most commonly through atrophy and a loss of type II (fast twitch) fibers, increased intramuscular fat and connective tissue which decreases muscle quality, is resistance training [1]. Resistance training, as the type of exercise that should be included in a falls prevention program, also reduces sarcopenia, coronary heart disease, hypertension, and diabetes mellitus [1, 63, 72-74].

Switching from physical gains of being physical active to the cognitive increments, a recently published review by the American College of Sports Medicine describes the current state of evidence in the aging population. It reviews effects of aerobic and resistance exercise training on cognitive health [75] and identifies promising effects of aerobic training, including large effects on executive functioning [76, 77] as well as higher activity [78] and increased brain volume [79], especially in brain regions that relate to these functions (e.g. the prefrontal cortex). Although knowledge about the effects of aerobic training provides robust evidence for the positive influence of exercise on cognitive functioning in old age, the sparse but promising literature about resistance training is, nevertheless,
extremely relevant [75]. Older adults may not have the physical condition to conduct aerobic exercises, as this type of exercises requires relatively healthy joints and a rather intact cardiovascular system, and both are frequently limited in older adults [80]. Resistance training benefits memory performance [81-84] and executive function [85], and has a positive impact on the functional plasticity of the brain [80].

**Cognitive and cognitive-motor training approaches**

Cognitive interventions improve brain health, which has been demonstrated cognitive speed [86], attention [87], and concentration [86], and evidence suggests that gains in cognitive performance are robust up to several years after training [88]. Computerized cognitive intervention appears to be preferred over traditional, paper-and-pencil cognitive training, and offers advantages such as individualization of the training [89]. Adding cognitive challenges to physical training seems to be more effective for improving executive functions [90] and walking tasks that are related to cognitive functions (i.e. dual task walking) [91] than isolated physical training. The assumption that intervention programs, aiming to improve walking function to a greater extent, should explicitly include both a cognitive and a motor part is gaining emphasis [16, 17, 92, 93]. Intact EF seem to be essential for a normal walking pattern [6] and, therefore, the cognitive part of the intervention should especially focus on divided attention, one of the core EFs in terms of walking under attention-demanding circumstances [94]. However, the possible causal association between the training of divided attention and changes in spatial and temporal dual task cost characteristics of gait still remains to be determined in sufficiently powered trials.

**1.4 Implementation of training – new technologies**

This introduction focused on the aging process, highlighting the importance of cognitive and motor training in ameliorating physical and cognitive performance. Next, the thesis will turn to the aspects of developing, testing and implementing such interventions. A training program with the aim to maximize outcomes should consider the individual needs and possibilities of older adults, e.g. either autonomous living or living in homes-for-the-aged. Proper exercise instruction, setting of a goal and a method to evaluate training progression are relevant, since training itself, often does not ensure benefits [95, 96]. In homes-for-the-aged, when age-adapted training equipment is available and proper exercise instruction and support is warranted, a solid foundation for effective training is laid. However, a variety of barriers make it difficult for older adults not living close to an appropriate training infrastructure to maintain or increase their physical activity level. These barriers might be overcome by the support of Information and Communication Technologies (ICTs) that have emerged over recent years in falls prevention. Interventions, that base on assistive technology devices
potentially help older adults to start exercising, and maintain physical independence [97]. However, a challenge in developing a program with ICTs is that older adults should be able to deal with them. A major barrier to successfully implement these technologies is lack of adoption and adherence to their use [98]. In combination with this, relevant factors to enhance training adherence and, through this, to increase success rates, are motivation and encouragement, social support, and providing feedback [99-101].

1.5 The aim and scope of this dissertation

The overall focus of this doctoral thesis is the development, testing and successful implementation of cognitive and motor training interventions aimed at reducing falls in older adults. The choice of this focus is based on the fact that there is a need for more intervention studies with a larger sample size, combining cognitive and motor training and examining its effects on falls and fall related factors, including physical and cognitive performance. In addition, even though exercising on a regular basis is recommended to improve health, well-being, and independence in old age, many older people lack motivation and face strong barriers to exercise.

The first part of this doctoral thesis (Chapter 2) describes the results of a multi-center randomized controlled trial. The study design of this experiment was based on the findings of an interventional and observational pilot study conducted at the Institute of Human Movement Sciences and Sport of the ETH Zurich [102]. This pilot trial, where a motor group that conducted strength and balance exercises was compared to a cognitive-motor group that performed strength, balance and cognitive exercises, was the foundation of the present study in this dissertation. The aim of the pilot trial was to develop a cognitive-motor training program, to evaluate the ability to recruit and retain elderly people, and to assess the effects of the interventions. The training groups achieved high adherence rates, and the protocol of the trial was deemed feasible to proceed to a sufficiently powered main study without modifying the protocol. Furthermore, the cognitive-motor group achieved greater reductions in the fear of falling and simple foot reaction time, and tended to better improve complex walking (i.e. greater reductions in dual task costs of walking). On the basis of the outcomes of this pilot trial, the experiment described in Chapter 2 was conducted with a sufficiently powered sample in 14 senior hostels in Switzerland (n=13) and Germany (n=1), including a total of 182 participants.

The second part of this thesis (Chapters 3, 4, 5) constitutes two experimental trials, performed with older adults, living independently, in their home-environments. The training program consisted of strength-balance exercises and was based on the use of novel technologies, i.e. a tablet computer. In collaboration with the Department of Computer Sciences of the University of Trento in Italy we developed a tablet-based strength-balance application – the ActiveLifestyle app. The ActiveLifestyle
app acts as proactive training software to assist, monitor, and motivate older adults to follow their personalized training plans autonomously at home, while integrating them socially. Since modern exercise equipment may not be suitable for older individuals, who may rather express a preference for more traditional therapy approaches [103], new treatments usually have to go through a series of phases to test whether they are feasible, safe and effective [104].

With this in mind, we performed a phase II trial according to the model for complex interventions advocated by the British Medical Research Council [104] to test the effects of the ActiveLifestyle app.

After developing the ActiveLifestyle intervention, which based on principles of exercise physiology, motivational strategies, and currently available best evidence, the first Experiment (Chapter 3) was conducted. The experiment aimed to test the feasibility and usability of the app, and the ability to recruit and retain older adults for such a new intervention, during a two-week trial period.

The long-term adherence and effects of the intervention were assessed in the second experiment with the ActiveLifestyle app (Chapters 4, 5). The effectiveness of tablet-based health intervention approaches has not yet been demonstrated in older adults and, to the best of our knowledge, there is no other software app dedicated to strength-balance training plans for older people. In the two-week pilot study (Chapter 3) it was not possible to assess aspects of long-term adherence and physical function. Chapters 4 and 5 present the results of a Phase II Preclinical Exploratory Trial.

Chapter 4 describes the exploration of IT-mediated motivation strategies included in the app and their effect on adherence to the physical exercise training plans.

Chapter 5 describes the effect of the home-based intervention on measures of gait quality and physical performance through planned comparisons between (1) the tablet-based and brochure-based interventions, (2) the individual and the social motivation strategies, and (3) the active (≥75% program compliance) and inactive (<75% program compliance) participants.

This doctoral thesis ends with a general discussion (Chapter 6) outlining the main results of all studies as well as general conclusions, clinical implications and suggestions for future work.

References


Chapter 2

Strength-balance supplemented with computerized cognitive training to improve dual task gait and divided attention in older adults: A multicenter randomized-controlled trial

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published in BMC Geriatrics 2014 (www.biomedcentral.com/1471-2318/14/134)
Abstract

**Background:** Exercise interventions often do not combine physical and cognitive training. However, this combination is assumed to be more beneficial in improving walking and cognitive functioning compared to isolated cognitive or physical training.

**Methods:** A multicenter parallel randomized controlled trial was conducted to compare a motor to a cognitive-motor exercise program. A total of 182 eligible residents of homes-for-the-aged (n=159) or elderly living in the vicinity of the homes (n=23) were randomly assigned to either strength-balance (SB) or strength-balance-cognitive (SBC) training. Both groups conducted similar strength-balance training during 12 weeks. SBC additionally absolved computerized cognitive training of alertness and divided & selective attention. Outcomes were change in dual task costs of walking, physical performance, simple reaction time, executive functions, divided attention, fear of falling and fall rate. All randomized participants were analysed with an intention to treat approach.

**Results:** All 182 participants were randomized (mean age ± SD: 81.5 ± 7.3 years) and allocated to either SB (n=98) or SBC (n=84). The attrition rate was 14.3%, thus, 156 participants completed the intervention (SB n=82; SBC n=74). Interaction effects were observed for dual task costs of step length (preferred walking speed: F(1,174)=4.94, p=0.028, η²=0.027, fast walking speed: F(1,166)=6.14, p=0.009, η²=0.040) and dual task costs of the standard deviation of step length (F(1,166)=6.14, p=0.014, η²=0.036), in favor of SBC. Significant interactions in favor of SBC were also seen in gait initiation (F(1,166)=9.16, p=0.003, η²=0.052), ‘reaction time’ (F(1,180)=5.243, p=0.023, η²=0.028) & ‘missed answers’ (F(1,180)=11.839, p=0.001, η²=0.062) as part of the test for divided attention. Within-group comparison revealed significant improvements in dual task costs of walking (preferred speed; velocity (p=0.002), step time (p=0.018), step length (p=0.028), fast speed; velocity (p<0.001), step time (p=0.035), step length (p<0.001)), simple reaction time (p<0.001), executive functioning (Trail making test B; p<0.001), divided attention (p<0.001), fear of falling (p<0.001), and fall rate (p<0.001).

**Conclusions:** Combining strength-balance training with specific cognitive training has a positive additional effect on dual task costs of walking, gait initiation, and divided attention. The findings further confirm previous research showing that strength-balance training improves executive functions and reduces falls.

**Trial registration:** This trial has been registered under ISRCTN75134517 (www.controlled-trials.com/ISRCTN75134517)

**Keywords:** cognitive-motor training, dual task costs, divided attention, cognitive functions, executive functions, exercise, fall prevention
2.1 Background

The progressive and dynamic aging process is characterized by functional and cognitive changes that often lead to physical performance deficits and deteriorations in walking. These changes occur even in the absence of overt diseases. Potential consequences are increased risk for falls, loss of independence in activities of daily living, and poor quality of life [1-5]. Functional dependence in older adults is associated with increased health care costs and mortality [6-8]. Minimizing falls is a common concern of many interventions as a third of people aged 65 and older and half of those aged 85 and older sustain falls each year, from which 10% result in serious consequences [9, 10]. One key factor in staying independent and maintaining mobility is, therefore, to enhance walking ability in older adults.

The general health protecting influence of physical activity in relation to muscular, skeletal, metabolic and cardiovascular functions is well documented [11-17]. The effect of physical [18] and cognitive [19-22] activity on brain functioning has also been recognized. Physical activity, for example, has been suggested reducing the incidence of dementia or cognitive deterioration [23-25], and is related to enhancements in cognitive functioning and brain plasticity [26-30]. Cognitive interventions resulted in improved cognitive speed [31], attention [32], and concentration [31]. Thus, cognitive functions are amenable both through physical and cognitive exercise, even in old age [23, 33-37].

Disparate lines of research converge on the notion that sensorimotor and cognitive aging are linked to each other in old age [38], and that daily tasks such as walking are dependent on both sensorimotor processes and higher level cognitive functions [39]. In the past walking has primarily been seen as representing an automated and reflex-controlled process [40, 41], which remains automatic when not deviating from learned programs [42]. However, older adults with cognitive impairments are exposed to falls, even when their motor functions are fairly intact [43, 44]. Recent literature suggests that the impact of sensorimotor impairments on falls is in part moderated by executive functions (EF) [45]. A review on this topic summarizes the interplay between EF, attention and gait [46]. Among healthy older adults, victims of falls performed poorly on EF and attention-demanding tasks [40, 47, 48], and the ability to pay attention seems to be an important requirement for walking that also influences the risk for falling [49]. Individuals with poor EF in turn have reduced gait speed [50], are more prone to falls [51] and have an increased risk of mortality [52]. EF has also been shown to associate with higher gait variability, which marks unsteadiness and inconsistency in walking, and likewise increases fall risk [53-56]. For minimized stride-to-stride fluctuation in gait an intact neural control system appears to be required [53]. A further walking aspect that is associated
with higher level sensorimotor functions is gait initiation, and difficulties to initiate gait are related to disorders in the frontal lobe [1].

Divided attention, one component of executive functions, and some aspects of selective attention seem to be especially impaired in the aging process [57]. Dual-task related gait changes result from the competition interference between two attention-demanding tasks [58], and studies of cognitive changes during the aging process indicate that older adults’ ability to divide attention is decreased [59]. Compared to other specific components of executive functions, divided attention especially associates with spatial and temporal dual task cost characteristics of gait [60].

Basic components of a motor intervention program aiming to improve gait function in older adults are strength and balance exercises [61-64]. Training attention and executive function also improves gait [65, 66]. However, two recent reviews that focused on the interplay between physical functions and cognition concluded that it seems important to combine motor and cognitive therapy into clinical practice to enable older adults to move safer in their physical environment [46, 67] and that computerized interventions seem promising for this purpose [67]. Such an approach was tested in a pilot study, where traditional strength-balance training got complemented with computerized cognitive training of attention [68]. Cognitive-motor training tended to improve gait and foot reaction time to a greater extent than motor training alone. Because of the small sample size the association remained undetermined. There is a need for more studies on this topic with larger sample sizes [36, 46], and also for studies that address the effects of preventive interventions on cognitive performance [36] and, thereby, link the cognitive component to falls [46]. This study, therefore, aimed to further explore the additional effect of the supplemented cognitive training in a sufficiently powered trial. This randomized controlled trial was designed to examine the effects of exercise training and combined exercise and cognitive training on the physical and cognitive functioning of older adults. We hypothesized that both training groups would show significant improvements on measures of physical and cognitive functioning and, that the combined training group (exercise and cognitive training) would show greater walking function and cognitive improvements than the exercise-only training group.

2.2 Methods

Trial design

This study was a multicenter parallel randomized controlled clinical trial (trial registration: ISRCTN75134517). The study was carried out from March 2011 to December 2013. Participants were recruited from 14 homes-for-the-aged in Switzerland (n = 13) and Germany (n = 1). Permission of the ethical committees of the Cantons Berne, Zurich, Lucerne, St Gall, Argovia in Switzerland and
Rhineland-Palatinate in Germany was received prior to study commencement. All participants provided written informed consent prior to participating in the study. The CONSORT Statement is used for reporting [69].

Participants

Eligible residents of the homes-for-the-aged and interested autonomous living adults living in the vicinity of the homes were invited to attend an information session where the content of the intervention program and study design were explained. Based on the pilot study [68], where a 46% recruitment rate was reported, we estimated 467 potential participants from the 14 homes-for-the-aged. A sample of 192 residents of the homes and 23 autonomous living adults living in the vicinity of the homes indicated interest to participate. Participants were included when older than 65 years, scoring a minimum of 22 points on the Mini-Mental State Examination (MMSE), able to walk 20 meters with or without aids, free of rapidly progressive illness, acute illness or unstable chronic illness. Thirty-three subjects had to be excluded (MMSE n = 9, health problems n = 16, motivation problems n=8). Hence, 182 individuals fulfilled all criteria. They were randomly allocated to either the strength-balance SB group (n = 94) or the strength-balance-cognitive SBC group (n=88) using simple (unrestricted) randomisation [70] based on a random-number table. Four participants that were not able to conduct the cognitive training due to vision problems were manually allocated to the SB group after randomization. Thus, we reported 98 participants in SB and 84 participants in SBC after this adaptation. Individuals who met the initial eligibility criteria took part in a personal questionnaire based interview to screen for cognitive and health problems. Subjects who stopped doing their exercises any time during the 12 weeks of the program were defined as drop-outs.

Sample size calculation

The sample size calculation for the number of participants is based on the primary outcome measure in the pilot study for the DTC of step duration and DTC of step length [68]. In order to avoid a type I or II error an estimated sample size of 64 (DTC of step duration) respectively 45 (DTC of step length) participants per group for a two group pre test – post test design was required, resulting in 80% power at an α-level of 0.05. To account for attrition over time, the required sample size was increased by 15% to 74 respectively 52 participants per group.

Motor intervention program

All participants performed an exercise program consisting of twice-weekly thirty minutes progressive resistance training on age-adapted machines and 10 minutes balance training during twelve weeks. Characteristics of age-adapted machines include a stepless increase or decrease of the resistance,
restriction of range of motion through range limiters, ergonomic seats and, through this, a reduction of stress on vulnerable joints. Almost all of the homes trained with our preferred equipment using air-pressure as resistance (Ab HUR Oy, 67100 Kokkola, Finland (http://www.hur.fi)). The requirement of the machines of the few homes that used weight stack machines was that they allowed increase or decrease of resistance in small steps of around 2-5 kg, depending on muscle group trained. The intervention was provided face to face to 4 to 6 participants at a time. The mix of strength training and balance exercises focusing on lower extremity muscle function was chosen to optimize transfer to functional tasks of daily living [71, 72].

Intensity, progression and duration of the program were based on previously published recommendations [11, 63, 73, 74]. Perceived exertion was obtained using the Borg’s scale of perceived exertion [75], and progression based on the participant’s statements. The muscle groups of the hip extensors, ab- and adductors, knee flexors and extensors, ankle dorsi- and plantar-flexors, abdominal- and back muscles as well as rhomoid muscles were trained (Figure 2.1). Additionally, one legged stance training, tandem standing and walking, walking on heels, backward and sideward walking, turns, sit-to stand-transfers and knee squats were executed. The balance program was performed using air-filled balance cushions (diameter 34 cm) (Sissel Schweiz, 8904 Aesch, www.sissel.ch), and consisted of static and dynamic functional exercises (e.g. standing on one leg, walking over cushions) [76]. Flexibility exercises followed each training session to maintain or improve the range of motion that is necessary for activities of daily living.

![Figure 2.1: The trained muscle groups of the strength training](http://www.hur.fi).

Cognitive intervention program

In addition to the physical training, one group received 12 weeks cognitive training, with the CogniPlus [77] training program (SCHUHFRIED GmbH, 2340 Mödling, Austria, http://www.schuhfried.at), 3 times a week for 10 minutes. The program was computer-based and supported the training of cognitive abilities (Figure 2.2). The control group did not have any alternative additional input.

The following tasks for attention training were used: the Alert training program trains alertness – the ability to temporarily increase and sustain the intensity of attention; the Select training program
trains selective attention – the ability to respond quickly to relevant stimuli and to suppress inappropriate responses; the Divid training program trains divided attention – the ability to perform different tasks simultaneously.

The ability dimensions were trained using realistic scenarios. In the Alert training program, a motorcycle is driven along a road, and the participant’s task was to react as quickly as possible when obstacles appear (e.g. an animal crossing the road), by pressing a reaction key. In the Select training program the participants drove through a tunnel in a mine rolley and had to react on relevant visual and/or acoustic stimuli (e.g. yellow birds making a noise pre-defined for that animal) and to suppress reaction on irrelevant stimuli (e.g. a gray mouse making a noise of a bird). During the Divid training program the participant’s task was to observe an airport as a security official. The participants had to simultaneously observe different screens with several control monitors (e.g. ticket counter, luggage conveyor) and announcements over the loudspeaker, and to react appropriately on these stimuli.

The training principle of progression was implemented in this part of the training. The intensity of the cognitive training program was progressively increased or decreased, based on the abilities of the performer. When performers adapted to a certain training level, program variables (e.g. speed) were automatically modified. The program has previously shown to be able to improve attention [78].

![Image](image.png)

**Figure 2.2:** Exercise example from the cognitive exercise program: a participant training selective attention.

**Primary outcome**

*Dual task costs of walking*

Spatio-temporal walking parameters were measured with the 7.92 meters portable electronic GAITRite® walkway (CIR Systems, Havertown, USA), Platinum Version 4.0 software, a valid and reliable tool for gait analysis in older adults [79]. Subjects were instructed to walk under four different conditions: (1) walk at self-selected speed (*preferred walking*), (2) at fast speed (*fast walking*), (3) at self-selected speed while continuously subtracting sevens or threes from a random given number between 200-250 or while enumerating animals or flowers (*DT preferred walking*), (4) fast walking while continuously subtracting or enumerating (*DT fast walking*). Participants walked
two or three trials for each condition. Derived walking parameters were: velocity (m*s^-1), step time (s), step length (m) and variability, expressed as standard deviation (SD) of step length (m).

We calculated for each subject and task the relative dual task costs (DTC), as percentage of loss relative to the single-task walking (expressed in absolute values), according to 100 * |(single task score – dual task score)/single task score| [80].

**Secondary outcomes**

**Physical performance measure**
Physical performance was assessed with the short physical performance battery (SPPB) and the expanded timed get-up-and-go (ETGUG) test. The expanded timed get-up-and-go (ETGUG) test measures times to complete six component tasks identifiable in the TUG test; sit-to-stand, gait initiation, walk 1, turn around, walk 2, slow down, stop, turnaround, and sit down [81]. SPPB is valid and reliable for lower extremity functions [82], and predictive for disability [83]. ETGUG serves as an objective and reliable assessment of functional ability in older adults [84].

**Simple reaction time**
Simple reaction time tasks were used to measure psychomotor speed. Reaction time was assessed using a hand-held electronic timer and a light as the stimulus. Depression of a switch by the finger and the foot served as response [85].

**Executive functions**
The Trail Making Test A & B assesses executive functions, attention, and processing speed, and consists of two parts; TMT-A and TMT-B. TMT-A is a visual-scanning task, and cognitive flexibility is required to conduct TMT-B [86].

**Divided attention**
We assessed divided attention with the computerized Vienna Test System (SCHUHFRIED GmbH, 2340 Mödling, Austria, http://www.schuhfried.at). The participant receives stimuli on two visual channels. The upper stimulus (upper channel) presented a light grey circle, and the lower stimulus a light grey square (lower channel) on a white screen. The two stimuli appear and disappear continuously, and sometimes one or both of the stimuli change the colour to dark grey. The task was to observe if one of the stimuli has changed from light grey to dark grey two times in series and, in this case, to press the response key [87]. Analysed parameters were: reaction time upper channel (s), reaction time lower channel (s), number of missed answers upper and lower channel.

**Fear of falling**
The Falls Efficacy Scale International (FES-I) was used as a measure of ‘concern’ about falling to determine the transfer effects of training. The FES-I has excellent internal and test-retest reliability [88].

All measurements and the intervention program were conducted in suitable locations at the homes-for-the-aged. Outcome variables were taken at baseline and after 12 weeks of the intervention. Individuals meeting the eligibility criteria took part in a personal questionnaire based interview screening for cognitive and health problems.

Falls

Falls, defined as ‘unexpected events in which the participant comes to rest on the ground, floor or lower level’ [89], were assessed from 6 months retrospectively to 12 months prospectively using a fall calendar. Fall rates (falls per month) were analyzed for three periods; 1) 6 months retrospectively to study commencement, 2) 3 months during the study, 3) 12 months following training ending. Retrospective falls were reported at study commencement and based on data information in the data systems of the homes, which was combined with interviews of the trainees. For the other two periods falls calendars were provided to the health care staff of the homes-for-the-aged, filled-in on a weekly basis and returned after a period ended.

Randomization

To ensure allocation concealment, participants in each home were enrolled by the health care staff, and randomized by the person assessing the outcome measures using simple (unrestricted) randomisation [70] based on a table of random numbers. The assessor generated an unpredictable allocation sequence, which was concealed until assignment occurred. Each participant in every home received a two digit number (01, 02, 03, ...) resulting in a rank order of the participants. With the help of the random numbers table the assessor decided a priori to pick a number from the table with a pencil and go through the table either from bottom-right to upper-left in a diagonal way, horizontally from left-to-right or right-to-left, etc. Even and uneven numbers decided group allocation. All individuals were allocated this way to one of the two groups where for each location a different number of the table of random numbers was taken. Because of the sample size achieved we decided not to compare the totals for each group and choose the group that would give most balance overall for the last participants to be included. With this procedure we ended up with a slightly uneven distribution, however, without having to use blocking or stratification. The health care staff assigned participants to the training groups. The intervention was absorbed in groups of 4 or 5 and supervised by instructed personnel of the homes-for-the-aged. Blinding of the investigator was not possible because the investigator conducted part of the assessments.
Statistical analysis

All available data were analyzed by initial group assignment and were performed with an intention to treat approach [90]. All participants (including drop-outs) were integrated in the analysis, regardless of their adherence rate. We assumed that all missing responses were constant and replaced the missing values with mean values of the group to which subjects were originally allocated [91]. A two-way repeated-measure analysis of variance (ANOVA) examined differences between groups and over time. We used pre-post as within-subject factor (2 levels) and groups as between-subject factor (2 levels). A probability level of $p < 0.05$ was considered significant. A trend to significance was defined as $0.05 < p \leq 0.10$. For effect size, we used $\eta^2$ in ANOVA analyses. Norms for interpreting $\eta^2$ are: 0.01=small effect, 0.06=moderate effect and 0.14=large effect [92]. Sensitivity analyses were performed to deal with outliers [93]. Outliers were excluded using a trimming method [94]. Criteria for outliers based on the interquartile range (IQR), where data below ($Q1-1.5*IQR$) or above ($Q3+1.5*IQR$) were defined as outliers [95]. All statistical procedures were conducted with SPSS (version 20.00) software (SPSS Inc. Chicago, IL, USA). An attendance rate of 75% and more was deemed acceptable and defined as adherence to the training plan [96].

2.3 Results

Variables describing the sample are summarised in Table 2.1. One hundred eighty two participants fulfilled the initial eligibility criteria and were randomly assigned to either SB (94) or SBC (88). With the reallocation of 4 participants from SBC to SB the intervention started with 98 Participants in the SB and 84 Participants in the SBC group. A total of 156 participants completed the intervention (137 subjects living in the homes-for-the-aged and 19 subjects living in the vicinity) resulting in 14.3% attrition (Figure 2.3). Adherence to strength-balance training was 91.4% for SB (21.9 out of 24 sessions) and 89.5% for SBC (21.5 out of 24 sessions). Average adherence to the cognitive intervention was 85.4% (307.4 out of 360 scheduled minutes).
<table>
<thead>
<tr>
<th>Group</th>
<th>SB group</th>
<th>SBC group</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of participants with a complete questionnaire</td>
<td>76</td>
<td>69</td>
</tr>
<tr>
<td>Age (mean±SD)</td>
<td>81.9±6.3</td>
<td>81.1±8.3</td>
</tr>
<tr>
<td>Sex (female, male)</td>
<td>52, 30</td>
<td>49, 25</td>
</tr>
<tr>
<td>MMSE score (mean±SD)</td>
<td>27.7±2.9</td>
<td>27.6±2.6</td>
</tr>
<tr>
<td><strong>Fall Risk factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow walking speed (&lt;1.22 m/s) n(%)</td>
<td>64 out of 77(83)</td>
<td>62 out of 74(84)</td>
</tr>
<tr>
<td>Fell in the last 6 months n(%)</td>
<td>23(30)</td>
<td>20(29)</td>
</tr>
<tr>
<td>3 or more prescription medications n(%)</td>
<td>45(59)</td>
<td>51(73)</td>
</tr>
<tr>
<td>Physical functioning; SPPB (mean±SD)</td>
<td>7.3±2.6</td>
<td>7.3±2.6</td>
</tr>
<tr>
<td>Fear of falling; FES-I (mean±SD)</td>
<td>25.4±8.0</td>
<td>26.8±9.6</td>
</tr>
<tr>
<td><strong>Education / profession n(%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University / College</td>
<td>4(5)</td>
<td>7(10)</td>
</tr>
<tr>
<td>Vocational Education</td>
<td>52(68)</td>
<td>41(59)</td>
</tr>
<tr>
<td>No educated profession</td>
<td>20(26)</td>
<td>21(30)</td>
</tr>
<tr>
<td>In a sitting position past profession</td>
<td>15(20)</td>
<td>18(26)</td>
</tr>
<tr>
<td><strong>Health questions n(%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of self-reported chronic diseases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint diseases</td>
<td>35(46)</td>
<td>34(49)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>40(53)</td>
<td>37(54)</td>
</tr>
<tr>
<td>Cardiac Problems</td>
<td>27(36)</td>
<td>29(42)</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>13(17)</td>
<td>12(17)</td>
</tr>
<tr>
<td>Type II diabetes mellitus</td>
<td>9(12)</td>
<td>11(16)</td>
</tr>
<tr>
<td>Problems limiting walking function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-reported walking problems</td>
<td>31(41)</td>
<td>34(49)</td>
</tr>
<tr>
<td>Problems with legs</td>
<td>40(53)</td>
<td>41(59)</td>
</tr>
<tr>
<td>Need walking aid</td>
<td>31(41)</td>
<td>36(52)</td>
</tr>
<tr>
<td>Hearing problems</td>
<td>41(54)</td>
<td>35(51)</td>
</tr>
<tr>
<td>Vision problems</td>
<td>34(45)</td>
<td>32(46)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>28(37)</td>
<td>21(30)</td>
</tr>
<tr>
<td>Estimated good health</td>
<td>48(63)</td>
<td>36(52)</td>
</tr>
<tr>
<td>Estimated better health compared with contemporary</td>
<td>26(34)</td>
<td>23(33)</td>
</tr>
<tr>
<td>Estimated good balance</td>
<td>29(38)</td>
<td>22(32)</td>
</tr>
<tr>
<td>Feel pain daily</td>
<td>22(29)</td>
<td>22(32)</td>
</tr>
<tr>
<td><strong>Physical activity questions n(%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practiced some sport in the past</td>
<td>34(45)</td>
<td>34(49)</td>
</tr>
<tr>
<td>Practiced strength exercises in the past</td>
<td>6(8)</td>
<td>5(7)</td>
</tr>
</tbody>
</table>
Figure 2.3: The study flow chart.
Primary outcome

**Dual task costs of walking**

Table 2.2 demonstrates results of the dual task costs of walking, excluding outliers. The results of sensitivity analyses [93, 97] in addition to the primary intention-to-treat analyses where outliers are included, and the participants are analysed in the group where they were initially allocated, are reported in an additional file of this manuscript (see *Additional file 2.1* at the end of the Chapter 2).

DTC preferred speed: Analyses of the DTC at preferred walking speed revealed a significant difference from pre- to post-test for velocity, step time and step length (Table 2.2). There was a significant interaction for step length ($F(1,174)=4.94, p=0.028, \eta^2=0.028$), in favour of SBC.

DTC fast speed: The DTC at fast walking speed showed significant differences between pre- and post-test, again for velocity, step time and step length (Table 2.2). There were significant interactions in favour of SBC (step length: $F(1,166)=6.14, p=0.009, \eta^2=0.040$; SD of step length: $F(1,166)=6.14, p=0.014, \eta^2=0.036$).

**Secondary outcomes**

**Physical performance measure**

The SPPB resulted in a large significant difference over time between pre-test and post-test $F(1,177)=227.6, p<0.001, \eta^2=0.563$: Participants improved their balance, gait initiation, and chair rise performance from pre- (SB: 7.33±2.59 points; SBC: 7.31±2.61 points) to post-test (SB: 9.24±2.30 points, SBC: 9.55±1.90 points). There was no significant main effect of group ($p=0.661$) and no significant interaction effect ($p=0.213$), suggesting that SPPB performance and the improvements were similar in both groups at all time-points.

The ETGUG total time showed a significant difference over time: pre- and post-test $F(1,175)=77.8, p<0.001, \eta^2=0.308$, a trend to both a significant effect of group ($p=0.052$) and an interaction effect ($p=0.054$). Participants improved their performance from pre-test (SB: 25.86±17.11s; SBC: 30.53±17.48s) to post-test (SB: 21.10±12.09s; SBC: 24.63±11.82). When analysing the component tasks of the test separately, a significant interaction effect $F(1,166)=9.16, p=0.003, \eta^2=0.052$ emerged for ‘gait initiation’. While SBC significantly improved from pre- (2.61±2.18s) to post-test (2.12±1.54s), there was no change for SB (pre-test: 1.89±1.23s; post-test: 2.11±2.22s).

**Simple reaction time**

There was a significant effect of training on simple reaction times of both hands and feet (Table 2.3), with both groups showing decreased RT. Between-groups comparison revealed a significant difference between the groups for the right foot ($F(1, 180)=5.863, p=0.016, \eta^2=0.032$) and no interaction.
Table 2.2: Dual task costs of walking of SB and SBC from pre- to post-test, between-groups differences and interaction effects.

<table>
<thead>
<tr>
<th>Conditions Parameters</th>
<th>SB group (n=77)</th>
<th>SBC group (n=74)</th>
<th>pre-post differences (both groups)</th>
<th>between-groups differences</th>
<th>interaction effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (mean±SD)</td>
<td>Post-test (mean±SD)</td>
<td>Pre-test (mean±SD)</td>
<td>Post-test (mean±SD)</td>
<td>P_within/η²</td>
</tr>
<tr>
<td>DTC preferred</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (%)</td>
<td>13.9±17.8</td>
<td>12.2±15.0</td>
<td>17.5±18.4</td>
<td>11.0±17.5</td>
<td>0.002* / 0.051</td>
</tr>
<tr>
<td>Step time (%)</td>
<td>12.0±25.2</td>
<td>9.6±14.4</td>
<td>31.3±88.7</td>
<td>10.0±18.7</td>
<td>0.018* / 0.033</td>
</tr>
<tr>
<td>Step length (%)</td>
<td>6.6±9.0</td>
<td>6.6±8.4</td>
<td>7.4±9.7</td>
<td>4.4±9.5</td>
<td>0.025* / 0.028</td>
</tr>
<tr>
<td>SD step length (%)</td>
<td>28.7±53.2</td>
<td>27.9±54.2</td>
<td>24.7±50.4</td>
<td>18.0±51.7</td>
<td>0.426 / 0.004</td>
</tr>
<tr>
<td>DTC fast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (%)</td>
<td>26.5±13.2</td>
<td>21.9±9.0</td>
<td>28.6±13.3</td>
<td>22.7±13.1</td>
<td>&lt;0.001* / 0.126</td>
</tr>
<tr>
<td>Step time (%)</td>
<td>23.1±24.5</td>
<td>17.2±10.1</td>
<td>18.8±12.7</td>
<td>17.5±17.2</td>
<td>0.035* / 0.028</td>
</tr>
<tr>
<td>Step length (%)</td>
<td>10.8±8.5</td>
<td>10.3±6.7</td>
<td>13.1±8.5</td>
<td>9.8±8.3</td>
<td>0.001* / 0.073</td>
</tr>
<tr>
<td>SD step length (%)</td>
<td>17.1±34.9</td>
<td>50.3±150.1</td>
<td>25.1±54.7</td>
<td>20.1±43.2</td>
<td>0.311 / 0.006</td>
</tr>
</tbody>
</table>

Notes: * = significant within-groups differences pre-post (P_within ≤ 0.05) & significant interactions of the groups (P_interaction ≤ 0.05); * = trends to significant within-groups differences pre-post (0.05 ≥ P_within ≤ 0.10), calculated with ANOVA. Abbreviations: DTC; dual task costs, η²: effect size η²=.01; small effect, η²=.06; moderate effect, η²=.14; large effect.
Executive functions

Improvements over time of both parts of the trail making test (A and B) were significantly affected by training (Table 2.3). There was no difference between SB and SBC and no interaction for this parameter.

Divided attention

The reaction times of the test program for divided attention were separately reported for the upper and the lower stimuli channel. There was a significant training related improvement over time in reaction time of both the upper and the lower channel (Table 2.3), and a significant interaction for the upper channel (F(1,180)=5.243, p=0.023, η²=0.028), in favour of SBC. Analysis of the number of missed answers revealed significant improvements over time for the groups together and a significant interaction for the upper channel (F(1,180)=11.839, p=0.001, η²=0.062), in favour of SBC.

Fear of falling

There was a significant effect of training from pre- to post-test for FES-I (Table 2.3) for the whole group. No differences were observed between SB and SBC and there was no interaction.

Table 2.3: Pre- and post-test performance for SB and SBC, differences between groups and interaction effects.

<table>
<thead>
<tr>
<th></th>
<th>SB group</th>
<th>SBC group</th>
<th>pre-post differences (both groups)</th>
<th>between-groups differences</th>
<th>interaction effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pre-test (mean ± SD)</td>
<td>post-test (mean ± SD)</td>
<td>pre-test (mean ± SD)</td>
<td>post-test (mean ± SD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple RT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT right hand</td>
<td>362.7±94.8</td>
<td>300.9±57.3</td>
<td>383.0±129.4</td>
<td>318.2±69.0</td>
<td>&lt;0.001* / 0.323</td>
</tr>
<tr>
<td></td>
<td>389.0±68.8</td>
<td>298.4±55.0</td>
<td>374.4±109.6</td>
<td>318.2±74.6</td>
<td>&lt;0.001* / 0.339</td>
</tr>
<tr>
<td>RT left hand</td>
<td>423.5±119.3</td>
<td>345.9±96.7</td>
<td>472.5±218.1</td>
<td>380.9±101.1</td>
<td>&lt;0.001* / 0.273</td>
</tr>
<tr>
<td>RT right foot</td>
<td>410.1±110.0</td>
<td>354.3±183.4</td>
<td>442.2±158.7</td>
<td>370.0±82.8</td>
<td>&lt;0.001* / 0.261</td>
</tr>
<tr>
<td>RT left foot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fear of falling</td>
<td>25.4±8.0</td>
<td>22.8±7.0</td>
<td>26.8±9.6</td>
<td>24.6±8.5</td>
<td>&lt;0.001* / 0.159</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.157 / 0.011</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.637 / 0.001</td>
</tr>
<tr>
<td>Executive functions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMT A</td>
<td>83.4±51.4</td>
<td>71.2±47.3</td>
<td>81.5±51.3</td>
<td>69.5±43.4</td>
<td>&lt;0.001* / 0.143</td>
</tr>
<tr>
<td></td>
<td>101.4±209.7</td>
<td>907.4±211.3</td>
<td>101.2±25.0</td>
<td>889.8±204.9</td>
<td>&lt;0.001* / 0.292</td>
</tr>
<tr>
<td>TMT B</td>
<td>188.5±73.0</td>
<td>166.3±75.0</td>
<td>189.5±78.8</td>
<td>164.4±76.9</td>
<td>&lt;0.001* / 0.207</td>
</tr>
<tr>
<td></td>
<td>10.7±4.6</td>
<td>10.1±5.0</td>
<td>13.3±5.9</td>
<td>10.0±5.5</td>
<td>&lt;0.001* / 0.082</td>
</tr>
<tr>
<td></td>
<td>13.5±5.8</td>
<td>11.5±5.7</td>
<td>15.0±7.2</td>
<td>11.4±6.2</td>
<td>&lt;0.001* / 0.161</td>
</tr>
<tr>
<td>Divided attention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT upper channel</td>
<td>940.1±170.0</td>
<td>885.7±169.9</td>
<td>1014.0±209.7</td>
<td>907.4±211.3</td>
<td>&lt;0.001* / 0.217</td>
</tr>
<tr>
<td></td>
<td>976.7±181.5</td>
<td>893.1±169.2</td>
<td>1012.3±25.0</td>
<td>889.8±204.9</td>
<td>&lt;0.001* / 0.292</td>
</tr>
<tr>
<td>RT lower channel</td>
<td>10.7±4.6</td>
<td>10.1±5.0</td>
<td>13.3±5.9</td>
<td>10.0±5.5</td>
<td>&lt;0.001* / 0.082</td>
</tr>
<tr>
<td>MA upper channel</td>
<td>13.5±5.8</td>
<td>11.5±5.7</td>
<td>15.0±7.2</td>
<td>11.4±6.2</td>
<td>&lt;0.001* / 0.161</td>
</tr>
<tr>
<td>MA lower channel</td>
<td>25.4±8.0</td>
<td>22.8±7.0</td>
<td>26.8±9.6</td>
<td>24.6±8.5</td>
<td>&lt;0.001* / 0.159</td>
</tr>
<tr>
<td></td>
<td>300.9±57.3</td>
<td>298.4±55.0</td>
<td>374.4±109.6</td>
<td>318.2±74.6</td>
<td>&lt;0.001* / 0.339</td>
</tr>
<tr>
<td></td>
<td>423.5±119.3</td>
<td>345.9±96.7</td>
<td>472.5±218.1</td>
<td>380.9±101.1</td>
<td>&lt;0.001* / 0.273</td>
</tr>
<tr>
<td></td>
<td>410.1±110.0</td>
<td>354.3±183.4</td>
<td>442.2±158.7</td>
<td>370.0±82.8</td>
<td>&lt;0.001* / 0.261</td>
</tr>
<tr>
<td></td>
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| Notes: * = significant within-groups differences pre-post (pwithin ≤ 0.05), significant between-groups differences (pbetween ≤ 0.05) & significant interactions of the groups (pinteraction ≤ 0.05); ** = trends to significant within-groups differences pre-post (0.05 ≥ pwithin ≤ 0.10) & trends to significant interactions of the groups (0.05 ≥ pinteraction ≤ 0.10); calculated with ANOVA. Abbreviations: n²: effect size n²=0.01; small effect, n²=0.06; moderate effect, n²=0.14; large effect; RT: reaction time, FES-I: Falls Efficacy Scale-International, MA: missed answers.
Falls

An average of 0.052 ± 0.08 falls per month for SB and 0.071 ± 0.1 falls per month for SBC were retrospectively (6 months) observable. In the intervention period 0.01 ± 0.047 falls for SB and 0.012 ± 0.073 for SBC occurred (3 months), and within 12 months following the intervention 0.022 ± 0.040 falls for SB and 0.046 ± 0.070 for SBC occurred (Figure 2.4). Fall rate was reduced by 81% for SB and 83% for SBC during the intervention training period, and by 58% and 46% for SB and SBC respectively at 12 months follow-up. Effect of time was highly significant from retrospective-to-training $F(1,177)$=44.73, $p<0.001$, $\eta^2=0.202$, from retrospectively-to-prospectively $F(1,177)$=16.844, $p<0.001$, $\eta^2=0.087$, and over the whole time frame retrospectively-training-prospectively $F(1,177)$=28.733, $p<0.001$, $\eta^2=0.140$. There was no significant interaction between the groups for the falls parameter, however, there were significant between groups differences (retrospectively-to-prospectively: $F(1,177)$=5.569, $p=0.019$, $\eta^2=0.031$; retrospectively-training-prospectively: $F(1,177)$=4.202, $p=0.042$, $\eta^2=0.023$).

Figure 2.4: Falls per month for SB and SBC.

Legend: SB = - - - and SBC = = = prior to study commencement (1; 6 months), during the study (2; 3 months), and after study completion (3; 12 months).
2.4 Discussion

This randomized controlled trial examined whether a twelve-week strength-balance exercise regimen, supplemented with computerised cognitive training, would lead to greater improvements in dual task costs of gait, in physical and in cognitive performance compared to strength-balance exercise alone. The study also aimed at exploring the effect on fear of falling and fall rate. We expected improvements in measures of dual task gait, executive functions, and in particular – divided attention, mainly in the strength-balance-cognitive group. In addition, we hypothesized observing different levels in falls behaviour between the groups. Although both groups attained improvements in physical and cognitive performance, the results suggest positive interaction effects for dual task costs of walking and divided attention, in favour of SBC. The findings support the notion that it is advantageous to combine physical and cognitive training into clinical practice. The combination seems to have a positive influence on older adults walking abilities under dual task conditions compared to more traditional exercise [67].

Findings from a systematic review demonstrate that a strength and balance exercise regimen is able to preserve or enhance walking abilities [62]. The goal of this study, however, was to optimize walking under dual task conditions as expressed through minimized DTC of walking. Previous findings suggest that resistance training alone has the potential to improve cognitive functions, and particularly executive functions [30, 98]. However, the results of studies with similar groups performing similar strength-balance training, revealed no changes in DTC of walking [99, 100]. When training in combination with video games such improvements are believed achievable [101]. We demonstrated in this study an additional effect of our cognitive program in the sense that the DTC of walking were minimized especially in the SBC group. The significant interaction effects observed for step length and step length variability favouring SBC extends previous work providing evidence for an association between DTC of step length during fast walking and divided attention [60] into a causal relation. That the group training cognitive skills improved on this measure is reasonable since changes in brain structure associate with reduced gait speed that partly results from shorter steps [102]. Interventions focusing on brain health seem, therefore, important when the aim is to improve gait [102]. The assumption that older adults that fall show shorter step lengths and higher variability compared to non-fallers [103] strengthens the importance of the improvements in these walking parameters of SBC. The results of our study are in line with reviews and intervention studies supporting the combination of cognitive and motor programs to attain beneficial effects on DTC of walking compared to more traditional interventions [46, 67, 101]. With a thrice-weekly ten-minute cognitive training focusing on alertness, selective and divided attention, combined with strength-balance exercises, DTC of walking can be minimized.
We found a significant improvement in SPPB scores within both groups reflecting enhanced lower extremity function and walking ability [104]. On average, a person that reaches less than 10 points on the SPPB is almost 3.5 times more susceptible to suffer from mobility disability than a person scoring the maximum of 12 points [104]. At the beginning of training both the SB and SBC groups reached a mean score of less than 7.5 points, however, they both increased towards 9.3 resp. 9.5 points. Improved gait initiation was only observed for SBC. The fact that this intervention impacted on gait initiation is important. Gait initiation is frequently repeated during daily activities, leading to accidental falls during the step initiation phase in people with deficits in balance control [105] and relates to the quality of fronto-striatal brain connections [106]. Stable and efficient mechanisms of the central nervous system (CNS) are required for the control of posture during gait initiation. These mechanisms are complex and require efficient peripheral sensory detection and afferent nerve conduction, followed by central neural processing and efferent nerve conduction [107]. Within older adults, there seems to be a loss of efficiency in these mechanisms leading to falls during gait initiation [108]. It can be hypothesized that by the use of the computerised cognitive training acquired skills led to transfer effects in gait initiation.

The link between cognitive functioning, gait, and the potential for falls was previously established [3]. Specifically, poor EF and attention control, one of the core EFs [109], seemed to be related to fall risk and mortality [51, 52, 110]. Although both our groups were able to improve cognitive functioning as expressed through improvements in reaction time as well as EF, only the group receiving the additional computerized cognitive intervention improved in divided attention skills. Thus, in line with other authors, we demonstrated that falls prevention programs have a positive impact on EF [111], however, the findings also support the assumption that specificity of training applies to these specific EFs. EFs are trainable by repeated practice and with a progressive exercise intensity design at any age [109]. Where the physical training group improved more global measures of cognitive functioning, only the combined training group exhibited training specific improvements.

The non-significant interactions for several cognitive and physical parameters between the groups indicate that both groups improved equally. This seems reasonable because previous research literature describing promotion of resistance training indicated improved cognitive functioning, enhanced functional brain plasticity [30], and altered trajectory of cognitive decline in older adults with probable cognitive deteriorations [112]. Increased performance in selective attention and executive cognitive function for example – achieved through resistance training - has been related to higher walking velocity [98], which in turn relates to improved EFs [113]. Reductions in walking velocity, in general, correlate with declined cognitive factors (e.g. attention and psychomotor speed), falls, and mortality [114-117].
The clinical relevance of improved divided attention might be influencing falls rate in elderly because this function was previously shown to be related to gait and to falls [60]. Our findings, however, reveal no additional effect of training this specific cognitive aspect when it comes to falls. Both training groups improved on the falls parameter with similar magnitudes. Fall rate was reduced in both groups by more than 80% during the intervention period, and by more than 40% during the following 12 months. These results are similar or superior to other interventions incorporating strength and balance exercises [118] and present a clinically relevant reduction in fall risk. Furthermore, our findings confirm the findings of a systematic review including 54 randomised controlled trials showing that exercise programs that combine strength and balance training of sufficient quality can reduce falls with 38% [119]. Our findings compare favourable to other studies that added training components in the sense that the addition of a cognitive component did not lead to a lower effect on falls rate [119]. Unsurprisingly, the lowest fall rate was observed during the study, when compliance was warranted, considering the link between executive functions, gait and falls, and the assumption that poor treatment adherence is related to poor EFs [109]. The fall rate was higher after study termination, however, still significantly lower than prior to study commencement.

Although not more effective in terms of fall events observed, applying a combination of cognitive-motor training might be advantageous to move safer in challenging environments [46, 120] and, therefore, reduces fall risk. We assume this given the additional positive effect of the cognitive intervention on divided attention. To react adequately under circumstances where attention is divided is an important requirement in most activities of daily life. Therefore, with the focus on physical and cognitive improvements in complex situations and the execution of attention-demanding tasks, strength-balance training should be combined with cognitive training.

The results of the sensitivity analysis for DTC of preferred walking were not robust to the exclusion of outliers and changed when they were excluded. The primary analysis, shown in the Additional file 1, revealed a statistical interaction effect for DTC of velocity favouring SBC, which was not significant in the analysis where outliers were excluded. The non-significant interaction for SD of step length in our analysis with the outliers included demonstrated a trend to statistical significance in the primary analysis. The differences in mean values and standard deviations of the groups observable between the analyses implies that the results of the primary analysis were affected by the outliers [93]. Removing these participants from the analysis was legitimate to avoid bias and to minimize random error [94, 121].

In this trial, the dual task costs of walking were assessed. Not, however, the cognitive dual task costs while walking. To assess the possible effects of our program on cognitive functions we resorted to specific cognitive tests. In our trial the main interest was the effect of an attention-demanding task...
on gait performance. Participants were instructed not to prioritize one task (walking) over the other (calculating) but to try and perform both as good as possible at the same time. The ability of counting backwards was not used as an outcome measure to determine the effect of training on cognitive performance, thus, causing the reliability of this instruction for reproduction purposes being of lesser importance for our study. The only reason for using the counting task was to disturb the gait pattern of our subjects and, by doing that, determine the dual task costs of walking. Allowing both gait and cognitive task performance to vary has previously been shown to better represent the dynamics of daily living tasks of older adults [122, 123] and is, furthermore, a reliable procedure to determine dual task costs of walking even in older adults with mild cognitive impairments [124].

An obvious strength of our study is the rather large sample size minimising the chance of type I and II errors. This study, therefore, reveals credible estimates for these measures because it is sufficiently powered. However, when evaluating the validity of a study it is important to consider both the clinical and statistical significance of the parameters [125]. Researchers and clinicians should not focus solely on small P-values to decide whether a treatment is clinically useful, but should also consider the magnitudes of treatment differences [125]. The majority of the between groups comparisons for fast walking show small-to-moderate magnitudes of treatment differences and should, accordingly, lead to a cautionary interpretation. The relationship between physical and cognitive training research and its effect on gait in older adults requires further exploration. A possible explanation for these small-to-moderate effect sizes might be caused by the implementation of cognitive training. The advantages of computerized training programs are documented in recent work [67, 126]. In our program the motor and the cognitive part were offered as separate entities consecutively. There is increasing evidence, however, that simultaneously performed cognitive-motor programs are more effective in influencing both cognitive and motor functioning [34, 127]. The individual and combined effects of physical and mental exercise interventions reported cognitive benefits to be larger with the combined cognitive and physical training paradigms [128, 129].

**Limitations**

This study has several limitations. As already discussed the small-to-moderate effect sizes should be considered when interpreting data. The small magnitudes of the interaction effects give rise to possible bias in our research design [130]. We treated the dropouts of this study as a part of the treatment group to which they were assigned even if they did not receive the full intervention. Intention to treat is a recommended approach to several types of non-adherence to the study protocol [131], able to reduce the potential drop out bias effect [132]. We replaced missing data with the mean values of the groups, thus allowing complete case analysis. A drawback of this approach is
reduced variability and weakening of covariance and correlation estimates in the data. We excluded outliers with a trimming method, which is a method applied when good reasons to believe that the subject(s) with the extreme value(s) was/were not from the same population [94] exist. The intention to treat analysis was not robust for some values of gait analysis with the outliers included. In particular the results for the SD for variability data (expressed as SD of step length) were different between the sensitivity analyses. A potential reason for outliers in the datasets is that the participants differed in baseline characteristics. One of our inclusion criteria was “able to walk 20 meters with or without walking aid”, thus, all people able to walk were included, independent of their walking characteristics (e.g. walking velocity or instability).

To move 4 participants from SBC to SB was based on a similar consideration in order to avoid a random error, and has, potentially, the same origin [121]: We only registered “vision problems” in the baseline demographics of the participants. The ability to follow a game on a computer screen was not mentioned as inclusion criteria, which might be considered for future studies.

Furthermore, the study contained the training of three different dimensions of attention as cognitive training. It warrants further research to examine which program/s was/were the reason for the examined results. An obvious limitation was that the test for divided attention was too difficult for several participants, leading to floor effects and multiple losses for the test. The interaction effect for measures of divided attention should also be interpreted cautiously, since magnitude of treatment differences is small-to-moderate.

**Conclusions**

Both strength-balance and strength-balance-cognitive training enhanced physical performance, reaction time, executive functions, and reduced fall rate and fear of falling substantially. Only strength-balance-cognitive training reduced dual task costs of walking and improved gait initiation, and divided attention was merely improved by the cognitive-motor group. The larger improvements in divided attention and dual task walking highlight that an exercise program aiming at improving tasks that require attentional control should include a cognitive challenging element. This study may constitute a reference for further studies in the topic of fall prevention in older adults with the aim to improve physical performance under dual task conditions, and to reduce falls. Future studies are advised to compare different types and modes of exercise where different specific perceptual and cognitive demands are to be considered in the research design; e.g. complementary motor and cognitive training paradigms against integrative motor-cognitive training approaches.

**Competing interests**

The authors declare that they have no competing interests.
Authors’ contributions

EVHR participated in the conception and the design, drafted the manuscript, participated in the critical revision of the manuscript for its content and approved the final version. EDDB participated in the conception and the design, drafted the manuscript, participated in the critical revision of the manuscript for its content and approved the final version. Both authors read and approved the final manuscript.

Acknowledgements

We gratefully acknowledge the support from the directors of the homes-for-the-aged who gave us the opportunity to perform the intervention in their facility. We acknowledge Rolf van de Langenberg, PhD, for statistical advice.
The Additional file 2.1 demonstrates the dual task costs of walking of SB and SBC from pre- to post-test, between-groups differences and interaction effects for the intention to treat analysis. All outliers are included. The participants that were reallocated from the SBC to the SB group (due to vision problems) are analysed as participants from SBC group (as initially allocated).

### Additional file 2.1: Sensitivity analysis for dual task costs of walking

<table>
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<tr>
<th>Conditions</th>
<th>Parameters</th>
<th>SB group Pre-test (mean±SD)</th>
<th>SB group Post-test (mean±SD)</th>
<th>SBC group Pre-test (mean±SD)</th>
<th>SBC group Post-test (mean±SD)</th>
<th>p_within/η²</th>
<th>p_between/η²</th>
<th>p_interaction/η²</th>
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<tr>
<td><strong>DTC preferred</strong></td>
<td>Velocity (%)</td>
<td>13.0±16.8</td>
<td>12.1±15.1</td>
<td>18.3±19.2</td>
<td>11.2±17.3</td>
<td>0.002* / 0.051</td>
<td>0.330 / 0.005</td>
<td>0.019* / 0.031</td>
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<td>Step time (%)</td>
<td>13.6±33.4</td>
<td>11.2±26.6</td>
<td>33.2±88.2</td>
<td>11.9±23.2</td>
<td>0.014* / 0.034</td>
<td>0.083* / 0.017</td>
<td>0.053* / 0.021</td>
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<td>Step length (%)</td>
<td>5.8±9.7</td>
<td>5.9±8.8</td>
<td>7.8±10.0</td>
<td>4.8±9.9</td>
<td>0.033* / 0.026</td>
<td>0.733 / 0.001</td>
<td>0.021* / 0.030</td>
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<td>SD step length (%)</td>
<td>30.5±57.8</td>
<td>28.5±54.7</td>
<td>69.4±225.1</td>
<td>24.0±60.0</td>
<td>0.058* / 0.021</td>
<td>0.206 / 0.009</td>
<td>0.082* / 0.017</td>
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<td><strong>DTC fast</strong></td>
<td>Velocity (%)</td>
<td>25.7±12.1</td>
<td>21.9±9.1</td>
<td>29.3±14.1</td>
<td>22.7±12.9</td>
<td>&lt;0.001* / 0.128</td>
<td>0.157 / 0.012</td>
<td>0.18 / 0.011</td>
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<td>Step time (%)</td>
<td>21.8±27.3</td>
<td>16.8±12.8</td>
<td>28.7±31.7</td>
<td>21.7±24.4</td>
<td>0.003* / 0.052</td>
<td>0.077* / 0.019</td>
<td>0.606 / 0.002</td>
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<td>Step length (%)</td>
<td>10.7±8.5</td>
<td>10.3±6.7</td>
<td>13.4±8.7</td>
<td>10.2±8.9</td>
<td>0.001* / 0.068</td>
<td>0.263 / 0.008</td>
<td>0.008* / 0.042</td>
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<td>SD step length (%)</td>
<td>16.3±35.3</td>
<td>51.9±149.5</td>
<td>39.3±107.7</td>
<td>21.2±42.7</td>
<td>0.18 / 0.005</td>
<td>0.723 / 0.001</td>
<td>0.007* / 0.043</td>
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**Notes:** * = significant within-groups differences pre-post (p_within ≤ 0.05) & significant interactions of the groups (p_interaction ≤ 0.05); ** = trends to significant within-groups differences pre-post (0.05 ≥ p_within ≥ 0.10), calculated with ANOVA. Abbreviations: DTC, dual task costs; η²: effect size η²=0.1; small effect, η²=0.06; moderate effect, η²=0.14; large effect.
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Chapter 3

Motivating and assisting physical exercise in independently living older adults: A pilot study

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Published in International Journal of Medical Informatics 82 (2013):5 325-334
Abstract

**Background:** With age reaction time, coordination and cognition tend to deteriorate, which may lead to gait impairments, falls and injuries. To reduce this problem in elderly and to improve health, well-being and independence, regular balance and strength exercises are recommended. However, elderly face strong barriers to exercise.

**Objective:** We developed Active Lifestyle, an IT-based system for active and healthy aging aiming at improving elderly's balance and strength. Active Lifestyle is a proactive training application, running on a tablet, which assists, monitors and motivates elderly to follow personalized training plans autonomously at home, while integrating them socially. The objective is to run a pilot study to investigate: (i) the feasibility of assisting the autonomous, physical training of independently living elderly with the Active Lifestyle system, (ii) the adherence of the participants to the training plans, and (iii) the effectiveness of the motivation instruments built into the system.

**Methods:** After three introductory meetings, 13 elderly adults followed personalized two-weeks strength and balance training plans using the Active Lifestyle app autonomously at home. Questionnaires were used to assess the technological familiarity of the participants, the feasibility aspects of the physical intervention, and the effectiveness of the motivation instruments. Adherence to the exercise plan was evaluated using the performance data collected by the app during the study.

**Results:** A total of 13 participants were enrolled, of whom 11 (85%) completed the study (mean age 77 ± 7 years); predominantly females (55%), vocational educated (64%), and their past profession requiring moderate physical activity (64%). The Active Lifestyle app facilitated autonomous physical training at home (median = 7 on a 7-point Likert scale), and participants expressed a high intention to use the app also after the end of the study (median = 7). Adherence with the training plans was 73% (89% on the balance exercises and 60% on the strength exercises). The outcome from our questionnaires showed that without the app the participants did not feel motivated to perform exercises; with the support of the app they felt more motivated (median = 6). Participants were especially motivated by being part of a virtual exercise group and by the capability to automatically monitor their performance (median = 6 for both).

**Conclusions:** This study shows that the Active Lifestyle app prototype has valuable potential to support physical exercise practice at home and it is worthwhile to further develop it into a more mature system. Furthermore, the results add to the knowledge base into mobile-based applications for elderly, in that it shows that elderly users can learn to work with mobile-based systems. The Active Lifestyle app proved viable to support and motivate independently living elderly to autonomously perform balance and strength exercises.

**Keywords:** Physical Exercises, Motivation, Elderly, Tablet, Mobility, Healthcare
3.1 Background

Health status is an important indicator of quality of life among older persons [1, 2]. Functional performance, chronic conditions, and diseases, which directly influence fitness, are related to the perceived health among middle-aged and older adults [2-4]. Chronic diseases are, furthermore, leading causes of death and disability in both developed and developing countries [5, 6]. Inactivity is at the origin of several chronic diseases [7]. Regular physical activity or exercise substantially prevents the development and progression of most chronic degenerative diseases [8-10], is of benefit to frail and older persons, and is the only therapy found to consistently improve sarcopenia, physical function, cognitive performance and mood in older adults [11]. For older people, a sedentary lifestyle also increases the risk of falls, whereas physically active older people have a reduced risk of falls with injuries [12-14]. In summary, it is evident that to increase older adults’ quality of life and fitness, we need to encourage the elderly to become more physically active [15, 16].

There are a variety of barriers that make it hard for elderly to maintain or increase their physical activity level. Neighborhoods and communities may be poorly designed or perceived as being unsafe, thus preventing elderly from leaving home [17, 18]. Older adults may have trouble getting to specialized facilities (e.g., community center for the aged) and physical training programs offered in such institutions [17, 18]. General health care professionals (e.g., nurses, family physicians) may lack the time or expertise to address problems of physical inactivity among their older patients, and often lack information about quality programs, training materials, and how to make referrals to community resources [19]. Furthermore, elderly often express the desire for training support at home [20].

Specialized healthcare professionals (i.e., sport medicine, gerontologists, physiotherapists and human movement scientists) strongly recommend physical training programs that focus on muscle strength and balance [21] to promote health, well-being, and functional independence of the elderly. Structured exercise training has a positive impact on older adults and may be used for the management of frailty [22-24]. Home environmental interventions based on different forms of assistive technology devices have, in this context, the potential to overcome some of the barriers to start training and maintain physical independence for independent living elderly [25]. However, the effectiveness of such an approach has not yet been demonstrated to a large extent. Modern exercise equipment may not always be suitable for elderly individuals, who might be concerned about the intensity of training sessions and may rather express to have a preference for more traditional therapy approaches [26]. New treatments usually have to go through a series of phases to test
whether they are feasible, safe and effective [27]. It seems, therefore, necessary to perform a pilot study to assess the feasibility of applying assistive technology devices in an elderly population with the aim to encourage performance of targeted physical exercise. Findings of such a study can inform a larger scale main Phase III study [27].

The objective of this study is to run a Phase II pilot study according to the model for complex interventions advocated by the British Medical Research Council [28] with an iPad-based app (short for \textit{application}) called Active Lifestyle, a software for the autonomous physical training of strength and balance for independently living elderly. We aim to investigate (i) the feasibility of assisting the autonomous, physical training of independently living elderly with the Active Lifestyle system, (ii) the adherence of the participants to the Active Lifestyle training plans, and (iii) the effectiveness of the system’s motivation instruments.

3.2 Methods

The \textit{ActiveLifestyle} app

\textit{ActiveLifestyle} is a pro-active software for \textit{active and healthy aging}, assisting and monitoring elderly during autonomous home-based physical workouts [29, 30]. The interface is designed to be simple and avoid frustration generated by the inability to use technology, and uses persuasive strategies to motivate elderly users to keep a routine of physical exercises.

The app supports strength and balance training plans. The \textit{strength} training should be done twice a week; it starts with 6 warm-up exercises, and is followed by 9 strength and 3 stretching exercises. There is a minimum number of sets (1–3) and repetitions (15–30) for each exercise. Some exercises also require the use of weights (2–6 kg). The \textit{balance} training should be done five days per week. Each session is composed of 3 exercises, in which the elderly repeatedly (1–3 times) holds a certain position for several seconds (15–30 s). The training program follows best practices recommendations [31] and generally accepted training principles (e.g., is progressive in nature) [32]. An example of exercises is illustrated in \textit{Figure 3.1} and the training procedure is presented in \textit{Figure 3.2} and in a video [33].
Figure 3.1 (a) and (b) illustrate the Chair stand exercise (strength); (c) shows the One leg stand exercise (balance).

Figure 3.2 Main screenshots of the training plan procedure.
To motivate the elderly, the app supports *individual* and *social* motivation instruments [34].

**Individual motivation** strategies aim at convincing someone to do something by making it enjoyable for this person, independently of any social pressure. The app specifically supports:

- **Conditioning through positive and negative reinforcement**: that is, immediately offering a reward/praise after an expected behavior to encourage the behavior and to increase the probability that it happens again, or reprimanding whenever undesired behavior happened aiming to decrease the probability of a reoccurrence of the behavior. We use metaphors for positive and negative reinforcement, i.e., a flower that grows whenever a session is completed (i.e., positive reinforcement) and that has a mood status that varies according to the person’s daily compliance to the plan (i.e., positive and negative reinforcement, if the person performs the exercise the flower is happy, otherwise it is sad) (see Figure 3.3a). The flower does not die or become ugly to avoid possible negative reactions on the users;

![Figure 3.3. Individual motivation instruments based on a flower metaphor.](image)

- **Goal-setting**: establishing specific, measurable, achievable, and time-targeted goals. We communicate the goal by anticipating the best achievable growth of the flower metaphor (Figure 3.3b);

- **Self-monitoring**: allowing people to monitor themselves and to modify their attitudes and behaviors. Coloring the respective flower growth stages reflects progress toward the goal (Figure 3.3b).

**Social motivation** strategies are built on social psychology. An individual’s social network (other people participating in the same training) is the source of motivation, e.g., Active Lifestyle uses:

- **Comparison**: allowing a person to compare similarities and differences between two or more parties, people tend to keep equality in their relationships. Whenever a person completes a workout session, an automatic message is posted on a *Bulletin Board* informing the training
community (i.e., other users following the same training plans). The message also shows the status of the individual’s flower metaphor.

- **External monitoring**: allowing one party to monitor the behavior of another party to modify behavior in a specific way. In Active Lifestyle, healthcare and IT experts have access to data on performance and compliance toward the plan. The elderly have access to their own flowers and to that of their training partners, so that they can monitor their progress toward the plan too.

**Sample**

Participants were 70 years old or older; able to walk independently with or without walking aids; able to follow instructions spoken in German, English, or Italian; and with no severe illness, cognitive impairment, progressive neurological diseases, stroke, severe cardiac failure, or high blood pressure.

**Setting**

Participants were recruited by convenience sampling (i.e., any subjects willing to participate and matching the selection criteria were accepted) from the “Informationsstelle fuer Altersfragen” in Wollerau, Switzerland. This institution, dedicated to deliver services and information related to aging to the elderly population, issued 220 invitation letters, together with an information sheet outlining the research, inviting independently living elderly of the region to participate. Ethical approval for the study was obtained from the ETH Ethics Committee (EK 2011-N-64).

**Interventions**

During an initial meeting, all potential participants received information about the Active Lifestyle app and the study. Interested people provided their personal contact data. During a second meeting, participants were taught how to use the iPad and the app. To ease learning, user guides with written content, illustrations about the app and the iPad were provided. During a third meeting, participants were taught how to perform the balance and strength exercises supported by the app. The same day, they also signed the consent form and answered health and technology familiarity questions. At the end of this meeting, participants received one resistance band, one Pilates’ ball, and one pair of ankle weights (2 kg). iPads with 3G SIM-card were lent to the participants. The installed and delivered version of the app contained a predefined training plan community (people participating in the study).

After these three meetings, the participants started a two-week home-based balance and strength training. To settle possible remaining obscurities, an additional meeting was scheduled on the second
day of the training period. Contact information of our team members was provided to all participants in case of further obscurities or problems.

At the end of the two-weeks training period, a final meeting was held to conclude the study and collect the equipment previously lent. At this time, the participants answered questions regarding the perceived usefulness, usability, visual attractiveness, and the effectiveness of the motivation instruments of the app.

**Outcome measures**

The criteria for success, an important part of a pilot study [27], were based on the feasibility of the steps that need to take place as part of a main study and focused on recruitment, attrition and adherence to the exercise. Values for these parameters were compared with median rates in falls prevention interventions in community settings for clinical trials [35], where recruitment of 70% of the residents that are eligible for the training session, a 10% attrition rate, and 50% adherence to the individually targeted exercises were deemed acceptable.

For recruitment, we measured the inclusion rate – i.e. the proportion of participants invited to participate who enrolled into the study – and distinguished between those who refused, did not respond or who were willing but excluded (volunteered but did not meet the study inclusion criteria).

For attrition, we measured the number of participants lost at final follow-up.

For adherence to the intervention we recorded engagement with the intervention, e.g., compliance with all four strength and ten balance training sessions. Adherence was computed by Active Lifestyle during the intervention and stored in a central database.

Effectiveness of the motivation instruments built into the system was determined based on the participants’ feedback, collected with a 7-Point Likert Scale questionnaire at the end of the intervention.

**Statistical analyses**

Descriptive statistics were used to analyze the questionnaires.

**3.3 Results**

**Participant demographics**

Detailed information about the participant demographics is summarized in Table 3.1.
Table 3.1. Characteristics of the participants.

<table>
<thead>
<tr>
<th>Intervention (n = 11)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender, n (%)</td>
<td>6/11(54.5)</td>
</tr>
<tr>
<td>Mean/median age [range] (years)</td>
<td>77.2/76 [70–85]</td>
</tr>
<tr>
<td>Vocational education, n (%)</td>
<td>7/11(63.6)</td>
</tr>
<tr>
<td>Moderate physical activity in past profession, n (%)</td>
<td>7/11(63.6)</td>
</tr>
</tbody>
</table>

**Health questions, n (%)**
- Estimated good health: 7/11(63.6)
- Estimated middle balance: 5/11(45.5)
- Feeling daily pain: 5/11(45.5)
- Fell in the last six months\(^a\): 0/11(0)
- Leisure time walking at least twice a week: 11/11(100)
- Practiced some sport in the past: 7/11(63.6)
- Never practiced strength exercises: 9/11(81.1)
- Wanted to improve fitness: 7/11(63.6)

**Technology familiarity, n (%)**
- Frequently use ATMs: 9/11(81.8)
- Don’t use books on tape or CD: 5/11(45.4)
- Sometimes use cellphones: 6/11(54.5)
- Don’t use digital photography: 5/11(45.5)
- Don’t use electronic book readers: 5/11(45.5)
- Don’t use GPS: 5/11(45.5)
- Don’t use automatic kiosks: 6/11(54.5)
- Use a computer: 9/11(81.1)
- Between 1 and 5 h per week: 4/11(36.3)
- Use the Internet: 9/11(81.1)
- Between 1 and 5 h per week: 5/11(45.5)

\(^a\) A fall was defined as unintentionally coming to the ground or some lower level, excluding the consequence of sustaining a violent blow, loss of consciousness, or sudden onset of paralysis, such as during a stroke or epileptic seizure [36].

Because the rationale for performing this pilot was Process, which deals with the assessment of the feasibility of the steps that need to take place as part of a future main study, we consider feasibility, recruitment, retention and adherence rates as primary findings [27].

**Feasibility of the Active Lifestyle intervention**

A total of 220 information letters were sent. The first information session was held and visited by fourteen residents; all eligible and invited to participate. Thirteen residents consented to join the study resulting in 7% recruitment rate for the total sample frame. The inclusion rate – fourteen invited to participate; thirteen enrolled – was 93%.
Eleven elderly conducted the two-weeks training resulting in a 16% attrition rate. Two individuals were lost; one was disappointed about not receiving the iPad after the second meeting and the other because of Wi-Fi connection problems. For adherence to the intervention we had 73% compliance with all 14 trainings (89% for balance and 60% for the strength exercises). There were no reports on adverse events during the training.

**Effectiveness of the Active Lifestyle intervention**

Detailed information about the effectiveness of the Active Lifestyle app and the motivation instruments, as well as the usability aspects are summarized in Table 3.2.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Median (range)</th>
<th>Percentage agreed</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Active Lifestyle app facilitates the performance of strength and balance exercises autonomously at home.</td>
<td>7(6–7)</td>
<td>100</td>
</tr>
<tr>
<td><strong>Use intention</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would use the app again</td>
<td>7(6–7)</td>
<td>100</td>
</tr>
<tr>
<td>I would recommend the app to my friends and family.</td>
<td>6(6–7)</td>
<td>100</td>
</tr>
<tr>
<td><strong>Perceived usefulness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The videos assisted to properly perform the exercises.</td>
<td>7(6–7)</td>
<td>100</td>
</tr>
<tr>
<td>The sound alarm helped to remind me about the planned workout sessions</td>
<td>4(3–7)</td>
<td>45.4</td>
</tr>
<tr>
<td>The calendar was useful to make me aware about which kind of workout session I need to perform every day.</td>
<td>7(6–7)</td>
<td>100</td>
</tr>
<tr>
<td><strong>Motivation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I usually don’t feel motivated to perform physical exercises, the app helped me</td>
<td>6(3–7)</td>
<td>63.6</td>
</tr>
<tr>
<td>It was funny to me to carry out the strength and balance exercises</td>
<td>6(3–7)</td>
<td>90.9</td>
</tr>
<tr>
<td>I like the pictures of the flower</td>
<td>7(6–7)</td>
<td>100</td>
</tr>
<tr>
<td>I would prefer another picture instead of a flower</td>
<td>5(2–7)</td>
<td>54.5</td>
</tr>
<tr>
<td><strong>Individual motivation instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt motivated when I saw the plant growing due to my performance</td>
<td>6(4–7)</td>
<td>90.9</td>
</tr>
<tr>
<td>I felt motivated when I saw my progress on the bar.</td>
<td>6(4–7)</td>
<td>90.9</td>
</tr>
<tr>
<td>I felt motivated when I saw the emotional status of the flower</td>
<td>6(4–7)</td>
<td>63.6</td>
</tr>
<tr>
<td><strong>Social motivation instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It motivated me to be part of a training group and to know that other people did the same exercises</td>
<td>6(4–7)</td>
<td>90.9</td>
</tr>
<tr>
<td>I usually compared my flower with others on the Bulletin Board</td>
<td>5(2–7)</td>
<td>63.6</td>
</tr>
<tr>
<td>I felt motivated to perform the plan because I knew that I was being monitored</td>
<td>6(2–7)</td>
<td>63.6</td>
</tr>
<tr>
<td><strong>Usability</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The operation of the application was easy</td>
<td>6(5–7)</td>
<td>100</td>
</tr>
<tr>
<td>I was able to use the app</td>
<td>7(6–7)</td>
<td>100</td>
</tr>
<tr>
<td>I was able to write messages on the Bulletin Board.</td>
<td>4(2–7)</td>
<td>45.4</td>
</tr>
<tr>
<td>I was able to read messages from the Bulletin Board.</td>
<td>6(6–7)</td>
<td>100</td>
</tr>
<tr>
<td>I was able to send messages to a person (inBox).</td>
<td>6(4–7)</td>
<td>63.3</td>
</tr>
<tr>
<td>I was able to receive messages from a person (inBox)</td>
<td>6(4–7)</td>
<td>72.7</td>
</tr>
<tr>
<td>I was able to navigate through the messages posted on the Bulletin Board using the scroll.</td>
<td>7(4–7)</td>
<td>90.9</td>
</tr>
<tr>
<td>I felt nervous to use the app</td>
<td>3(1–7)</td>
<td>18.1</td>
</tr>
<tr>
<td>The application worked without any problems.</td>
<td>6(2–7)</td>
<td>72.7</td>
</tr>
</tbody>
</table>
All participants affirmed that *Active Lifestyle facilitates autonomous performance of balance and strength exercises*. This is confirmed by a high *intention to use* the app again or to *recommend* it to friends or family members (100%, range 6–7). Some participants verbally expressed their disappointment with the end of the training and the impossibility to continue training with it (the app is not yet commercially available).

Participants expressed a high *perceived usefulness* of the videos. According to some feedbacks, the videos are “absolutely great” and “very helpful.” Others stated “I adjusted my posture based on them” or “the exercises were easy with the videos”. One explanation for such high approval can be derived from the fact that most of the participants had never performed strength exercises before (82%).

The *Weekly Exercises Calendar* – a menu option that allows the user to check the planned workout sessions weekly – was considered useful by all users. The *sound alarm* was useful to few users only (46%).

**Effectiveness of the motivation instruments**

Most of the participants did not feel *motivated* performing physical exercises in general, however, they felt motivated with the Active Lifestyle app (64%) because it was fun to follow the exercises with the app (91%). Their mood after doing the exercises was relaxed (41%), happy (25%), tired (19%), uncertain (9%), exhausted (3%), unhappy (1%), bored (1%), and restless (1%). Values were retrieved from the database based on the participants’ feedback after each workout session (Figure 3.2e).

The individual motivation instruments were effective. Most participants *felt motivated when they saw the flower growing or could monitor their progress toward the plan* (both 91%). At study end we noticed that the participants appreciated the flower metaphor. When filling the questionnaires, most of them made spontaneous comments saying that it was “lovely”, “tender and cheerful”, or “a sunflower is funny, it makes you happy”. However, one woman suggested a racing car instead of the flower. According to her, the car is a perfect metaphor, since it also needs to get warm to work properly. The same high motivation was not achieved with the *mood status of the flower* (64%).

The social motivation instruments also achieved good results. The majority of the participants *felt motivated by being part of a training plan group* (91%). “I am happy to see others doing the same exercises; I am not a single athlete”. Monitoring and comparing the flower were similarly effective (64%). One woman said “I need someone to push me!” Two participants checked their friends’ flowers on the Bulletin Board daily and whether they did the exercises. However, another woman said “Of course not, I am not nosy!” but she also told us “my husband and I always looked at the
Bulletin Board to see if there was something interesting to read”. The same participants also reported “...after two days I could reach the same level as my husband, it made me happy”. From such results, we understood that our participants felt motivated by being part of a social group and by knowing that other people are doing the same exercises and are facing similar challenges (e.g., pain, difficulty wearing the ankle weights). It was, however, possible to notice their interest in knowing how others were doing and comparing other performances with their own. This might be indicative of the human tendency to keep equality (Herzberg's equity theory [37]).

Usability

All participants were able to use the Active Lifestyle app and agreed that it is easy to use. The scrolling and reading activities were performed by most participants. For instance, navigate through the messages posted on the Bulletin Board using the scroll (91%); read the posts from the Bulletin Board (100%); and receive messages on the inBox (73%, some participants never received a message, so they were not able to express their opinion about this feature). Although the writing activities did not show the same high usage, not all were able to write private messages on the Bulletin Board (64%) and public messages on the inBox (46%). Both messages are written following the same approach and appearance. The only difference is that the public messages can be read by all participants, as opposed to the private messages that are only available for selected persons.

A few participants in the beginning felt anxiety at the prospect of using the app (19%) (e.g., they felt afraid of not being able to use the app correctly or of having problems in using the tablet). With further questions we discovered that one woman had problems to use the app the first day only; after the extra meeting she, however, learned the use and was comfortable with it. Another woman performed the exercises early in the morning when she usually had cold fingers. Due to that, the tablet was not effectively reacting to her touches.

3.4 Discussion

The aim of this study was to investigate (i) the feasibility of the Active Lifestyle system for physical interventions, (ii) the adherence of the participants to the pre-defined training plans, and (iii) the effectiveness of the motivation instruments built into the system.

We demonstrated the feasibility of acquiring acceptable attrition and adherence rates for independently living elderly to the experimental training. Our target of about 70% recruitment rate (as observed by [35] for similar studies) for the total sample frame, however, by far not met. Those individuals that responded and visited an information session, however, showed a large inclusion and adherence rate. These findings indicate the importance of recruitment strategies and information
sessions to create awareness of the need for strength and balance training and the necessary trust for people to also enroll in a study. The differing adherence for the strength and balance training components should be addressed in a revised version of our app. It might be that the balance part required less effort and was easier to perform in contrast to the strength exercises. Many participants made remarks about the load of the strength exercises, e.g., some participants had difficulties to walk or had a surgery on the knee or hip and, therefore, could not perform the recommended number of sets.

The ankle weights were a barrier to the adherence to the strength exercises because, apart from the effort required to lift the weights, most participants reported difficulties to wear and wrap them around their ankles. One man bought a new pair of weights that were easier to wear and close. Another woman mentioned “tying the weights is almost the hardest!”

Compliance with the intervention was excellent. Eleven of initially thirteen included elderly individuals completed the training. This is far more than the rate that could have been expected [35]. It should be noted, however, that the mean compliance rate for interventions in independent living elderly that was determined for several studies summarized in a systematic review [32] mainly focused on studies with far longer time periods. Our data should, therefore, be replicated in another study where the intervention is applied during several training sessions over several weeks. It can be expected that because of such a longer period less favorable compliance and retention rates will be achieved. Our findings warrant, however, such follow-up studies based on these first results.

Regarding motivation, we noticed that all participants felt motivated by making something grow with their effort and by receiving a simple reward (e.g., a new picture of the flower metaphor). We infer that positive reinforcement using the growing flower metaphor worked successfully, even if approximately half of the participants (55%) would have preferred other metaphors. The selection of a metaphor (e.g., flower vs. car) is indeed very subjective and depends on the individual preferences of each participant.

About the low rate of writing activities, we hypothesize two possible reasons. Firstly, participants did not know each other, so they did not feel comfortable to write. Secondly, a minor part of them did not have good typing skills. For instance, one woman once wrote a non-understandable not correctly written message on the board. When she was asked about the sending messages option at the Bulletin Board or at the inBox, she said “I would write more, but for that I need to learn how to do it better.” This 81 years old participant, however, never used the Internet or a computer before.
Lessons learned

We conclude that the participants enjoyed the training and felt motivated to follow the training plans using the iPad-based Active Lifestyle app. At the final meeting we received encouraging and motivating comments from the participants, e.g., their desire to continue using the app, their disappointment for not being able to continue performing the exercises without the app (the training plan finished, and they tried to continue performing after that). One woman, used to perform exercises with a book (“Fit after 40”), commented, “the app is much better”. To her the study was a much more motivating way to exercise. She and her husband took notes to continue the exercises even after the study. Another woman said that her doctor was impressed with the result of her cholesterol exam. The oldest man sustained a heart attack two years ago and stopped doing sports. According to him, “this was a great opportunity to reactivate” “…it was perfect. I noticed progress, especially on my balance”. One person bought a tablet after the third meeting, and two expressed their intention to buy one soon and to install the app. However, because the test period was two weeks these findings are only preliminary. We cannot completely exclude the risk of the positive effect due to the news value of the app-based exercise program. The main focus was to evaluate the feasibility of the iPad-based intervention and the ability to recruit and retain elderly subjects. Home-based physical training with an iPad application seems to be feasible, as defined through recruitment, attrition and adherence to the exercise intervention. Our approach has shown to be a safe, low-cost and motivating way to activate and start with targeted physical exercise in older adults. To further clarify the influence of the iPad-based intervention on elderly subjects, for future studies we will consider a study design with a longer intervention period and a control group that will perform usual care exercises.

We learned that the motivational instruments worked. However, the possibility to chat did not motivate to use the Bulletin Board and the inBox features. Most participants were motivated being part of a training community, however, they were initially not willing to share their thoughts and feelings with strangers. We assume that if they learn how to use the app to make friends, receive feedback from people experiencing the same aging effects, and find a way to keep close and share their thoughts and life with old friends and family members, they might change their attitude. For that we need to build additional motivation and encouragement (i.e., dedicated mechanisms or features, in which the elderly have to reply questions, participate in collaborative activity or comment on specific topics). Another important aspect seems enabling communication and sharing of information between the elderly and their younger family members. During the intervention, we had only six comments on the Bulletin Board, of which three were addressed to our IT expert. We received sixteen private messages with suggestions and general comments about the exercises/app (e.g., “I am glad, my legs are not always so hard!” “The right leg is much stronger than the left leg! I feel that the training is necessary”).
We also noticed that some of the participants felt very proud about using the tablet and shared this experience with their families. One woman showed the tablet and the app to her grandchildren, who were impressed: “grandma has an iPad, wow!” The oldest woman received hints from her daughter about how to perform the heel-to-walk exercise; she had difficulties to walk along a straight line. Finally, another participant invited her sister to perform the exercises together. These results reinforce our intention to enable family members to interact with the elderly via the app and to monitor their performance. We believe that social and emotional support can be a motivation instrument that should be accounted for in the revised version of our app.

Limitations

This study had some limitations. Because we wanted to assess the feasibility of the processes that are key to the success of a future main Phase III study [27] we decided to start with a short training period to avoid risks (e.g., late detection of bugs that can cause a higher participants withdrawal, high investment to provide the tablets and 3G SIM-card Internet connections). Due to that we did neither focus on recruitment strategies nor on outcomes of physical functioning. We were also not able to evaluate how the participants will respond to long-term use of the system. It can be hypothesized that, similar to observations made with devices such as the Wii Fit, persons will start to train enthusiastically in an initial phase and then abandon the use. However, we believe that an important difference between the Wii Fit training and our program is that ours contains dedicated physical training plans for elderly, designed by human movement scientists, who also monitor progress and support training participants, which turns the Active Lifestyle app a dedicated training software for elderly. In the next main Phase III study we should consider a longer training plan period (12-weeks) and also perform an assessment of the physical functioning status of participants, preferably with a pre-test/post-test randomized study design. From this pilot we can conclude, however, that sending letters to potentially qualifying elderly was not a good strategy to recruit participants.

This pilot study assessed the feasibility of our approach in a rather small sample, which might be considered another limitation. However, the purpose of Phase II trials, which may be randomized or not randomized [27], is to provide preliminary evidence on the clinical efficacy of an intervention. The processes of development, feasibility and piloting, evaluation and implementation are in nature iterative [27]. Another limitation of this study was the direct contact of our research and development team with the participants. It cannot be excluded that the participants were highly compliant to the training in an effort to please the researchers. However, at this initial test phase such contacts were necessary in order to understand the needs of the users and investigate what needs to be improved in the Active Lifestyle app.

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Conclusion

We conclude that pilot studies with explicit feasibility objectives are important foundational steps in preparing for large trials. On-going formal review of the multifaceted issues inherent in the design and conduct of pilot studies can provide invaluable feasibility and scientific data for IT developers and rehabilitation specialists alike, and may be highly relevant for furthering the development of theory-driven, mobile-based rehabilitation.

This study shows that Active Lifestyle has potential to support physical exercise at home and it is worthwhile to further develop it into a more mature system. The results add to the knowledge base on mobile-based applications for elderly, in that it shows that elderly users can learn to work with mobile-based systems. The Active Lifestyle app proves feasible to support and motivate independently living elderly adults to autonomously perform balance and strength exercises at home. The Active Lifestyle intervention in a main study is deemed feasible with some need for protocol modifications regarding recruitment strategies, motivational instruments and information on physical performance measures. In our further work we will more specifically examine the effectiveness of Active Lifestyle on measures of physical functioning, with longer training periods, and larger sets of participants. Additionally, we will investigate how the users of the Active Lifestyle app react to social and individual motivation factors, and compare their adherence and motivation against a control group.

Author's contributions

All authors participated during the conception and design of this study, as well as to the data analysis and interpretation, drafting and revising phases of this article. All authors contributed to drafting the manuscript, critically revising it for important intellectual content, and gave their approval of the final version to be submitted.

Conflicts of interest statement

None declared.

Acknowledgements

This work was carried out with the support of Maria Messmer-Capaul of the Fachstelle für préventive Beratung Spitex-Zürich and Corinne Heck of the Informationsstelle fur Altersfragen. We would also like to thank all participants of the study for their great enthusiasm and support. This work is partially sponsored by the Trento Legge 6 project “Anchise”.
Reprinted from International Journal of Medical Informatics, Volume 82, Issue 5, Patrícia Silveira¹,
Eva van het Reve², Florian Daniel¹, Fabio Casati¹, Eling D. de Bruin², Motivating and assisting physical
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Chapter 4

Tablet-based strength-balance training to motivate and improve adherence to exercise in independently living older people: A phase II preclinical exploratory trial

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Abstract

Background: Reaction time, coordination, and cognition performance typically diminish in older adults, which may lead to gait impairments, falls, and injuries. Regular strength–balance exercises are highly recommended to reduce this problem and to improve health, well-being, and independence in old age. However, many older people face a lack of motivation in addition to other strong barriers to exercise. We developed ActiveLifestyle, an information technology (IT)-based system for active and healthy aging aiming at improving balance and strength. ActiveLifestyle is a training app that runs on a tablet and assists, monitors, and motivates older people to follow personalized training plans autonomously at home.

Objective: The objectives were to (1) investigate which IT-mediated motivation strategies increase adherence to physical exercise training plans in older people, (2) assess the impact of ActiveLifestyle on physical activity behavior change, and (3) demonstrate the effectiveness of the ActiveLifestyle training to improve gait speed.

Methods: A total of 44 older adults followed personalized, 12-week strength and balance training plans. All participants performed the exercises autonomously at home. Questionnaires were used to assess the technological familiarity and stage of behavior change, as well as the effectiveness of the motivation instruments adopted by ActiveLifestyle. Adherence to the exercise plan was evaluated using performance data collected by the app and through information given by the participants during the study. Pretests and posttests were performed to evaluate gait speed of the participants before and after the study.

Results: Participants were 75 years (SD 6), predominantly female (64%), held a trade or professional diploma (54%), and their past profession was in a sitting position (43%). Of the 44 participants who enrolled, 33 (75%) completed the study. The app proved to assist and motivate independently living and healthy older adults to autonomously perform strength–balance exercises (median 6 on a 7-point Likert scale). Social motivation strategies proved more effective than individual strategies to stimulate the participants to comply with the training plan, as well as to change their behavior permanently toward a more physically active lifestyle. The exercises were effective to improve preferred and fast gait speed.

Conclusions: ActiveLifestyle assisted and motivated independently living and healthy older people to autonomously perform strength–balance exercises over 12 weeks and had low dropout rates. The social motivation strategies were more effective to stimulate the participants to comply with the training plan and remain on the intervention. The adoption of assistive technology devices for physical intervention tends to motivate and retain older people exercising for longer periods of time.
4.1 Background

The primary goal of public health care is to increase the number of years of good health and maintain independence and quality of life as long as possible. Healthy aging is characterized by the avoidance of disease and disability, the maintenance of high physical and cognitive function, and sustained engagement in social and productive activities. These 3 components together define successful aging [1].

An important part of successful aging is maximization of physical performance. The ability to fully participate in productive and recreational activities of daily life may be affected when the capacity to easily perform common physical functions decreases [1]. Thus, health status is an important indicator of quality of life among older people [2, 3]. It has been demonstrated that components of health-related fitness and functional performance or serious, chronic conditions and diseases that directly influence the components of fitness and performance are related to perceived health among middle-aged and older adults [3-5].

Regular physical activity or exercise substantially prevents the development and progression of most chronic degenerative diseases [6-8], is of benefit to frail and older persons, and is the only therapy found to simultaneously improve sarcopenia, physical function, cognitive performance, and mood in older adults [9]. For older people, a sedentary lifestyle also increases the risk of falls, whereas physically active older people have a reduced risk of falls with injuries [10-12]. An important marker for improvements in physical function that influences health and survival is gait speed [13]. In summary, to increase older adults’ quality of life and fitness, we need to encourage them to become or stay physically active [14-15] and increase their fitness through training.

The objective of this research is to run a phase II study [16] with a tablet app called ActiveLifestyle [17], an app for the autonomous strength-balance physical training for independently living older adults. We aimed to investigate (1) which information technology (IT)-mediated motivation strategies increased adherence to physical exercise training plans in older people, (2) whether these strategies could induce physical activity behavior change, and (3) the effectiveness of ActiveLifestyle training to improve gait speed.

Related Work

Home environmental interventions to prevent functional decline seem to be effective [18] and are preferred by older people (ie, instead of leaving their houses to exercise) [19]. Interventions with integrated assistive technology devices have, in this context, the potential to further help in
overcoming some of the barriers to start training [20] and maintaining physical independence for independently living older people [21]. Recently developed innovative ideas designed to alter clinical practice in sports were based on the development of tablet apps for prevention, for instance [22]. Tablet and smartphone software apps specifically designed for health purposes are, in general, enthusiastically adopted as a means of delivering self-managed health interventions [23-25]. However, such tablet-based interventions are often plagued by high attrition rates and varying levels of user adherence [24, 25]. Furthermore, the effectiveness of tablet-based health intervention approaches has not yet been demonstrated in older people.

From a pilot study, we knew it is feasible to use assistive technology devices in an older population with the aim of encouraging performance of physical exercise [20]. The short-duration pilot did not focus on aspects of physical functioning, but indicated that the app could be improved by explicitly considering additional motivational strategies. It is well known that motivation strategies affect adherence to health interventions [26]; however, only a few solutions explore different motivation techniques to stimulate regular physical activity [26-28]. Most of these solutions have the drawback that they do not specifically focus on older people. Albaina et al. [29] presented a user-friendly software interface running on a small touchscreen display to motivate older adults to walk. The authors used a graphical representation of a flower to motivate and assist seniors to monitor their daily amount of steps collected by pedometers through this simple metaphor of their performance. To the best of our knowledge, there is not another software app dedicated to strength-balance training plans for older people.

4.2 Methods

**ActiveLifestyle**

ActiveLifestyle is a software app for active aging, aimed at assisting, monitoring, and motivating older people during autonomous home-based physical workouts [20, 30, 31]. The software takes usability aspects into account, to ensure that older users can use it independently and it adopts a set of motivation strategies to stimulate users to exercise regularly. A video of the app is available on YouTube [32], and the app can be downloaded from the Apple App Store [17].

Three levels of strength-balance training plans are supported in the app: beginner, intermediate, and expert. In all levels, the balance training should be done 5 days per week. Sessions are composed of 3 exercises, in which the trainees repeatedly (1-3 times) hold a certain position for several seconds (15-30 sec). Each level has different exercises, allowing progression as the person advances through the levels (eg, at the intermediate level the older person must perform the exercises while standing on a towel; at the expert level the exercise must be performed with the eyes closed). Strength training
has 3 levels and should be done twice a week; starting with 6 warm-up exercises, then 10 strength and 2 stretching exercises. A minimum number of sets (1-3) and repetitions (12-30) are available for each exercise. Some exercises require the use of weights (2-6 kg). The required effort of the exercises increases according to the level (eg, the beginner level does not require weights; the intermediate level requires ankle weights and performance in the sitting position; the expert level requires weights and exercises performed in standing position). The strength-balance training follows best practices recommendations and training principles (eg, it is progressive in nature) [33, 34]. Figure 4.1 illustrates some exercises supported by ActiveLifestyle. All exercises are available on YouTube [35].

![Figure 4.1: Exercise examples.](image)

In addition to the actual physical training, ActiveLifestyle features a set of individual and social motivation instruments. In general, individual motivation strategies aim to convince someone to do something because it is inherently enjoyable for this person, independently of any social pressure. ActiveLifestyle specifically supports:

- Conditioning through positive and negative reinforcement by immediately offering a reward/praise after an expected behavior to encourage the behavior and increase the probability that it happens again, or reprimands undesired behavior to decrease the probability of a reoccurrence of that behavior. Metaphors for reinforcement include a flower
that grows whenever a session is completed (i.e., positive reinforcement) and a gnome who takes care of the flower. The gnome’s mood status varies according to the person’s daily compliance to the plan (i.e., positive and negative reinforcement; if the person performs the exercise, the gnome is happy, otherwise he is sad) (see Figure 4.2a).

- Goal setting by establishing specific, measurable, achievable, and time-targeted goals. The goal is anticipated by visually conveying the achievable maximum growth of the flower (see Figure 4.2b).
- Self-monitoring by allowing people to monitor themselves and to modify their attitudes and behaviors. Coloring the flower growth stages reflects progress toward the goal (see Figure 4.2b).
- Awareness by presenting the benefits of being physically active through written content on a bulletin board and by showing inspiring stories (e.g., link to newspapers, videos, or websites) (Figure 4.3).

Figure 4.2: Metaphors within the app to motivate older people through conditioning, goal setting, and self-monitoring.

Figure 4.3: ActiveLifestyle tips to improve awareness about the benefits of being physically active.
Social motivation strategies are built on social psychology. An individual’s social network (other trainees) may act as source of motivation. ActiveLifestyle uses:

- **Comparison** by allowing a person to compare similarities and differences between 2 or more parties. People tend to keep equality in their relationships. Whenever a person completes a workout session, an automatic message is posted on a bulletin board informing the training community (ie, other users following the same training plans) about the complete session. The message also carries the status of the individual’s flower.

- **External monitoring** by allowing 1 party to monitor the performance of another party. ActiveLifestyle enables health care experts to access data on performance and compliance with the training plan. The older users have access to their own flower and to that of their training partners, enabling monitoring progress of peers.

- **Emotional support** by encouraging exchange of written messages between trainees and experts to motivate and assist. ActiveLifestyle uses a bulletin board and an “inBox.” The first is a public channel where all members of the training community have access. The second is a bidirectional private channel for contact with professionals capable of giving advice and feedback on trainings.

- **Collaboration** by offering a collaborative activity designed as a game, in which to progress in the game, a group of trainees must jointly be compliant with the training plan. The To the Top game is a trekking trail with 24 predefined points (2/week). The aim of the game is to climb a mountaintop, as a group of successful trainings ends. Compliance with the training plan is evaluated twice weekly on group level. A total of 65% or more members of a group have to perform the scheduled workout to be awarded a new flag on the trail (representing progress toward the mountaintop). Each flag uncovers a story with trivia about the Matterhorn and what is needed to conquer the mountain as a parable explaining the benefits associated with being physically active (*Figure 4.4).*

ActiveLifestyle comes in 2 versions. The individual version contains only the individual motivations strategies. The social version supports individual and social motivation strategies, and a virtual training plan community and communication features. In addition to the motivation strategies, ActiveLifestyle supports 6 main features accessible through its menu:

- **The What’s Next?** option invites the users to start the performance of due workout sessions.
- **The weekly exercises** option shows the scheduled strength–balance sessions organized per week.
The progress option shows the users’ progress thought the conditioning, goal setting, and self-monitoring strategies previously mentioned in both versions. The social version also supports the collaboration strategy through the To the Top game.

The bulletin board allows the users to receive written messages, which may include links for websites and YouTube videos. Three types of messages are supported: (1) workout session completed messages (in green) to inform the participant(s) about the conclusion of a scheduled session of exercises; (2) ActiveLifestyle tips messages (in pink) to support the awareness motivation strategy illustrated in Figure 4.3; and (3) public messages (in white) written by the training members. Only the social version supports the third type of message and has the ability to send messages to the entire training plan community.

The friends option lists the members of the training plan community (ie, older users and experts). Only the social version supports this feature.

The inBox option allows users to exchange private text messages with their list of friends.

All the previously mentioned features and motivation strategies can be inspected at the Life Participation Project website [31].

Figure 4.4: The To the Top collaboration game within the app.
**Eligibility Criteria**

Participants were older adults aged 65 years or older; living independently; able to walk independently with or without walking aids; able to follow instructions spoken in German, English, or Italian; and with no severe illness, cognitive impairment, progressive neurological disease, stroke, severe cardiac failure, or high blood pressure. Ethical approval for the study was obtained from the Eidgenössische Technische Hochschule (ETH) Ethics Committee (EK 2011-N-64).

**Setting**

Participants were recruited by convenience sampling from 2 institutions for older people and 1 organization responsible for coordinating and providing at-home nursing care for seniors. The Senioren Begegnungszentrum Baumgärtlihof, a day center dedicated to delivering services and information related to the older population (Horgen, Switzerland), advised potential participants through its mailing list and by notes in the local newspaper. The Alterswohnungen Turm-Matt, a cooperative offering housing and daily living facilities to older people (Wollerau, Switzerland), informed and advised potential participants in person or by phone and distributed flyers to advertise the study. The Fachstelle für präventive Beratung Spitex-Zürich, a home-care nursing organization (Spitex-Zürich), promoted the study by sending letters and specifically inviting patients in need of better physical performance. Spitex-Zürich nurses selected potential participants based on the eligibility criteria.

**Intervention**

To investigate the effects of different motivation strategies, a pretest/posttest preclinical trial was performed. For convenience, the ActiveLifestyle groups were composed of (1) an individual group that followed training using the individual version of ActiveLifestyle; (2) a social group that followed training using the social version of the app, (3) a control group that followed exercises with printed information without additional motivation strategy. The individual and social groups were randomly composed of participants recruited from Baumgärtlihof and Spitex-Zürich, whereas the participants in the control group were recruited from Turm-Matt because of time and resource constraints (eg, lack of research team members, the control group was not randomized with the other participants). Figure 4.5 shows the recruitment process and the flow of participants through the study. Videos of some parts of the interventions can be watched on YouTube [35]. The development of our intervention follows a framework for the design and evaluation of complex interventions [36] and should at this stage be considered as a preclinical exploratory trial. For this reason, we did not use a pure randomized, controlled research design; therefore, we did not register this study as a clinical trial.
Outcome Measures

Adherence and Attrition
Adherence was computed by ActiveLifestyle during the intervention and stored in a central database. The control group adherence was assessed with paper-based training logs. To calculate adherence, the total number of workout sessions for each participant was divided by 81, which was the total number of possible training sessions for the 12-week period (because of technical issues, the training was suspended for 3 days and the trainees were aware of the 81 training sessions in advance). The adherence of participants who dropped out was calculated by dividing the number of workout sessions attended up to the point of dropout from the study by 81 [37]. Values were compared between groups and with median rates in community-based fall prevention interventions [38]. For attrition, we measured the number of participants retained and lost at the final follow-up.

Gait Speed
The effect of the training on physical performance was assessed by measuring preferred and fast walking speed [39] with the GAITRite walkway, a valid and reliable tool for measuring gait in older people [40-42].

Motivation Instruments
The effectiveness of the motivation instruments built into the system was assessed based on the participants’ feedback, collected with a 7-point Likert scale self-reported questionnaire at the end of the intervention, and on the performance (adherence, attrition, and gait speed) comparison among the 3 groups of participants.

Change of Behavior
The level of exercise adoption was evaluated according to the Transtheoretical Model (TTM) [43], which describes how people modify or acquire behavior. A self-reported TTM questionnaire was applied before and after the training period. Participants were classified into 4 groups: contemplation (eg, thinking about physical behavior change), preparation (eg, already somewhat physically active), action (eg, doing enough physical activity), and maintenance (eg, making physical activity a habit).

Statistical Analyses
Analysis of variance (ANOVA) was used to test for differences in adherence to the training program between groups, as well as gait speed over time and between groups. Significant main effects were followed up by post hoc t tests with correction for multiple comparisons. Between-group differences in attrition were analyzed using a chi-square ($\chi^2$) test. Questionnaires on enjoyment, motivation, and change of behavior were analyzed using Kruskal–Wallis ANOVA and Wilcoxon signed rank tests ($W$).
In all analyses, the level of significance was set at $P \leq 0.05$. For effect size, we used $\eta^2$ in all ANOVA analyses, Cohen’s $d$ for all post hoc analyses, mean square contingency coefficient ($\phi$) for chi-square tests, and Pearson $r$ ($r$) for Kruskal–Wallis ANOVA and Wilcoxon signed rank tests. The $r$ is calculated as $r = Z / \sqrt{N}$, in which $Z$ is the standardized difference and $N$ is the total number of samples. Suggested norms for interpreting $\eta^2$ are 0.01=small, 0.06=moderate, and 0.14=large effect [44]. For small, moderate, and large effects, these norms are 0.2, 0.5, and 0.8, respectively, for Cohen’s $d$ and 0.1, 0.3, and 0.5, respectively, for both $\phi$ and $r$ [44]. All tests were conducted using SPSS Version 21.0 (IBM Corp, Armonk, NY, USA).

4.3 Results

Demographics

Detailed information about the participants’ demographics, based on the Health and Technology Familiarity self-reported questionnaires, is summarized in Table 4.1.

<table>
<thead>
<tr>
<th>Table 4.1. Participants’ demographics (N=44).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>Female gender, n (%)</td>
</tr>
<tr>
<td>Age (years), mean (SD)</td>
</tr>
<tr>
<td>Hold trades or professional diploma, n (%)</td>
</tr>
<tr>
<td>In a sitting position past profession, n (%)</td>
</tr>
<tr>
<td>Health questions, n (%)</td>
</tr>
<tr>
<td>Estimated good health</td>
</tr>
<tr>
<td>Estimated average balance</td>
</tr>
<tr>
<td>Feel pain but not every day</td>
</tr>
<tr>
<td>Flexibility questions, n (%)</td>
</tr>
<tr>
<td>Fell in the past 6 months*</td>
</tr>
<tr>
<td>Walk at least twice a week</td>
</tr>
<tr>
<td>Practiced some sport in the past</td>
</tr>
<tr>
<td>Never practiced strength exercises</td>
</tr>
<tr>
<td>Technology familiarity, n (%)</td>
</tr>
<tr>
<td>Frequently use automated teller machines</td>
</tr>
<tr>
<td>Frequently use cellphones</td>
</tr>
<tr>
<td>Frequently use digital photography</td>
</tr>
<tr>
<td>Don’t use Global Positioning System devices</td>
</tr>
<tr>
<td>Don’t use automatic kiosks</td>
</tr>
<tr>
<td>Don’t know what an e-book is</td>
</tr>
<tr>
<td>Use a computer</td>
</tr>
<tr>
<td>Between 1-5 hours per week</td>
</tr>
<tr>
<td>Use the Internet</td>
</tr>
<tr>
<td>Between 1-5 hours per week</td>
</tr>
</tbody>
</table>

* A fall was defined as unintentionally coming to the ground or some lower level, excluding the consequence of sustaining a violent blow, loss of consciousness, or sudden onset of paralysis, such as during a stroke or epileptic seizure [45].
Adherence and Attrition

Table 4.2 presents the adherence to ActiveLifestyle strength–balance training plans. Adherence across training plans differed significantly between groups ($F_{2,41}=4.8, P=.01 r^2=.19$). Post hoc t tests with Benjamini–Hochberg correction revealed a large and significant difference between the social group (mean 81.9%, SD 1.6%) and the control group (mean 48.1%, SD 41.5%; $t_{19.2}=3.1, P=.02 d=0.91$). The difference between the individual group (mean 71.1%, SD 25.2%) and the control group was moderate to large ($t_{26.9}=1.9, P=.10, d=0.63$). The difference between the individual and social groups was moderate yet nonsignificant ($t_{18.6}=1.4, P=.19, d=0.50$).

<table>
<thead>
<tr>
<th>Training plan</th>
<th>Individual group</th>
<th>Social group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visited</td>
<td>Planned</td>
<td>%</td>
</tr>
<tr>
<td>Balance training plan</td>
<td>547</td>
<td>812</td>
<td>67</td>
</tr>
<tr>
<td>Strength training plan</td>
<td>221</td>
<td>322</td>
<td>69</td>
</tr>
<tr>
<td>Across training plans</td>
<td>768</td>
<td>1134</td>
<td>68</td>
</tr>
</tbody>
</table>

**Table 4.2. Adherence to ActiveLifestyle strength–balance training plans**

**Figure 4.5: Flowchart of participants.**
Thirty-three older adults completed the 12 weeks of training, resulting in a 25% attrition rate in total, 21% in the individual group (3/14), 8% in the social group (1/13), and 41% in the control group (7/17). Figure 4.6 illustrates the number of remaining participants in each group per week after enrollment. More details about the dropout reasons are reported in Figure 4.5. A chi-square test revealed that attrition rate was higher in the control group (41.2%) than in the combined ActiveLifestyle groups (14.2%; $\chi^2_{1}=3.9$, $P=.05$, $\phi=0.30$).

![Graph of the number of remaining participants in each group per week.](image)

**Figure 4.6**: Graph of the number of remaining participants in each group per week.

**Gait Speed**

*Table 4.3* shows participants’ preferred and fast gait speed during the pretest and posttest evaluations. With respect to preferred gait speed, the 3 groups were similar. We used 2 mixed 2-way ANOVA’s (1 for preferred and 1 for fast gait) with within-subject factor pre–post (2 levels) and between-subject factor group (3 levels). For preferred gait speed, there was a significant difference between pretest and posttest ($F_{1,30}=29.5$, $P<.001$, $\eta^2=0.50$). Participants walked significantly faster in the posttest (1.276 m/s) than they did in the pretest (1.142 m/s). There was no significant main effect of group ($P=.07$) and no significant interaction effect ($P=.65$), suggesting that preferred gait speeds and their improvements were similar in all groups.

The results for fast gait speed were similar to those for preferred gait speed. Again, there was a large difference between pretest and posttest: Participants walked significantly faster in the posttest (1.72
m/s) than in the pretest (1.56 m/s; \( F_{1,29}=20.1, \ P<.001, \ \eta^2=0.41 \)). The main effect of group was significant also (\( F_{2,29}=5.3, \ P=.01 \ \eta^2=0.27 \)). Post hoc tests revealed that the individual group (1.89 m/s) was significantly faster than the control group (1.45 m/s; \( t_{19}=3.94, \ P=.003, \ d=1.31 \)), and faster than the social group (1.58 m/s; \( t_{20}=2.05, \ P=.08, \ d=.89 \)), though not statistically significant. The individual group, by chance, was the fastest from the beginning. Fast gait speed was not significantly different between the control group and the social group (\( P=.39 \)).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pretest mean (SD)</th>
<th>Posttest mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred speed (m/s)</td>
<td>1.26 (0.18)</td>
<td>1.42 (0.21)</td>
</tr>
<tr>
<td>Fast speed (m/s)</td>
<td>1.80 (0.27)</td>
<td>1.98 (0.31)</td>
</tr>
<tr>
<td>Social group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred speed (m/s)</td>
<td>1.10 (0.25)</td>
<td>1.24 (0.31)</td>
</tr>
<tr>
<td>Fast speed (m/s)</td>
<td>1.50 (0.35)</td>
<td>1.66 (0.50)</td>
</tr>
<tr>
<td>Control group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred speed (m/s)</td>
<td>1.07 (0.19)</td>
<td>1.17 (0.22)</td>
</tr>
<tr>
<td>Fast speed (m/s)</td>
<td>1.39 (0.22)</td>
<td>1.51 (0.27)</td>
</tr>
</tbody>
</table>

**Motivation Instruments**

Detailed information about the effectiveness of ActiveLifestyle’s motivation instruments and user-intention aspects are summarized in Table 4.4.

Most participants affirmed that ActiveLifestyle facilitates the autonomous performance of balance–strength exercises. This was confirmed by a high intention to use the app again or to recommend it to friends or family members. The individual group was unanimous in the evaluation of these 2 user-intention aspects, whereas the social group presented high values but not with unanimity. In general, the participants of both groups did not feel motivated to perform physical exercises before the study.

All the participants thought it was fun to perform the strength and balance exercises. Few participants (<25%) felt frustrated, worried, or nervous during the study. More than half of the participants, 54% from the individual group and 67% from social group will miss ActiveLifestyle.

The individual motivation strategies seemed to be more effective on the individual group level than on the social group level. Most of the individual group felt motivated by the goal-setting and self-monitoring strategies (91%), both represented by the progress bar metaphor (panel b in Figure 4.2), as well as for being aware of the benefits of being physically active–aware (82%). Conditioning through positive and negative reinforcement also motivated the participants. In all, 64% felt motivated when they saw the plant growing, whereas 55% felt motivated by the mood status of the gnome.

The most effective motivating strategies for the social group were conditioning through positive social inclusion and external monitoring (all 83%). After that, the social group felt motivated through
the awareness of the benefits of physically activity (82%), emotional support (75%), the monitoring of their progress toward the plan (goal setting and self-monitoring) (67%), participation in the collaboration game (58%), positive and negative reinforcement (conditioning) (50%), and the comparison of their performance with other training participants on the bulletin board (42%).

Most participants in the individual group (64%) expressed that they would feel more motivated if they could use the social version of ActiveLifestyle, but the reverse was not true. Only a few participants in the social group expected to be less motivated using the individual version of the app (8%). Mann–Whitney U tests comparing the Likert scores for all questions presented in Table 4.4 did not detect any significant differences between the groups.

<table>
<thead>
<tr>
<th>Evaluation statements</th>
<th>Individual (n=14)</th>
<th>Social (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ActiveLifestyle facilitates the performance of autonomous strength–balance exercises at home</td>
<td>7 (6-7)</td>
<td>7 (4-7)</td>
</tr>
<tr>
<td><strong>Use intention</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would use the app again</td>
<td>6 (5-7)</td>
<td>6 (4-7)</td>
</tr>
<tr>
<td>I would recommend the app to my friends and family</td>
<td>6 (6-7)</td>
<td>6 (3-7)</td>
</tr>
<tr>
<td><strong>Enjoyment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It was fun to carry out the strength and balance exercises</td>
<td>6 (6-7)</td>
<td>6 (5-7)</td>
</tr>
<tr>
<td>I felt frustrated during the study</td>
<td>2 (1-5)</td>
<td>2 (1-6)</td>
</tr>
<tr>
<td>I felt worried during the study</td>
<td>2 (1-6)</td>
<td>2 (1-7)</td>
</tr>
<tr>
<td>I felt nervous during the study</td>
<td>1 (1-6)</td>
<td>1 (1-4)</td>
</tr>
<tr>
<td>I will miss the exercises and the ActiveLifestyle app</td>
<td>5 (2-7)</td>
<td>6 (3-7)</td>
</tr>
<tr>
<td><strong>Motivation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I usually do not feel motivated to perform physical exercises, ActiveLifestyle helped me</td>
<td>6 (1-7)</td>
<td>6 (2-7)</td>
</tr>
<tr>
<td><strong>Individual motivation instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt motivated when I saw my performance on the progress bar (goal setting and self-monitoring)</td>
<td>6 (4-7)</td>
<td>91 (1-7)</td>
</tr>
<tr>
<td>I felt motivated by being aware about the benefits of being physically active (awareness)</td>
<td>6 (3-7)</td>
<td>82 (3-7)</td>
</tr>
<tr>
<td>I felt motivated when I saw the plant growing due to my performance (conditioning)</td>
<td>6 (4-7)</td>
<td>64 (1-7)</td>
</tr>
<tr>
<td>I felt motivated when I saw the emotional status of the gnome (conditioning)</td>
<td>5 (2-7)</td>
<td>55 (1-6)</td>
</tr>
<tr>
<td>I would feel more motivated using the social version of ActiveLifestyle, in which I could interact with other training partners</td>
<td>5 (1-7)</td>
<td>64 (1-6)</td>
</tr>
<tr>
<td><strong>Social motivation instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt motivated for being part of a training group and knowing that other people did the same exercises</td>
<td>—</td>
<td>6 (2-7)</td>
</tr>
<tr>
<td>I felt motivated to perform the plan because I knew I was being monitored (external monitoring)</td>
<td>—</td>
<td>6 (2-7)</td>
</tr>
<tr>
<td>I felt motivated for being emotionally supported by the other training partners and by the ActiveLifestyle experts (emotional support)</td>
<td>—</td>
<td>6 (2-7)</td>
</tr>
<tr>
<td>I felt motivated with the collaboration activity to reach the top of the mountain (collaboration)</td>
<td>—</td>
<td>6 (3-7)</td>
</tr>
<tr>
<td>I usually compared my flower with others on the bulletin board (comparison)</td>
<td>—</td>
<td>4 (1-6)</td>
</tr>
<tr>
<td>I would feel more motivated using the individual version of ActiveLifestyle, which does not require interaction with other training partners</td>
<td>—</td>
<td>4 (1-6)</td>
</tr>
</tbody>
</table>
Change of Behavior

Table 4.5 shows the stage of behavior change of the participants at the beginning ($t_0=0$ weeks) and at the end ($t_1=12$ weeks) of the intervention.

Wilcoxon signed rank tests comparing pretest and posttest behavioral scores in each group revealed a trend—with a large effect size—in the social group ($W=1.79, P=.07, r=0.52$). Hence, the social group tended to change their behavior toward integration of ActiveLifestyle into their daily routine. No behavioral changes were detected in the control group ($P=.28$) or the individual group ($P=.50$). Although this suggests between group differences with respect to behavioral change, no such differences could be shown statistically; a Kruskal–Wallis ANOVA directly comparing change of behavior between the 3 groups was nonsignificant ($P=.75$).

Table 4.5. Stage of behavior change of the participants according to the Transtheoretical Model (TTM).

<table>
<thead>
<tr>
<th>Stage of behavior change</th>
<th>$t_0 = 0$ weeks</th>
<th>$t_1 = 12$ weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contemplation</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Preparation</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Action</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Social group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contemplation</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Preparation</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Action</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td><strong>Control group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contemplation</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Preparation</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Action</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

4.4 Discussion

Principal Findings

The aim of this study was to investigate (1) which IT-mediated motivation strategies increase adherence to physical exercise training plans in older people, (2) whether the ActiveLifestyle app induces physical activity behavior change, and (3) the effectiveness of the ActiveLifestyle training to improve gait speed. The main focus was to evaluate the ability to retain older people in the exercise program. Based on findings from a systematic review [39], we could expect a 10% attrition rate and 50% adherence rate for the individually targeted exercise training. Although the control group showed 41% attrition (primarily because of lack of exercise motivation), both tablet-based training groups showed far lower values, 21% and 8% for the individual and social ActiveLifestyle groups, respectively. These last 2 numbers also contain the effect of morbidities not related to the
motivation to train (i.e., unexpected health problems). Especially in the control group participants, the lack of motivation for continuous training was high. The degree of engagement with the intervention was more than 68% for the individual group and 73% for the social group, both using the ActiveLifestyle app, and 54% for the control group. Compared with median rates for attrition (10%) and adherence (50%) in fall prevention interventions in community settings, we achieved better or similar rates for the tablet-based training groups. From previous research [46], we know that the intention to undertake strength-balance training in older people is closely related to all elements of coping appraisal. Elements of coping appraisal include the belief that strength-balance training has multiple benefits, a positive social identity, and the feeling that family, friends, and doctors would approve of taking part in such training [46]. It can be hypothesized that ActiveLifestyle is effective in influencing attrition and adherence because it explicitly supports individual and social motivation instruments.

The reason to use a tablet solution is related to the numerous potential advantages attributed to such a tool (e.g., tablets are relatively robust, and using fingers instead of a mouse or a touch pad make them much more intuitive and easy to use compared with smartphones, notebooks, and desktops). A tablet-based intervention, such as ActiveLifestyle, constitutes a powerful tool to provide feedback about performance and motivation to endure practice because of social inclusion. Interventions that use frequent, nonfrequent, or direct remote feedback are to be favored versus treatments without feedback, because the former seem to be more effective than the latter and they are equally effective as supervised exercise interventions [47]. The second most-mentioned barrier to physical exercise for subjectively insufficiently active older adults is lack of company. Direct remote contact seems to be a good alternative to supervised on-site exercising [47]. Such feedback can easily be adapted to the individual participant’s baseline motor performance and progressively augmented with task difficulty. ActiveLifestyle has been demonstrated to have the potential to engage people who otherwise would lack interest to participate in a physical exercise regimen. Especially in the older population, it is difficult to maintain high adherence to training programs [48]. The participants of the present study allocated to the tablet groups showed good compliance rates. The losses related to low exercise compliance (n=6) in the control training group were caused by a lack of motivation. The reasons for discontinuation of training in the tablet groups were not because of rejection of the app; they were because of health problems. In a future phase III trial, the follow-up period for the assessment of adherence and attrition should preferably be extended to 12 months to enable the comparability of this future study with reference values of previous physical interventions [39]. Although the result of a 12-week intervention, our findings are encouraging and indicate the effectiveness of a tablet-based training approach in older people. This encourages further exploration of this training approach in seniors.
Analyzing the participants’ answers to the motivation instruments of ActiveLifestyle, most of the individual participants (64%) would feel more motivated using the social version of the app, whereas the opposite is not true (8%) (both tablet groups were aware of the different versions of ActiveLifestyle). Regarding the physical activity habits, the training group using the social version of ActiveLifestyle was the only group showing a tendency to change behavior. At the end of the intervention, 50% of the social group participants changed their behavior according to the TTM. At the beginning, these participants were at the contemplation or preparation stages (thinking about or already being somewhat physically active), and they were classified as being on the maintenance stage (making physical activity a habit) by the end. However, a further longitudinal study with a larger sample, including evaluation after the end of the intervention, is required to be able to ascertain change of physical behavior.

Gait speed is a clinically relevant indicator of functional status associated with important geriatric health outcomes (ie, impact health care activities have on people) [49]. Slowing down has been recognized as an indicator of failing health and vulnerable old age [49]. Some researchers hypothesize that gait speed may act as a vital sign, giving indications of the health status of older people. Mortality, for example, is substantially reduced when gait speed is improved through interventions [51]. Large epidemiological studies reveal that a 0.1 m/s faster walking speed is related to a 12% decrease in mortality [13]. In this respect, it is encouraging that all older people in our training groups that adhered to their training plan, independently of their group allocation, showed an increase in both preferred and fast walking speed.

In addition to the high level of adherence caused by the social motivation instruments, the training community created by the study served to improve the connectedness of the participants, which may help people to garner social support for making physical changes in their daily lives [52]. Two women who did not know one another started to perform the exercises together to check if they were following the correct posture. Some participants contacted other training partners using the app or via email or phone when they faced problems. The same support was also requested from our team of experts, who frequently (especially at the beginning of the study) received phone calls because of technical problems or doubts about the exercises.

As learned in our previous study [20], some of the participants felt proud of being able to use new technology. One of our oldest participants (83 years) installed Skype to call his daughter living in Central America. He confessed that his daughter was very surprised. In the beginning, 1 woman was afraid of not being able to correctly operate the tablet because she had never used a computer before. After the study, she bought a tablet on her own to play with her grandchildren and installed Wi-Fi at home to be more connected with them. Another woman expressed a similar concern at the
beginning of the training, but finished the study with a new tablet and a Gmail account: “I’m proud to be in possession of the iPad and to be able to write to my friends. The whole matter was a change for me.”

Limitations

The study has some limitations. One of them is the rather small sample size. The study reveals first estimates for gait speed measures and stages of behavior change and warrants further research in larger populations. However, the purpose of preclinical exploratory trials is to provide preliminary evidence on the clinical efficacy of an intervention [16, 36]. When evaluating the validity of a study, it is important to consider both the clinical and statistical significance of the findings [53]. Studies that claim clinical relevance may lack sufficient statistical significance to make meaningful statements or, conversely, may lack practicality despite showing a statistically significant difference in treatment options. Researchers and clinicians should not focus on small P values alone to decide whether a treatment is clinically useful; it is necessary to also consider the magnitude(s) of treatment differences and the power of the study [53]. Encouraging in this context is the observation that most of the between-groups comparisons for adherence show medium or medium-to-high magnitude(s) of treatment differences in favor of the tablet groups. The relationship between tablet-based physical training research and its effect on adherence and fitness in older individuals requires further exploration. Another limitation of this study is related to the research design used. The different recruitment methods and the lack of initial randomization and blinding may have introduced a selection bias that questions the validity of the adherence/motivation findings. Analogous studies with similar or frailer populations and the use of a true randomized controlled research design should be performed to substantiate or refute our findings.

The participants of this study can be classified as normal walkers with a preferred gait speed between 1.0 and 1.4 m/s. Future studies with community dwelling populations that exhibit mildly abnormal (0.6-1.0 m/s) or seriously abnormal gait speed (<0.6 m/s) [50] should be performed to investigate whether similar or even better results in physical performance variables can be obtained.

Conclusion

The finding of this study supports the notion that it is advantageous to combine physical training with specifically targeted IT motivation instruments that offer the possibility to socialize in a group in clinical practice. The combination seems to have a positive influence on older adults’ training adherence in comparison to more traditional exercise. ActiveLifestyle proved to assist and motivate independently living and healthy older adults to autonomously perform strength–balance exercises. The social motivation strategies seemed to be more effective to stimulate the participants to comply
with the training plan and remain on the intervention. The adoption of assistive technology devices for physical intervention tends to motivate and retain older people exercising for longer periods of time.

Acknowledgments

This work was carried out with the support of Maria Messmer-Capaul and her team at the Fachstelle für präventive Beratung Spitex-Zürich, of Claudia Nüesch at the Senioren Begegnungszentrum Baumgärtlihof, and Data Quest, who provided tablets for the study. We would like to thank all the participants for their great enthusiasm and support. This work is partially sponsored by the European Institute of Innovation & Technology (EIT) project Virtual Social Gym and the EU FP7 SME Capacities program BPM4People.

Conflicts of Interest

None declared.

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Chapter 5

Tablet-based strength-balance training to motivate and improve adherence to exercise in independently living older people: Part 2 of a phase II preclinical exploratory trial

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published in Journal of Medical Internet Research 2014;16(6):e159 (www.jmir.org/2014/6/e159)
Abstract

**Background:** Home-based exercise programs can improve physical functioning and health status of elderly people. Successful implementation of exercise interventions for older people presents major challenges and supporting elderly people properly while doing their home-based exercises is essential for training success. We developed a tablet-based system—ActiveLifestyle—that offers older adults a home-based strength-balance training program with incorporated motivation strategies and support features.

**Objective:** The goal was to compare 3 different home-based training programs with respect to their effect on measures of gait quality and physical performance through planned comparisons between (1) tablet-based and brochure-based interventions, (2) individual and social motivation strategies, and (3) active and inactive participants.

**Methods:** A total of 44 autonomous-living elderly people (mean 75, SD 6 years) were assigned to 3 training groups: social (tablet guided, n=14), individual (tablet guided, n=13), and brochure (brochure guided, n=17). All groups joined a 12-week progressive home-based strength-balance training program. Outcome measures were gait performance under single and dual task conditions, dual task costs of walking, falls efficacy, and physical performance as measured by the Short Physical Performance Battery (SPPB). Furthermore, active (≥75% program compliance) and inactive (<75% program compliance) individuals were compared based on their characteristics and outcome measures.

**Results:** The tablet groups showed significant improvements in single and dual task walking, whereas there were no significant changes observable in the brochure group. Between-groups comparisons revealed significant differences for gait velocity (U=138.5; P=.03, r=.33) and cadence (U=138.5, P=.03 r=.34) during dual task walking at preferred speed in favor of the tablet groups. The brochure group had more inactive participants, but this did not reach statistical significance (U=167, P=.06, r=.29). The active participants outperformed the inactive participants in single and dual task walking, dual task costs of walking, and SPPB scores. Significant between-groups differences were seen between the tablet groups and the brochure group, in favor of the tablet groups.

**Conclusions:** A tablet-based strength-balance training program that allows monitoring and assisting autonomous-living older adults while training at home was more effective in improving gait and physical performance when compared to a brochure-based program. Social or individual motivation strategies were equally effective. The most prominent differences were observed between active and inactive participants. These findings suggest that in older adults a tablet-based intervention enhances training compliance; hence, it is an effective way to improve gait.

**Keywords:** gait, aging, exercise therapy, tablet, delivery of health care
5.1 Background

One of the major opportunities to extend years of active independent life and to promote an independent lifestyle is to be physically active on a regular basis [1-3]. Physical activity can prevent several diseases (eg, cancer and type II diabetes mellitus) and has the potential to enhance both physical and cognitive functioning and cardiovascular and psychological health [4-8]. For older adults, structured exercise training is recommended to postpone frailty and vulnerability [9, 10] and to minimize several chronic degenerative diseases that result from an inactive lifestyle [11, 12]. The evidence that sedentary people lose a relatively large fraction of their muscle mass in the aging process [1] confirms that avoiding physical inactivity is an obvious aim for interventions [12]. In past research, the effect of physical activity has also been linked to an increase in life expectancy [13], diminishing probability of a fall [14-16], and in preventing sarcopenia [1, 17]. Accordingly, keeping older adults physically active is a crucial step toward prevention of several diseases.

Walking requires efficient circulatory, heart, lung, nervous, and musculoskeletal systems [18]. In combination with deficits in these systems, walking ability in old age often deteriorates. Gait quality assessment with dedicated gait analysis systems [19], expressed through measures of variability [20], showed that both stride time and stride length variability are associated with the control of the rhythmic stepping mechanism [21]. Errors in foot placement control and/or displacement of the center of mass may result in higher variability [21, 22], which in turn leads to falls in older adults [23,24]. Furthermore, gait speed is one of the factors reflecting functional ability and independence [25]. Slowed walking may reflect damaged organ systems [18, 26]. Relationships between faster gait speed and reduced mortality [18, 27], and shorter length of stay in geriatric hospitals [28, 29] have been demonstrated. In contrast, reduced gait speed can be associated with falls and a decline in cognitive factors [30], such as attention and psychomotor speed [31]. This reduction in gait speed in older people has been shown to be a result of shorter step lengths [32, 33] and increased double support time [33, 34], which are changes in gait that relate to falls in elderly [35]. Another important determinant of gait function in both healthy and unhealthy elderly is lower extremity muscle function [36]. To summarize, a decrease in walking ability and abnormal walking frequently results in disability and falls, which can lead to a loss of independence in activities of daily living [37], institutionalization, and death [38, 39]. Furthermore, a lack in gait quality can lead to a fear of falling [37].

When strength training is complemented with balance exercises, a transfer to functional tasks of daily living may be expected [40]. Therefore, to optimize walking quality, strength and balance training, previously showed to be effective [41-43], should be applied and adhered to.
Home-based exercise programs—provided that they are performed correctly—can be effective in improving physical functioning [15] and health status of elderly people [1]. Especially for older adults without access to exercise facilities (eg, because they live in rural or remote areas), an effective home-based intervention at regular intervals potentially offers great benefits. Large travel distances and deteriorations in locomotion could potentially limit the ability of these people to visit a training center [44, 45]. However, despite the fact that exercise has been widely accepted as beneficial for health, successful implementation of exercise interventions presents a major challenge for many older people [46].

The importance of monitoring and supporting elderly people while doing their home-based exercises should not be neglected. Providing feedback, social support, motivation, and encouragement seem to be essential factors in enhancing adherence [47-49]. Although older adults often express the desire for training support at home [50], these factors are difficult to implement in home-based exercise programs. Remote feedback strategies may have the potential to replace live supervision while exercising at home [51]. For an overview about related work on this topic, we refer to our previous studies describing our phase II study [52] with the tablet-based app ActiveLifestyle [53]. This part of our study compares 3 different home-based training programs and their effect on measures of gait quality while considering adherence to the training program. We hypothesized differing results for (1) tablet-based groups when compared to a brochure group, (2) a tablet group with social motivation strategies when compared to a tablet group with individual motivation strategies, and (3) active participants when compared to inactive participants.

5.2 Methods

The ActiveLifestyle app

ActiveLifestyle offers autonomous-living older adults tablet-based software that supports them doing their physical exercises. The app assists, monitors, and motivates this group of people while doing their exercise program at home. The program consists of a strength and balance training plan. Exercises are shown with videos and explained with written and oral instructions. Details of the exercises are given in the Intervention Program section. The ActiveLifestyle app comes in 2 different versions: the individual version contains individual motivation strategies and the social version consists of individual and social motivation strategies. Social and individual motivation strategies were included to help participants comply with the training plan. A summary description of these motivation strategies is provided here because a detailed description has been published elsewhere [53]. The intention of the integrated individual motivation strategies (ie, conditioning through positive and negative reinforcement, goal setting, self-monitoring, awareness) is to convince the
person about the expected gain for himself/herself (eg, enhance awareness of health benefits by doing strength and balance exercises). Social motivation strategies (ie, comparison, external monitoring, emotional support, collaboration) aim at supporting individuals (eg, through a social network consisting of training partners and caregivers). ActiveLifestyle supports 6 main features accessible through its menu:

- The What’s Next? option invites the users to start the performance of due workout sessions.
- The Weekly Exercises option shows the scheduled strength-balance sessions organized per week.
- The Progress option shows the user’s progress through the conditioning, goal setting, and self-monitoring strategies previously mentioned in both versions. The social version, in addition to these strategies, also supports the collaboration strategy through a collaborative game.
- The Bulletin Board allows the users to receive written messages, which may include links to websites and YouTube videos. Three types of messages are supported: (1) workout session completed messages to inform the participant(s) about the conclusion of a scheduled session of exercises, (2) ActiveLifestyle tips messages to support the awareness motivation strategy, and (3) public messages written by the training members. It is important to note that only the social version supports the third type of messages and can send messages to the whole training plan community.
- The Friends option lists the members of the training plan community (ie, older users and experts). Only the social version supports this feature.
- The inBox option allows users of the social version to exchange private text messages with their list of friends.

To minimize failure to follow the program because of a memory lapse, an alarm clock helps to remind participants about their training thrice daily. The application has previously shown to be feasible for older adults [54].

**Participants**

A sample of 44 autonomously living older adults was selected according to the following inclusion criteria: older than 65 years, able to walk 20 meters with or without aids, and free of rapidly progressive illness, acute illness, or unstable chronic illness. Ethical approval for the study was obtained from the ETH Ethics Committee (EK 2011-N-64). All participants provided written consent before they participated in the study.
Participants were recruited by convenience sampling from 2 institutions for older people and 1 organization responsible for coordinating and providing at-home nursing care for seniors. The Senioren Begegnungszentrum Baumgärtilhof, a day center dedicated to deliver services and information related to the older population (Horgen, Switzerland), advised potential participants through its mailing list and by notes in the local newspaper. The Alterswohnungen Turm-Matt, a cooperative offering housing and daily living facilities to older people (Wollerau, Switzerland), informed and advised potential participants in person or by phone and distributed flyers to advertise the study. The Fachstelle für präventive Beratung Spitex-Zürich, a home-care nursing organization (Spitex-Zürich), promoted the study sending letters and specifically inviting patients in need of better physical performance. Spitex nurses selected potential participants based on the eligibility criteria.

Participants who fulfilled the inclusion criteria were assigned to either the brochure group (n=17), the social group (n=13), or the individual group (n=14). The social and individual groups received a tablet with the ActiveLifestyle app. Both the social and individual group versions of the app consisted of individual motivation strategies, whereas social motivation strategies were added only for the social group. Participants in the brochure group did their exercises using a training plan on paper sheets.

Participants who stopped doing their exercises during the 12 weeks of the program were defined as dropouts.

**Design**

**Overview**

This study was designed as a phase II preclinical exploratory trial. The outcome variables were measured at baseline (T0) and after 3 months of the intervention. Pre and post measurements took place in suitable locations at the participating institutions. Individuals from the tablet groups visited 1 class to learn how to use the tablet and the included ActiveLifestyle app. A second class was held for all 3 groups to give instructions on how to do the exercises. The training exercise program was to be conducted at home. A flowchart of participants is presented in Figure 5.1.

At entry to the study, a medical history through self-report was taken for demographic and health-related information.
Motor Intervention Program

Interventions that aim to improve walking function and prevent falls should include both strengthening and balance exercises [55]. Therefore, we developed a program with the help of guidelines and recommendations from previous studies [12, 56-58]. Participants from all groups performed the same strength and balance exercises. Detailed information about the physical exercises is shown in Table 5.1 and an exercise example is given in Figure 5.2. The intervention consisted of twice-weekly progressive resistance training for 12 weeks. Training devices used were resistance bands and soft balls. Exercises with resistance bands showed to be efficient in enhancing physical functioning in autonomously living older adults [59]. Before the strength exercises, participants conducted a warm up. Flexibility exercises followed the program to maintain or improve range of motion necessary for daily activities. Additionally, all participants performed 3 balance exercises 5 times a week. Frequency, intensity, and duration of the exercises were based on published recommendations [12, 56, 58, 60].

**Strength training**  
**Exercise 5**  
Seated leg extension  
3 x 12  
1. Tie the weight cuff around your ankle.  
2. Breath in slowly  
3. While exhaling, straighten the leg  
4. While inhaling you lower the heel  
Knees should always remain at the same height, body is straight.

**Figure 5.2:** Example of an exercise instruction: intermediate seated leg extension with weights.
<table>
<thead>
<tr>
<th>Exercises</th>
<th>Beginner</th>
<th>Intermediate</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm up; 2 times/week</strong></td>
<td>1 set, 10 repetitions</td>
<td>1 set, 10 repetitions</td>
<td>1 set, 10 repetitions</td>
</tr>
<tr>
<td></td>
<td>Standing shoulder rotation</td>
<td>Standing shoulder rotation</td>
<td>Standing should rotation</td>
</tr>
<tr>
<td></td>
<td>Standing arms circles</td>
<td>Standing arms circles</td>
<td>Standing arms circles</td>
</tr>
<tr>
<td></td>
<td>March</td>
<td>March</td>
<td>March</td>
</tr>
<tr>
<td></td>
<td>Standing foot to heel point</td>
<td>Standing foot to heel point</td>
<td>Standing foot to heel point</td>
</tr>
<tr>
<td></td>
<td>Standing side tap</td>
<td>Standing side tap</td>
<td>Standing side tap</td>
</tr>
<tr>
<td></td>
<td>Rest head left and right</td>
<td>Rest head left and right</td>
<td>Rest head left and right</td>
</tr>
<tr>
<td><strong>Strength training; 2 times/week</strong></td>
<td>2 sets, 12 repetitions</td>
<td>3 sets, 12 repetitions</td>
<td>3 sets, 12 repetitions</td>
</tr>
<tr>
<td>Chair stand</td>
<td>Chair stand, arms stretched out</td>
<td>Fast chair stand</td>
<td></td>
</tr>
<tr>
<td>Seated hip flexion</td>
<td>Standing hip flexion</td>
<td>Standing hip flexion without placing foot on the floor</td>
<td></td>
</tr>
<tr>
<td>Seated hip adduction</td>
<td>Standing hip adduction</td>
<td>Standing hip adduction</td>
<td></td>
</tr>
<tr>
<td>Seated hip abduction</td>
<td>Standing hip abduction</td>
<td>Standing hip abduction without placing foot on floor</td>
<td></td>
</tr>
<tr>
<td>Seated leg extension</td>
<td>Standing leg extension</td>
<td>Standing leg extension</td>
<td></td>
</tr>
<tr>
<td>Standing leg curl</td>
<td>Standing leg curl</td>
<td>Standing leg curl a, without placing foot on floor</td>
<td></td>
</tr>
<tr>
<td>Standing heel lift</td>
<td>Standing heel lift</td>
<td>One-leg heel lift</td>
<td></td>
</tr>
<tr>
<td>Seated sit-ups</td>
<td>Seated sit-ups, arms behind head</td>
<td>Seated sit-ups, straight arms overhead</td>
<td></td>
</tr>
<tr>
<td>Seated side arm raise with resistance band</td>
<td>Standing side arm raise with resistance band</td>
<td>Side arm raise with resistance band, fast movement</td>
<td></td>
</tr>
<tr>
<td>Seated toe lift</td>
<td>Seated toe lift</td>
<td>Standing toe lift</td>
<td></td>
</tr>
<tr>
<td><strong>Stretching; 2 times/week</strong></td>
<td>3 sets, 15 seconds</td>
<td>3 sets, 15 seconds</td>
<td>3 sets, 15 seconds</td>
</tr>
<tr>
<td>Seated leg stretch</td>
<td>Seated leg stretch</td>
<td>Seated leg stretch</td>
<td></td>
</tr>
<tr>
<td>Seated hip stretch</td>
<td>Seated hip stretch</td>
<td>Seated hip stretch</td>
<td></td>
</tr>
<tr>
<td><strong>Balance; 5 times/week</strong></td>
<td>3 sets, 15 seconds</td>
<td>3 sets, 15 seconds</td>
<td>3 sets, 15 seconds</td>
</tr>
<tr>
<td>One-leg stand</td>
<td>One-leg stand on a towel</td>
<td>One-leg stand, eyes closed</td>
<td></td>
</tr>
<tr>
<td>Full tandem stand</td>
<td>Full tandem stand on a towel</td>
<td>Full tandem stand, eyes closed</td>
<td></td>
</tr>
<tr>
<td>Heel-to-toe walk</td>
<td>Heel-to-toe walk, forward and backward</td>
<td>Heel-to-toe walk, eyes closed</td>
<td></td>
</tr>
</tbody>
</table>

*With ankle weights (0.5-2 kg per leg)*
To ensure exercise progression during the whole program, the intervention was divided into 3 levels. From week 1 to week 4, participants trained at the beginner level; from week 5 to week 8, they trained at the intermediate level; and from week 9 to week 12, they trained at the expert level. The 3 training levels differed in exercise execution, number of sets, and training additives (e.g., ankle weights for strength exercises, towels for balance exercises).

Following performance of each strength and balance exercise, participants registered their performed sets, repetitions, and perceived exertion on Borg’s scale of perceived exertion [61]. The social and individual groups were automatically asked to provide feedback of their exercise experience in the app. Without this feedback, the program would not continue. The brochure group received a paper form to provide this feedback information with a pencil. This information was expected following each strength and balance exercise.

![Timeline and exercise levels](image)

**Figure 5.3:** Timeline and exercise levels.

**Test procedures and outcome measures**

*Program adherence*

The criteria for success of our pilot study [62] were based on feasibility objectives and focused on compliance with the training plan (e.g., the attendance rate of participants). For adherence to the intervention, the compliance of the participants with all trainings was recorded. A compliance rate of 75% was deemed acceptable [63]. Participants were defined as active participants when 75% or more of all planned exercises were performed or as inactive with an attendance less than 75% [64]. Compliance within the exercise program for the groups using tablets was assessed with an automatic registration after completing the exercises, whereas participants of the brochure group had to fill in a training plan diary.

*Gait analysis*

Gait was measured with the portable electronic GAITRite walkway with Platinum Version 4.0 software (CIR Systems, Sparta, NJ, USA). Sampling rate was 60 Hz [65, 66]. This system is a valid and reliable tool for measuring spatial and temporal parameters of gait [67]. Participants were instructed to walk under 4 conditions for 2 or 3 trials each, depending on their physical condition: (1) at their self-selected speed (preferred walking), (2) at their fastest speed (fast walking), (3) at their self-
selected speed while concurrently performing a cognitive task (dual task preferred walking), and (4) at their fastest speed while concurrently performing a cognitive task (dual task fast walking). For the cognitive task, participants were asked to continuously subtract 7 or 3 from a given number while walking. If they were not able to perform the cognitive task, the arithmetical task was modified to a verbal fluency task. The verbal fluency task consisted of enumerating animals or flowers. Participants were asked not to give priority to one task over the other in the dual task test condition, but to try to perform both (walking and calculating) equally well at the same time.

The following temporal-spatial parameters were taken for analysis: velocity (cm/s), cadence (steps/min), step time (s), step length (cm), double support time (s), and variability of step time and length. Variability was expressed as standard deviation of step time (SD step time) and standard deviation of step length (SD step length) over the measured number of gait cycles while walking on the GAITRite walkway.

To quantify participants’ ability to execute 2 tasks simultaneously, we calculated the relative dual task costs (DTC) of walking according the following formula [68, 69]: DTC (%)=100 * (single task score-dual task score) / single task score.

**Physical performance and fear of falling**

Lower extremity functioning was assessed with the Short Physical Performance Battery (SPPB). This test battery consists of a balance test, a 3-meter gait test, and a 5 chair-rises test. The sum of the 3 components comprises the final SPPB score with a possible range from 0 to 12 (12 indicating the highest degree of lower extremity functioning). The SPPB is a valid and reliable measure of mobility in older adults [70] and can predict future disability [71].

The Falls Efficacy Scale International (FES-I) questionnaire was used as a measure of concern about falling to determine the transfer effects of training. This scale assesses both easy and difficult physical activities and social activities (scale: 1=not at all concerned, 2=somewhat concerned, 3=fairly concerned, 4=very concerned). The FES-I has excellent internal and test-retest reliability [72].

**Statistical analysis**

All statistical procedures were conducted with SPSS version 21.00 (SPSS Inc. Chicago, IL, USA). All available data were analyzed by initial group assignment and were performed with an intention-to-treat approach [73]. All participants were included in the analysis regardless of their adherence rate. We assumed that all missing responses were constant and replaced the missing values with mean values of the group to which participants were originally allocated [74]. Because of the nonnormality of the data, baseline comparison and interaction effects of groups (between-groups differences) were undertaken using a Mann-Whitney U test. The effects size, $r$, was calculated as $r=z/\sqrt{N}$ (where $z$
is the approximation of the observed difference in terms of the standard normal distribution and $N$ is the total sample number). To identify differences between pretests and posttests (within-group differences) a Wilcoxon signed rank test was conducted. We identified differences between (1) the brochure group and the tablet groups (brochure group vs social and individual groups), (2) between the 2 tablet groups: (social group vs individual group), and (3) between active and inactive participants using planned comparisons.

Suggested norms for interpreting $r$ are .10=small effect, .30=moderate effect, and .50=large effect. A probability level of $P<.05$ was considered to be statistically significant.

5.3 Results

Overview

Participants’ demographics and baseline characteristics are summarized in Table 5.2. Results are based on a self-report health questionnaire. In general, there were no significant between-groups differences of baseline demographics for most parameters using planned comparisons: (1) brochure group vs social group and individual groups and (2) social group vs individual group. We detected significant differences between (1) brochure group vs social and individual groups in joint diseases, practiced some sport in the past, and 3 or more medications daily. The brochure group reported less joint diseases ($U=139$, $P=.01$, $r=.38$), practiced less sport in the past ($U=144$, $P=.02$, $r=.36$), and took less medication ($U=166.5$, $P=.04$, $r=.32$).

Program adherence

The median relative training adherence was 59.3% in the brochure group (IQR 0.0%-88.9%), 84.0% in the social group (IQR 77.2%-89.5%), and 80.9% (IQR 52.8%-88.9%) in the individual group. We registered 7 active (41%) and 10 inactive (59%) participants for the brochure group ($n=17$), 11 active (85%) and 2 inactive (15%) participants for the social group ($n=13$), and 8 active (57%) and 6 inactive (43%) participants for the individual group ($n=14$). In total, 26 of 44 participants reached the goal of 75% adherence or more and were analyzed as active (59%), whereas 18 of 44 (41%) were classified as poor compliers and inactive participants. The brochure group had more inactive participants, but this did not meet statistical significance ($U=167$, $P=.06$, $r=.29$). There were no significant differences between the 2 tablet groups. By further investigating differences in baseline characteristics between active and inactive participants, we found significantly more inactive participants with type II diabetes mellitus ($U=178$, $P=.03$, $r=.34$). There were no further differences between active and inactive participants concerning their baseline characteristics. Details on the 25% attrition rate have been previously published [53].
### Table 5.2. Participants’ demographics and baseline characteristics (N=44).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Brochure n=17</th>
<th>Group Social n=13</th>
<th>Individual n=14</th>
<th>Activity level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD)</td>
<td>76 (15)</td>
<td>74 (5)</td>
<td>75 (6)</td>
<td>75 (5)</td>
</tr>
<tr>
<td>Sex, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10</td>
<td>8 (62)</td>
<td>10 (71)</td>
<td>15 (58)</td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>5 (38)</td>
<td>4 (29)</td>
<td>11 (42)</td>
</tr>
<tr>
<td>Fall risk factors, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow walking speed (&lt;1.22 m/s)</td>
<td>10 (59)</td>
<td>9 (69)</td>
<td>7 (50)</td>
<td>14 (54)</td>
</tr>
<tr>
<td>Fell in the last 6 months*</td>
<td>4 (24)</td>
<td>5 (38)</td>
<td>2 (14)</td>
<td>5 (19)</td>
</tr>
<tr>
<td>3 or more prescription medications</td>
<td>1 (6)</td>
<td>4 (31)</td>
<td>5 (36)</td>
<td>8 (30)</td>
</tr>
<tr>
<td>Physical functioning; SPPB (points)</td>
<td>9.8</td>
<td>9.7</td>
<td>9.9</td>
<td>10.1</td>
</tr>
<tr>
<td>Fear of falling; FES-I (points)</td>
<td>17.9</td>
<td>20.0</td>
<td>18.5</td>
<td>18.9</td>
</tr>
<tr>
<td>Education/profession, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University/college</td>
<td>1 (6)</td>
<td>2 (15)</td>
<td>3 (21)</td>
<td>3 (12)</td>
</tr>
<tr>
<td>Vocational education</td>
<td>10 (59)</td>
<td>7 (54)</td>
<td>7 (50)</td>
<td>18 (69)</td>
</tr>
<tr>
<td>No educated profession</td>
<td>6 (35)</td>
<td>4 (31)</td>
<td>4 (29)</td>
<td>5 (19)</td>
</tr>
<tr>
<td>In a sitting position past profession</td>
<td>6 (35)</td>
<td>6 (46)</td>
<td>7 (50)</td>
<td>13 (50)</td>
</tr>
<tr>
<td>Health questions, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of self-reported chronic diseases</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint diseases</td>
<td>4 (24)</td>
<td>7 (54)</td>
<td>9 (64)</td>
<td>13 (50)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>5 (29)</td>
<td>4 (31)</td>
<td>3 (21)</td>
<td>8 (31)</td>
</tr>
<tr>
<td>Cardiac problems</td>
<td>3 (18)</td>
<td>4 (31)</td>
<td>4 (29)</td>
<td>6 (23)</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>3 (18)</td>
<td>2 (15)</td>
<td>2 (14)</td>
<td>3 (12)</td>
</tr>
<tr>
<td>Type II diabetes mellitus</td>
<td>1 (6)</td>
<td>1 (8)</td>
<td>3 (21)</td>
<td>1 (4)</td>
</tr>
<tr>
<td>Self-reported walking problems</td>
<td>5 (29)</td>
<td>6 (46)</td>
<td>3 (21)</td>
<td>8 (31)</td>
</tr>
<tr>
<td>Need walking aid</td>
<td>1 (6)</td>
<td>2 (15)</td>
<td>1 (7)</td>
<td>3 (12)</td>
</tr>
<tr>
<td>Hearing problems</td>
<td>6 (35)</td>
<td>5 (38)</td>
<td>4 (29)</td>
<td>8 (31)</td>
</tr>
<tr>
<td>Vision problems</td>
<td>8 (47)</td>
<td>6 (46)</td>
<td>4 (29)</td>
<td>11 (42)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>3 (18)</td>
<td>5 (38)</td>
<td>2 (14)</td>
<td>6 (23)</td>
</tr>
<tr>
<td>Estimated good health</td>
<td>8 (47)</td>
<td>8 (62)</td>
<td>5 (36)</td>
<td>17 (65)</td>
</tr>
<tr>
<td>Estimated better health compared with contemporary</td>
<td>8 (47)</td>
<td>3 (23)</td>
<td>3 (21)</td>
<td>11 (42)</td>
</tr>
<tr>
<td>Estimated good balance</td>
<td>5 (29)</td>
<td>3 (23)</td>
<td>4 (29)</td>
<td>7 (27)</td>
</tr>
<tr>
<td>Feel pain daily</td>
<td>4 (24)</td>
<td>2 (15)</td>
<td>3 (21)</td>
<td>5 (19)</td>
</tr>
<tr>
<td>Physical activity questions, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practice some physical activity</td>
<td>7 (41)</td>
<td>6 (46)</td>
<td>3 (21)</td>
<td>11 (42)</td>
</tr>
<tr>
<td>Practiced some sport in the past</td>
<td>10 (59)</td>
<td>8 (62)</td>
<td>10 (71)</td>
<td>14 (54)</td>
</tr>
<tr>
<td>Practiced strength exercises in the past</td>
<td>3 (18)</td>
<td>6 (46)</td>
<td>3 (21)</td>
<td>6 (23)</td>
</tr>
</tbody>
</table>

*A fall was defined as an event, which resulted in a person coming to rest on the ground or other lower level.

### Gait analysis

Table 5.3 details the results of the spatiotemporal walking parameters of the 3 groups. Participants’ performance in the posttest was significantly higher than in the pretest throughout all 4 conditions (preferred walking, fast walking, preferred dual task walking, fast dual task walking) for the 2 tablet groups (social group and individual group). In contrast, apart from step length during fast walking, there were no significant improvements in the brochure group observable. The active participants performed significantly better at posttests compared to pretests, whereas the inactive participants did not improve.
<table>
<thead>
<tr>
<th>Condition and parameters</th>
<th>Single task walking, median (IQR)</th>
<th>Dual task walking, median (IQR)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td></td>
</tr>
<tr>
<td>Brochure group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>109.9 (103.7, 112.1)</td>
<td>109.9 (106.8, 125.4)</td>
<td>.09</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>109.7 (101.7, 110.1)</td>
<td>109.7 (106.9, 115.4)</td>
<td>.07</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>60.0 (60.0, 65.4)</td>
<td>60.0 (60.0, 67.2)</td>
<td>.06</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.55 (0.55, 0.57)</td>
<td>0.55 (0.52, 0.55)</td>
<td>.07</td>
</tr>
<tr>
<td>SD steplength (cm)</td>
<td>2.70 (2.38, 2.74)</td>
<td>2.70 (2.32, 3.70)</td>
<td>.24</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.022 (0.018, 0.022)</td>
<td>0.022 (0.013, 0.022)</td>
<td>.51</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.35 (0.32, 0.36)</td>
<td>0.35 (0.32, 0.35)</td>
<td>.14</td>
</tr>
<tr>
<td>Fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>142.3 (139.8, 145.0)</td>
<td>142.3 (142.3, 160.0)</td>
<td>.06</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>127.8 (121.5, 127.8)</td>
<td>127.8 (125.4, 128.7)</td>
<td>.20</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>66.7 (66.3, 70.5)</td>
<td>66.6 (66.6, 74.1)</td>
<td>.02</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.48 (0.48, 0.49)</td>
<td>0.48 (0.47, 0.48)</td>
<td>.17</td>
</tr>
<tr>
<td>SD steplength (cm)</td>
<td>2.96 (2.65, 2.98)</td>
<td>2.96 (2.66, 3.16)</td>
<td>.24</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.020 (0.013, 0.020)</td>
<td>0.020 (0.011, 0.020)</td>
<td>.65</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.27 (0.27, 0.27)</td>
<td>0.27 (0.25, 0.27)</td>
<td>.17</td>
</tr>
<tr>
<td>Social group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>108.3 (95.87, 129.73)</td>
<td>108.3 (103.9, 129.73)</td>
<td>.06</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>106.1 (101.1, 112.3)</td>
<td>106.1 (105.7, 117.7)</td>
<td>.06</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>60.9 (54.6, 67.3)</td>
<td>60.9 (58.9, 75.1)</td>
<td>.04</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.57 (0.54, 0.59)</td>
<td>0.51 (0.51, 0.57)</td>
<td>.01</td>
</tr>
<tr>
<td>SD steplength (cm)</td>
<td>2.05 (1.80, 2.31)</td>
<td>2.05 (1.52, 2.61)</td>
<td>.37</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.019 (0.015, 0.021)</td>
<td>0.019 (0.011, 0.020)</td>
<td>.14</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.33 (0.30, 0.38)</td>
<td>0.32 (0.27, 0.35)</td>
<td>.02</td>
</tr>
<tr>
<td>Fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>146.5 (136.0, 382.8)</td>
<td>152.8 (136.3, 200.5)</td>
<td>.03</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>128.5 (121.2, 136.2)</td>
<td>133.6 (119.8, 154.7)</td>
<td>.06</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>69.6 (59.7, 76.5)</td>
<td>69.4 (65.4, 78.3)</td>
<td>.42</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.47 (0.45, 0.49)</td>
<td>0.50 (0.51, 0.59)</td>
<td>.05</td>
</tr>
<tr>
<td>SD steplength (cm)</td>
<td>2.62 (2.05, 2.37)</td>
<td>2.66 (2.16, 3.11)</td>
<td>.59</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.014 (0.011, 0.018)</td>
<td>0.014 (0.010, 0.017)</td>
<td>.89</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.25 (0.20, 0.27)</td>
<td>0.25 (0.17, 0.27)</td>
<td>.25</td>
</tr>
<tr>
<td>Individual group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>123.0 (112.9, 137.2)</td>
<td>132.8 (123.0, 156.1)</td>
<td>.01</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>113.7 (109.2, 119.3)</td>
<td>124.4 (113.6, 128.9)</td>
<td>.01</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>64.8 (61.6, 70.4)</td>
<td>64.8 (64.1, 70.4)</td>
<td>.08</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.53 (0.50, 0.55)</td>
<td>0.48 (0.47, 0.53)</td>
<td>.01</td>
</tr>
<tr>
<td>SD steplength (cm)</td>
<td>1.88 (1.68, 2.10)</td>
<td>1.74 (1.48, 1.86)</td>
<td>.18</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.017 (0.015, 0.019)</td>
<td>0.013 (0.011, 0.017)</td>
<td>.01</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.30 (0.27, 0.33)</td>
<td>0.27 (0.23, 0.30)</td>
<td>.01</td>
</tr>
<tr>
<td>Fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>179.1 (167.2, 290.9)</td>
<td>183.8 (175.0, 216.3)</td>
<td>.03</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>146.1 (144.1, 254.6)</td>
<td>155.7 (146.4, 171.1)</td>
<td>.01</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>73.6 (69.7, 75.4)</td>
<td>73.6 (70.2, 76.2)</td>
<td>.53</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.41 (0.39, 0.42)</td>
<td>0.39 (0.35, 0.41)</td>
<td>.01</td>
</tr>
<tr>
<td>SD steplength (cm)</td>
<td>2.72 (2.34, 3.04)</td>
<td>2.72 (2.34, 3.97)</td>
<td>.79</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.014 (0.011, 0.017)</td>
<td>0.012 (0.010, 0.014)</td>
<td>.37</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.19 (0.16, 0.20)</td>
<td>0.16 (0.12, 0.19)</td>
<td>.04</td>
</tr>
</tbody>
</table>
Table 5.3. Participants’ single and dual task walking performance during the pretests and posttests and within-group significance calculated with Wilcoxon signed rank test.

<table>
<thead>
<tr>
<th>Condition and parameters</th>
<th>Single task walking, median (IQR)</th>
<th>Dual task walking, median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td><strong>Active</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preferred</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>117.1 (104.5, 129.3)</td>
<td>121.0 (107.5, 153.5)</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>109.1 (102.1, 116.8)</td>
<td>111.7 (116.7, 126.3)</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>64.6 (58.4, 69.3)</td>
<td>65.8 (60.8, 74.4)</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.55 (0.51, 0.59)</td>
<td>0.51 (0.48, 0.56)</td>
</tr>
<tr>
<td>SD step length (cm)</td>
<td>2.06 (1.82, 2.41)</td>
<td>1.71 (1.40, 2.17)</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.017 (0.014, 0.021)</td>
<td>0.012 (0.011, 0.018)</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.31 (0.29, 0.37)</td>
<td>0.29 (0.25, 0.38)</td>
</tr>
<tr>
<td><strong>Fast</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>157.3 (141.0, 181.8)</td>
<td>166.9 (145.7, 204.9)</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>131.1 (119.8, 145.9)</td>
<td>135.7 (121.7, 163.5)</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>71.8 (63.0, 77.6)</td>
<td>72.7 (67.0, 81.6)</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.46 (0.41, 0.50)</td>
<td>0.44 (0.37, 0.49)</td>
</tr>
<tr>
<td>SD step length (cm)</td>
<td>2.66 (2.13, 3.49)</td>
<td>2.62 (1.93, 3.33)</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.013 (0.011, 0.016)</td>
<td>0.011 (0.009, 0.018)</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.24 (0.19, 0.27)</td>
<td>0.22 (0.13, 0.26)</td>
</tr>
<tr>
<td><strong>Inactive</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preferred</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>109.9 (104.9, 116.7)</td>
<td>109.9 (109.9, 125.4)</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>109.7 (106.9, 117.4)</td>
<td>111.3 (109.7, 114.1)</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>60.0 (60.0, 64.1)</td>
<td>60.4 (60.0, 64.8)</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.55 (0.53, 0.56)</td>
<td>0.54 (0.53, 0.55)</td>
</tr>
<tr>
<td>SD step length (cm)</td>
<td>2.58 (1.91, 2.70)</td>
<td>2.39 (1.82, 2.70)</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.022 (0.017, 0.022)</td>
<td>0.019 (0.017, 0.022)</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.35 (0.32, 0.35)</td>
<td>0.34 (0.30, 0.35)</td>
</tr>
<tr>
<td><strong>Fast</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>142.2 (142.2, 179.1)</td>
<td>144.4 (142.2, 179.3)</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>127.8 (127.4, 144.5)</td>
<td>128.2 (127.8, 146.4)</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>66.6 (66.6, 73.6)</td>
<td>67.0 (66.6, 73.6)</td>
</tr>
<tr>
<td>Step time (s)</td>
<td>0.48 (0.42, 0.48)</td>
<td>0.47 (0.41, 0.48)</td>
</tr>
<tr>
<td>SD step length (cm)</td>
<td>2.93 (2.70, 2.96)</td>
<td>2.96 (2.72, 2.96)</td>
</tr>
<tr>
<td>SD step time (s)</td>
<td>0.017 (0.014, 0.020)</td>
<td>0.018 (0.014, 0.020)</td>
</tr>
<tr>
<td>Double support time (s)</td>
<td>0.027 (0.019, 0.027)</td>
<td>0.026 (0.019, 0.027)</td>
</tr>
</tbody>
</table>
Differences between the brochure group and the tablet groups, between the 2 tablet groups, and between active and inactive participants are summarized in Table 5.4. Performance of the tablet groups differed significantly from the brochure group in the dual task walking condition with preferred walking speed: dual task preferred walking (velocity: \( U=138.5, P=.03, r=.33 \); cadence: \( U=138.5, P=.03, r=.34 \)). Preferred, fast walking and dual task preferred walking did not show significant differences between the 2 tablet groups (social group vs individual group). However, a significant difference was found for dual task fast walking (SD of step length: \( U=49, P=.04, r=.39 \)).

Comparison between active and inactive participants revealed significant differences in velocity throughout all conditions (preferred: \( U=145, P=.03, r=.32 \); fast: \( U=146.5, P=.04, r=.32 \); dual task preferred walking: \( U=82.5, P>.001, r=.55 \); dual task fast walking: \( U=100.5, P=.001, r=.05 \)). Although the active participants outperformed the inactive participants in most parameters in walking conditions, preferred walking, dual task preferred walking, and in dual task fast walking, there were no further significant differences for fast walking.

Analyses of dual task costs (DTC) with preferred walking speed revealed significant differences between pretest and posttest for the individual group (velocity: \( P=.03, z=-2.134 \); cadence: \( P=.02, z=-2.401 \); step time: \( P=.02, z=-2.401 \); double support time: \( P=.02, z=-2.401 \)). In contrast, performance over time did not increase for the brochure and social groups. In the fast walking condition, DTC decreased for the brochure group (SD of step time: \( P=.047, z=1.988 \)). No significant differences were reported between (1) the brochure group and the tablet groups, and (2) the social group and the individual group.

Between-group differences in DTC of walking revealed significant greater performance for the active group when compared with the inactive group (DTC preferred: velocity: \( U=151.5, P=.047, r=0.30 \); cadence: \( U=139.5, P=.02, r=.34 \); step time: \( U=149.5, P=.04, r=.31 \); DTC fast: SD of step time: \( U=152.5, P=.049, r=.30 \)).

Participants’ single and dual task walking performance during the pretests and posttests and within-group significance calculated with Wilcoxon signed rank test.
Table 5.4. P values of participants’ walking performance (between-groups differences after intervention phase calculated with Mann-Whitney U test).

<table>
<thead>
<tr>
<th>Condition/parameters</th>
<th>Brochure vs social and individual</th>
<th>Social vs individual</th>
<th>Active vs inactive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>r ^a</td>
<td>P</td>
</tr>
<tr>
<td>Preferred</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>.08</td>
<td>.26</td>
<td>.96</td>
</tr>
<tr>
<td>Cadence</td>
<td>.09</td>
<td>.26</td>
<td>.63</td>
</tr>
<tr>
<td>Step length</td>
<td>.22</td>
<td>.18</td>
<td>.53</td>
</tr>
<tr>
<td>Step time</td>
<td>.14</td>
<td>.22</td>
<td>.92</td>
</tr>
<tr>
<td>SD step length</td>
<td>.91</td>
<td>.02</td>
<td>.99</td>
</tr>
<tr>
<td>SD step time</td>
<td>.08</td>
<td>.26</td>
<td>.44</td>
</tr>
<tr>
<td>Double support time</td>
<td>.19</td>
<td>.20</td>
<td>.53</td>
</tr>
<tr>
<td>Fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>.37</td>
<td>.14</td>
<td>.96</td>
</tr>
<tr>
<td>Cadence</td>
<td>.09</td>
<td>.25</td>
<td>.66</td>
</tr>
<tr>
<td>Step length</td>
<td>.38</td>
<td>.13</td>
<td>.96</td>
</tr>
<tr>
<td>Step time</td>
<td>.24</td>
<td>.18</td>
<td>.90</td>
</tr>
<tr>
<td>SD step length</td>
<td>.53</td>
<td>.10</td>
<td>.96</td>
</tr>
<tr>
<td>SD step time</td>
<td>.40</td>
<td>.13</td>
<td>.44</td>
</tr>
<tr>
<td>Double support time</td>
<td>.36</td>
<td>.14</td>
<td>.72</td>
</tr>
<tr>
<td>Dual task preferred</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>.03</td>
<td>.33</td>
<td>.44</td>
</tr>
<tr>
<td>Cadence</td>
<td>.03</td>
<td>.33</td>
<td>.37</td>
</tr>
<tr>
<td>Step length</td>
<td>.37</td>
<td>.14</td>
<td>.99</td>
</tr>
<tr>
<td>Step time</td>
<td>.05</td>
<td>.29</td>
<td>.47</td>
</tr>
<tr>
<td>SD step length</td>
<td>.28</td>
<td>.16</td>
<td>.92</td>
</tr>
<tr>
<td>SD step time</td>
<td>.20</td>
<td>.19</td>
<td>.47</td>
</tr>
<tr>
<td>Double support time</td>
<td>.11</td>
<td>.24</td>
<td>.17</td>
</tr>
<tr>
<td>Dual task fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>.20</td>
<td>.19</td>
<td>.59</td>
</tr>
<tr>
<td>Cadence</td>
<td>.07</td>
<td>.28</td>
<td>.59</td>
</tr>
<tr>
<td>Step length</td>
<td>.58</td>
<td>.08</td>
<td>.20</td>
</tr>
<tr>
<td>Step time</td>
<td>.14</td>
<td>.22</td>
<td>.47</td>
</tr>
<tr>
<td>SD step length</td>
<td>.30</td>
<td>.16</td>
<td>.04</td>
</tr>
<tr>
<td>SD step time</td>
<td>.61</td>
<td>.08</td>
<td>.38</td>
</tr>
<tr>
<td>Double support time</td>
<td>.22</td>
<td>.18</td>
<td>.96</td>
</tr>
</tbody>
</table>

^a Effect size (small effect: r = .1; medium effect: r = .3; large effect: r = .5).
Physical performance and fear of falling

Table 5.5 demonstrates changes over time for fear of falling (FES-I) and physical performance (SPPB) for the 3 groups. The SPPB showed significant improvements for all groups. There were no differences between pretest and posttest for FES-I. Significant group differences for FES-I were observed between the brochure group and tablet groups ($U=151.5$, $P=.04$, $r=.31$); however, not between the 2 tablet groups ($U=89.5$, $P=.94$, $r=.01$) or the active and inactive participants ($U=210.5$, $P=.53$, $r=.09$). We found a significant difference between active and inactive participants in SPPB ($U=139$, $P=.02$, $r=.36$).

<table>
<thead>
<tr>
<th>Test</th>
<th>Brochure group, median (IQR)</th>
<th>Social group, median (IQR)</th>
<th>Individual group, median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td>$P$</td>
</tr>
<tr>
<td></td>
<td>9.8 (9.4, 11.0)</td>
<td>11.0 (9.8, 12.0)</td>
<td>.02</td>
</tr>
<tr>
<td>SPPB</td>
<td>9.7 (8.0, 11.0)</td>
<td>12.0 (9.7, 12.0)</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>9.9 (8.8, 11.0)</td>
<td>11.0 (9.9, 12.0)</td>
<td>.02</td>
</tr>
<tr>
<td>FES-I</td>
<td>17.9 (16.0, 17.9)</td>
<td>17.9 (17.0, 17.9)</td>
<td>.49</td>
</tr>
<tr>
<td></td>
<td>20.0 (17.0, 21.5)</td>
<td>20.0 (17.0, 20.6)</td>
<td>.23</td>
</tr>
<tr>
<td></td>
<td>18.9 (17.5, 20.0)</td>
<td>18.0 (16.0, 18.9)</td>
<td>.27</td>
</tr>
</tbody>
</table>

Social interaction

We registered the number of dispatched messages. The total number of messages dispatched to the bulletin board was 31 from the social group participants sent by 8 of 13 social group participants. The caregivers dispatched a total of 37 messages to the bulletin board. Six of 13 social group participants wrote 13 messages to another participant. Participants received 84 messages from caregivers; 93 messages were dispatched by 11 social group participants to caregivers. Thus, most interaction occurred between caregivers and participants and not between participants, indicating the importance of social support from caregivers.

5.4 Discussion

Principal findings

This study compared 3 different home-based training programs and their effect on measures of gait quality while considering adherence to the training program. We hypothesized that there would be differing results for (1) the tablet-based groups when compared to the brochure group, (2) the tablet group with social motivation strategies when compared to the tablet group with individual motivation strategies, and (3) active participants when compared to inactive participants. The outcomes of interest were gait quality and lower extremity physical performance. Furthermore, the aim was to assess the influence of different motivation strategies offered to the trainees.
**Gait analysis**

From previous studies, we know that home-based exercise training can have beneficial effects on physical performance outcomes [1, 75], provided the program is adhered to [76]. Our results of the walking quality analysis show significant improvements from pretest to posttest, especially in the training groups that showed high adherence rates. The tablet groups reached higher adherence rates compared to the brochure group. Furthermore, participants in the tablet groups were able to improve gait velocity throughout all walking conditions (preferred and fast single task walking, preferred and fast dual task walking), whereas the brochure group failed to increase this performance aspect following 12 weeks of training. Usual gait speed is a predictor for disability, falls, and mortality [26]. In comparison to our brochure group and the inactive participants, the tablet groups and the active participants reached improvements of 10 cm/s or more. Such improvements represent clinically meaningful change in gait speed [26]. Walking at fastest speed may serve as a useful diagnostic measure for people at higher risk for multiple falls. In the fast walking condition, shorter step length relates to falls [77]. We reported an improvement in step length during walking in our group of active participants, but not in the inactive participants. Both the tablet groups and the active participants improved velocity during fastest walking. Compared to literature reference values where an expected preferred and fast walking speed for independently living elderly would be approximately 133 cm/s and 207 cm/s, respectively [78], our samples performed worse pretraining. Following training, however, the tablet groups improved toward these reference values.

Frail elderly people and elderly people who tend to fall exhibit increased variability in measures of gait [23, 79, 80]. Elderly nonfallers present low rates of variability of temporal variables [20,24]. Decreased leg strength explains greater variability [81]. This study shows that tablet-based exercise may decrease gait variability provided the trainees adhere to the training plan. The brochure group demonstrated no decrease in gait variability after the intervention. In contrast, the tablet groups showed significantly lower variability throughout all measurement conditions. This especially holds true for the group with individual motivation strategies and for step time variability. Step time and double support time—factors that have been previously related to falls [35]—decreased throughout all conditions, again solely in the tablet groups. Thus, our trial underpins the importance of training program compliance in preventive exercise programs for elderly and indicates that an appropriate targeted tablet-based exercise application is able to positively influence exercise adherence in independent-living elderly training at home. Because of the higher training adherence, the tablet-based exercise groups improved their single and dual task walking to a larger extent compared to a group trained with a more conventional type of brochures-based training.
Dual task walking (ie, the ability to perform a second task while walking) is a key element to remain independent because this is an ability required for many activities in daily life. Daily activities pose high cognitive demands and safe walking should be practicable under cognitively distractive or otherwise challenging conditions. Our findings in dual task walking are similar to some extent to the findings of Pichierri et al [82], who reported no improvements in dual task walking with an isolated motor training program. This finding was in-line with previous studies that investigated the effect of an isolated physical training program that were not able to demonstrate improvements in walking under attention-demanding circumstances [83, 84]. Our intervention did not consist of a cognitive training part and it can be speculated that an extension of our program with a cognitive challenge will be more effective in influencing walking under attention-demanding circumstances. Future research should be directed to investigating the value of additional cognitive elements to the training program to substantiate these assumptions.

**Physical performance**

We found a significant improvement in SPPB scores within all groups, reflecting enhanced lower extremity function and walking ability [85]. On average, a person that reaches less than 10 points on the SPPB is almost 3.5 times more susceptible to suffer from mobility disability than a person scoring the maximum of 12 points [85]. All 3 groups reached a median relative score of 11 points or more in the posttests, compared to a median relative score of less than 10 points in the pretests.

**Program adherence**

An important issue in the field of exercise interventions with elderly people is adherence to the training plan [76]. Elderly people will only be able to reap the gains from exercise under the precondition that they comply with and progress through the exercise plan. A systematic review investigating adherence to multifactorial interventions in falls prevention in community settings for clinical trials reported rates ranging between 28% and 95%. The general range was approximately 75%, which was the reason we chose this level to divide our training group into active versus inactive participants. Compared with these values [86], we achieved better or similar rates as 75% adherence; however, this was for the tablet-based training groups only. Furthermore, we observed the most prominent differences in training effects between the active and the inactive participants. Active participants demonstrated significantly higher performance in several spatial-temporal walking parameters compared to the inactive participants. This supports findings from other studies showing that better compliance leads to significantly higher training-related benefits [87, 88] and indicates that adherence moderated treatment effectiveness. We report on values after 3 training months, but Nyman and Victor [64] reported values that may be expected by 12 months. In a future phase III trial,
the follow-up period for the assessment of adherence and attrition should preferably be extended to a similar time frame to facilitate comparability of this future study with reference values.

Social support [48] and commitment to or advice from health experts, physicians, or caregivers are reasons for higher compliance rates and more moderate exercise conduction [44, 89]. In an analysis of compliance in home-based exercise programs, an increase in compliance was registered in a brochure-based group compared with the outcome of a control group who did not receive any recommendations [90]. Moreover, a DVD-supported training program reported better adherence compared to brochures [89]. DVDs might help to overcome motivational problems [89] and enhance exercise correctness [91] compared to brochure-guided exercise programs. The amount of messages dispatched indicates that most interactions occurred between caregivers and participants and not between participants. This reflects the importance of social support of caregivers to the trainees.

Motivation is an important parameter for home-based exercise performance [92] and should be explicitly considered in the design of interventions. The program used in our study explicitly considered motivational elements and allowed participants contacting experts and training partners. The most active participants were found in the social group, whereas the most inactive participants belonged to the brochure group (although this did not meet statistical significance). This result supports our assumption that social motivation strategies enhance compliance. Apart from that, there seems to be no direct gain from social motivation strategies on walking quality compared with individual motivation strategies because the results of the 2 tablet groups did not differ in the outcome measures.

**Limitations**

An obvious limitation of this study is that the groups were only partly randomized. Therefore, this study only reveals first estimates and warrants further research with a properly randomized model. A further limitation is the rather small sample size. Measurements of compliance are based on written information of participants, which cannot be seen as an instrument that guarantees the participants followed the exercises. Better control instruments would be a useful extension to further studies.

Additionally, correctness of the exercise was not controlled. To overcome this problem, further research should include technologies to control posture and movement pattern. Video analysis with 3-dimensional motion tracking equipment or microelectromechanical systems (MEMS) can offer opportunities to link clinicians and potential users [93]. Another option is the Health Hub (HH) software that allows recognition and analysis of motion [93].

We treated the dropouts of this study as part of the treatment group to which they were assigned even if they did not receive the full intervention. Intention-to-treat is a recommended approach to
several types of nonadherence to the study protocol [94], able to reduce the potential dropout bias effect [95]. We replaced missing data with the mean values of the groups, thus allowing complete case analysis. A drawback of this approach is reduced variability and weakening of covariance and correlation estimates in the data. Future adequately powered studies with larger samples should be performed with both intention-to-treat and per-protocol analysis.

Conclusions

The findings of this study are in-line with previous research that demonstrated improvements in gait quality and physical performance of older adults after strength-balance exercises. This study adds useful information about home-based training programs for older adults. Our participants adhered better to the weekly physical intervention when provided with the ActiveLifestyle app. This clearly described exercise program, including motivational aspects, an attractive design, automatized reminders, and the opportunity to give feedback about performed exercises to training supervisors, seems to contain important elements to enhance adherence and compliance rates, which leads to training-related improvements. The trainees that complied with the training plan improved gait and physical performance. The tablet-based program resulted in higher rates of adherence compared to the brochure-based program. These findings suggest that in older adults a tablet-based intervention may enhance compliance and potentially offers an effective way to improve gait.

Acknowledgments

This work was carried out with the support of Maria Messmer-Capaul and her team of the Fachstelle für präventive Beratung Spitex-Zürich, Claudia Nüesch of the Senioren Begegnungszentrum Baumgärtlihof, and Data Quest who provided tablets for the study. We would like to thank all the participants for their great enthusiasm and support. This work is partially sponsored by the project Anchise funded by the Autonomous Province of Trento, Italy, and the EIT project Virtual Social Gym and performed in collaboration with Tomsk Polytechnic University within the project Evaluation and enhancement of social, economic and emotional well-being of older adults under the Agreement No:14.Z50.31.0029.

Conflicts of Interest

None declared.

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6 Epilogue

There is sufficient evidence that being physically active on a regular basis is one of the most promising opportunities to extend years of active independent life [1]. Although the relevance of avoiding a sedentary lifestyle has long been recognized, the successful implementation of exercise is often challenged by several barriers. Older adults face barriers, e.g. no access to appropriate training equipment, and lack of support and motivation that prevent them from starting and maintaining training.

A physical intervention program that aims at improving gait function in older adults should explicitly include strength and balance exercises [2-5]. The fact that older adults fall, even when their motor functions are fairly intact, suggests that a program aiming at preventing falls should also consider the training of cognitive functions and, especially, higher level cognitive functions (i.e. executive functions) [6]. Until now, most programs did not combine cognitive and motor training, and the focus was not on executive functions [7]. Furthermore, most of the few studies that so far tested a cognitive-motor approach, describe their low sample size as being a limitation [8-12].

This doctoral dissertation addresses the further exploration of the additional effect of cognitive training, focusing on attention, whilst comparing a motor to a cognitive-motor training group in a sufficiently powered multicenter randomized-controlled trial. The research goal was to elaborate the effectiveness of cognitive-motor training compared to isolated motor training in improving physical and cognitive performance, and in reducing falls.

Furthermore, the thesis also discusses the approach of implementing training with the help of a tablet app called ActiveLifestyle, an app for autonomous strength-balance training aiming at older adults living independently. The tablet-app was created to assist, monitor, and motivate during training. In addition to examining acceptance, feasibility and usability of the new technologies, the objective was to compare the physical benefits of the participants training with the app to those training with a brochure.

6.1 Main findings of the cognitive-motor intervention study

*Strength-balance supplemented with computerized cognitive training to improve dual task gait and divided attention in older adults: A multicenter randomized-controlled trial*

As discussed in the prologue, most of the current studies combining cognitive and motor training are only pilot studies and, thus, only reveal first estimates, and/or do not report falls behavior [8, 13, 14]. These limitations are addressed by the study presented in Chapter 2. The primary outcome, the dual
task costs of walking, investigates the attentional requirements of walking through measuring the loss of performance for walking with concurrent performance of a cognitive task. Both groups attained improvements in physical and cognitive performance, however, the results of the test for dual task walking and divided attention demonstrated positive interaction effects favoring SBC. In line with findings from previous literature the study demonstrated that a strength-balance training is able to preserve or enhance dual task walking ability [3], and to improve executive functions [15]. However, strength-balance training alone fails to reduce dual task costs of walking [16, 17]. Linking it to the study with tablet- and brochure-based strength-balance training presented in Chapter 5, neither the tablet groups nor the brochure group minimized the dual task costs of walking. These findings support and substantiate the suggestion of previous pilot studies with the aim to enhance complex walking performance, i.e. that cognitive and motor training should be combined [10, 18].

A parameter of walking that seems directly related to divided attention is step length. The significant interaction in favor of SBC for dual task costs of both step length and the variability of step length extend previous results, linking motor-cognitive training causally to step length [19]. The parameter step length shows a relationship with brain structure changes [20]. Indirectly it correlates with survival, since reduced gait speed, a parameter associated to mortality [21], partly results from shorter steps [22].

The relevance of combining cognitive and motor training was also demonstrated for gait initiation, which is a frequently repeated task in daily life and was considerably more improved by the cognitive-motor group. The mechanisms of the central nervous system controlling gait initiation are stable and efficient, however, disturbances of these mechanisms, which require efficient peripheral sensory detection, central neural processing and nerve conduction, lead to a loss in balance control and falls during gait initiation [23-26]. To quickly initiate a step in the event of falling is partly dependent on the efficiency of our response-processing system. In the event of falling, the goal is to regain a stable position, which often happens through a step, and the faster the step the higher the probability that a fall is prevented [27-29]. Interestingly, but not unexpectedly, both our groups improved simple reaction time. During this task participants had one reaction opportunity (to press a button) to one visual stimulus (a light). The results of reaction time during the task for divided attention, where reacting on two visual stimuli channels through pressing a button was required, were completely different from the results for simple reaction time. The additional cognitive training positively influenced reaction time in a more complex situation. Falls often occur in complex situations where attentional resources reach their limit. Accordingly, fast response time in these situations is crucial to control posture while stepping and walking, and to avoid falls [30].
The impact on fall events of this trial was excellent. The reduction of falls from a pre-training period to a training period exceeded 80% for both groups, revealing no statistically significant differences between the groups. A further discussion about the impact on falls, its clinical relevance and further research is provided later in this epilogue.

In addition to the encouraging results on physical and cognitive performance as well as fall prevention, the excellent compliance rate of 90% in both groups for strength-balance and 85% for the cognitive interventions reinforce the suggestion that these training types are feasible and appreciated by older adults. This study expanded the current knowledge of falls behavior, physical and cognitive performance following strength-balance and cognitive training.

6.2 Main findings of the ActiveLifestyle studies

This section discusses the two pilot studies that investigated feasibility, usability, adherence and effectiveness of motivational instruments as well as physical performance measures of the tablet-app ActiveLifestyle \((\text{Chapters 3, 4 and 5})\). The first two-week trial \((\text{Chapter 3})\) with a special focus on aspects of feasibility, usability and effectiveness of motivational instruments was a welcome and relevant study to test the new assistive technology device in older adults before putting effort in a more extended study with a longer duration. Attrition was acceptable and compliance high, however, the recruitment rate (7%) was far below the expectations of 70% [31].

All participants of the two-week study confirmed that the app facilitated exercising at home. They expressed a strong intention to use and recommend the app to friends or family members. The individual and social motivation instruments (conditioning through positive and negative reinforcement, goal-setting, self-monitoring, comparison and external monitoring) were effective: whereas most of the participants did not feel motivated to exercise in general, 90% stated that it was fun to do it with the app. The pilot study with explicit feasibility objectives was a foundational step in the preparation of a larger study. The ActiveLifestyle app was adapted with respect to the outcomes of this study. For example, more information technology (IT)-mediated motivational elements, such as awareness, emotional support and collaboration, were included in the software. In that respect, the first study served as a key to the success of the phase II study described in \text{Chapters 4 and 5}.

One of the most remarkable findings of the 12-week phase II pre-clinical trial \((\text{Chapters 4 and 5})\) was the difference in attrition rate between the three groups (social group SG, individual group IG, and brochure group BG). The tablet groups reported an acceptable attrition rate of 8%, relative to an attrition rate of 21% for SG and an extremely high rate of 41% for IG, i.e. the group that was training with a brochure.
Whereas the tablet groups improved walking generally through all conditions and most parameters, the brochure group failed to show desirable outcomes. As expected, the results largely depend on adherence to the training plan. While analyzing differences between the active (>75% compliance) and inactive (≤ 75% compliance) participants of the total sample, the active outperformed the inactive throughout almost all walking conditions and parameters. The most active participants belonged to the social group, whereas the most inactive participants belonged to the brochure group. These results imply that the tablet and, especially, social motivation strategies seemingly enhance compliance rates and through this improve walking ability.

The 12-week trial confirmed the high usability of the app, already registered in the 2-week trial.

6.3 Methodological issues

Randomized controlled trial (Chapter 2)

In this trial an intention-to-treat analysis was performed, which is a recommended approach to several types of nonadherence to the study protocol [32]. Despite the large sample size in this trial, the intention-to-treat analysis was not robust for some values of gait analysis. Therefore, a sensitivity analysis was performed [33, 34], including an analysis with and one without outliers. The sensitivity analysis is a recommended option for the scenario of available outliers. It is believed that the subject(s) with the extreme value(s) was/were not from the same population, and that they differed in baseline characteristics. From this point of view, inclusion criteria of a study similar to this that plans to reproduce the findings should be discussed. Subjects who are not able to walk a certain distance in a determined time frame should be excluded.

Furthermore, four participants who were allocated to the cognitive-motor group were not able to conduct the computerized cognitive intervention due to vision problems. Although problems in vision were registered in the health questionnaire at baseline, some of the participants were not able to follow a computer game. In future studies, subjects who are not able to follow a computer game (due to vision problems) should be excluded from the measurements.

From the viewpoint of the assessments in the study presented in Chapter 2, a methodological issue to be discussed is the test for divided attention. The test program was not adapted for the very old adults in this trial, leading to 34 losses for the test because of floor effects. The program presented a big challenge because of a missing contrast between the stimuli, i.e. the light gray and dark gray figures. Moreover, the complete test battery for divided attention consists of both a 10-minute visual and a 10-minute cross-modal visual and acoustic stimuli program. Following an initial test before starting the measurements, it had already been decided to omit the cross-modal part. Even with this change it was too difficult for many people, and it is recommended to use other computerized or
non-computerized assessments for divided attention. This test was not included in the pilot project [10], the study that served as the foundation of this multicenter randomized controlled trial. New treatments usually have to go through a series of phases to test whether they are feasible, safe and effective [35]. The test of this assessment in a pilot study would have been helpful, highlighting the relevance of such pilot trials.

In general, there is no need for modification of the strength-balance intervention program. The program has shown to be effective in improving physical and cognitive functions and in reducing falls. To provide the training using resistance machines was an optimal choice regarding safety, effectiveness, and adaptability to the participants’ performance.

**Pilot study (Chapter 3)**

The recruitment rate (7%) was far from meeting the expectations of 70% [31]. Especially for older adults living independently, where the contact to health care providers is not urgently warranted, recruitment strategy plays an important role. In the studies in homes-for-the-aged, recruitment is assumed to be 46% [10]. In the homes included in the study, the directors and health care experts from the staff of the homes were, in addition to the information session held by the investigators, relevant motivators influencing the decision of the older adults to participate. Recruitment strategy was, consequently, one point tackled in the newer version of the app used in the 12-week pilot study (Chapters 4 and 5). Instead of sending out cold letters, information sessions were organized to create awareness of the need for such training and to gain trust from people.

**Preclinical exploratory trial (Chapter 4, 5)**

The different sample sizes of the three groups (SG, IG and BG) and the missing randomization hinder the generalization of the results reported for the pilot study presented in Chapters 4 and 5. An effective replication of the study should explicitly allocate participants with a randomization method to their training groups.

There are some other methodological issues that need discussion. The study was not supervised and no direct remote control through e.g. videotaping was ensured, hence the compliance rates of participants only based on their statements. There is, therefore, a possibility that they did not follow the exercises. A better control through remote feedback might have resulted in different outcomes.

Furthermore, drop-outs from the study were treated as part of the treatment group to which they were assigned. The values of almost half of the brochure group were replaced with mean values (attrition rate of 41%). In this respect, per protocol analysis (only participants that comply with the training protocol) would have revealed differing results. To show the differences between per
protocol and intention-to-treat analysis would have been of interest regarding the effectiveness of the different training programs on physical performance, and the way the different training devices influence compliance rates.

6.4 Using tablets as training device

Using tablets offers numerous potential advantages compared to other technologies such as smartphones, notebooks and desktops. Tablets are relatively robust, and using fingers instead of a mouse or a touch pad makes them much more intuitive and easy to use. In comparison to training methods based on a DVD or a brochure, a tablet-app such as ActiveLifestyle provides feedback about performance and enables social interaction – factors that seem to enhance motivation and compliance. Direct remote contact might help overcome one of the most mentioned barriers to physical exercise, the lack of social support. The implementation of an alarm clock, which reminds participants thrice daily to start training, presents an extra gain in our view – even when not directly mentioned as being useful by many participants (Chapter 3). The app requires the user to press one of the buttons “let’s start” or “later”, and it is suspected that if people were uncertain about their motivation to train, they rather started training with the app than with the brochure, since they did not want to press “later” thrice daily. The alarm clock, therefore, did not only serve as a reminder but also as a feature that probably influences decision-making. The answers of the participants to questions about the usability of the app, as presented in Chapter 3, demonstrate a 100% agreement with the statements “The operation of the application was easy” and “I was able to use the app”. It can be concluded that with the app, participants mostly felt motivated and expressed a strong intention to use the app also after study termination, even when they initially did not feel motivated to engage in physical training.

6.5 Clinical relevance and impact on falls

The results from the randomized control trial about the influence of cognitive and motor training on fall related risk factors are important from several viewpoints. The causes of a fall are multifaceted and, therefore, a reduction of fall risk factors do not necessarily reduce falls. Observing falls behavior, pro- and retrospective to study, as well as during the intervention is essential. Although there was no difference between the groups, a reduction of 80% and more from a pre-training period to the study period is clinically relevant. The falls rate continued to be lower, also up to one year after the intervention, with a reduction of 50% compared to the pre-training period. All homes-for-the-aged continued with the training after study termination, thus, the implementation of the training in these homes can be seen as successful. Falls were reported for a total of 135 participants (Figure 2.3 of Chapter 2). Six months after study termination 105 former study participants continued performing
strength training and balance (61 twice and 44 once a week), whereas 30 participants stopped training. In a twelve-month follow-up, 84 participants continued training (52 twice and 32 once a week), 51 stopped training due to various reasons.

A clinically relevant observation is that the lowest fall rate was observed during the study, when compliance was warranted. Experiment 3 of this thesis presented in Chapter 5 highlights the importance of training compliance. The active participants with a compliance rate of 75% or more performed significantly better on all outcome measures than the inactive participants with a compliance rate of less than 75%. Adherence to the training plan, therefore, seems to be a crucial factor for positive outcomes.

Gait speed appears to be a clinically relevant indicator of health status and survival. Epidemiological studies reveal that an improvement of 0.1 m/s in gait speed relates to a 12% decrease in mortality [21]. Our participants performed worse in gait speed pre training compared to literature reference values of elderly living independently. Post training, the group that was training with tablets improved towards these values. Additionally, all participants that adhered to their training plan showed an increase in both preferred and fast walking speed by 0.1 m/s or more, which is beneficial to extend life. In fast walking, shorter step length relates to falls [36]. The active participants in our study presented in Chapter 5 improved step length, however, not the inactive participants.

A person who achieves less than 10 points in the Short Physical Performance Battery (SPPB) appears to be almost 3.5 times more susceptible to suffer from mobility disability than a person scoring the maximum of 12 points. All groups of both studies improved significantly in the level of SPPB. The groups of our study presented in Chapter 2 increased their scores by around two points, however, post-test values remained just below 10. All of the groups of the study presented in Chapter 4 and 5 were able to cross the 10-point level.

6.6 Suggestions for future research

I now return to the discussion about the reduction of fall rates in our multi-center randomized controlled trial presented in Chapter 2. Future research should, in addition to counting and analyzing falls of the participants, also gather information about the social and economic consequences of falls, especially in terms of health care systems. Studies that quantify the impact of falls in older adults on health care expenditures, and how prevention interventions programs can affect these costs, could provide useful information, assisting policy makers facing major challenges in countries with an ageing society.

A proper economic evaluation of interventions aiming at decreasing the fall rate of older adults should shed light on two important aspects: First of all, in order to incentivize insurers, prevention
interventions must be cost effective. Secondly, since insured individuals mostly cannot be forced to take advantage of preventive offers made available by insurers, considerations of cost effectiveness need to be complemented by the marginal willingness to pay.

Research groups of the Universities of Sydney and Brisbane recently published a research protocol on a related topic [37]. One of the main outcomes will be the comparison of the cost-effectiveness between a group performing progressive resistance and balance training, and a group receiving conventional care. The researchers aim to recruit 300 residents, living in 20 aged care facilities. A cost benefit analysis will be undertaken to examine the costs for providing the exercise intervention, e.g. training equipment and training instructors, and the cost reduction in health costs, e.g. medical services, number of nights admitted, and rehabilitation visits, that can be achieved by preventing falls.

With respect to finding no additional effect of the cognitive training part on fall events, it is further suggested to reproduce this study and replace the computerized cognitive training with simultaneously performed computerized cognitive-motor training. Most of those studies that combined cognitive-motor training did so in sequential fashion, like the randomized controlled trial that was part of this study. A recent review on this topic concluded that simultaneously performed cognitive-motor training might enhance training gains compared to cognitive and motor training consecutively offered [38]. Another recently published systematic review intended to examine the effect of interactive cognitive-motor training (ICMT) in reducing fall risk in older people [8]. This review provides preliminary evidence that this training regimen can have an impact on physical and cognitive fall risk factors. During interactive cognitive-motor training the user interacts with a computer interface via gross motor movements, e.g. stepping, and immediately receives feedback on the projection screen [8, 14]. With ICMT several important aspects – aspects which often are impaired in older adults and relate to fall risk [39] such as information processing, selective attention, inhibition, planning/decision making, and motor response, can be addressed in parallel.

This review also indicates that only one of the included studies reported on falls [8]. Although with encouraging results, due to the modest sample size, this study only reveals first estimates and warrants further research. Again, the importance of assessing falls and the relevance of conducting sufficiently powered, high-quality trials – both warranted in our randomized controlled trial – is highlighted. A next step in this research field could include the execution of a randomized controlled trial similar to the study presented in Chapter 2 of this dissertation with some modifications: It is recommended to compare a strength-balance-cognitive to a strength-balance-ICMT training group that assesses divided attention and dual task costs of walking, as well as retro- and prospective falls. Since the test study results between a strength-balance and a strength-balance-cognitive group did
not differ, it is suggested to add a third group “strength-balance” group as a control group. The hypothesis is that the strength-balance-ICMT group would benefit most in all measures, since the ICMT training presents the most realistic scenario for preventing falls. The training takes place in a standing position, reacting appropriately through efficient peripheral sensory detection, efferent nerve conduction, central neural processing and afferent nerve conduction – factors that are important for balance control, e.g. during gait initiation [23-26].

As a further aspect of the review by Schoene et al. [8] the advantages of ICMT were discussed. ICMT includes features that potentially increase adherence, e.g. positive reinforcement while exercising, feedback, and goal-setting [8, 40]. These features were also part of our tablet-based app and can be understood as partly responsible for the high adherence rates. As demonstrated in Chapter 5, whilst comparing active (compliance ≤ 75%) and inactive participants (compliance > 75%), higher compliance was related to enhanced effectiveness of training. The ActiveLifestyle app in combination with the relatively low-cost ICMT training [8, 41] potentially provides a feasible and effective falls prevention program for older adults living autonomously.

The ActiveLifestyle app in its present version overlooks the training of cognitive factors. The pilot exploratory trials mainly focused on the development of encouraging assisting training software, running on a device easy to use for older adults autonomously at home, which was also effective in improving walking and physical performance. However, as discussed in-depth in the randomized controlled trial in Chapter 2, the training of cognitive and especially executive functions should be added. Future research should therefore implement cognitive exercises on the app or, as mentioned above, combine the tablet-based training with ICMT.

Combining the experience with computerized cognitive training (Chapter 2) and the implementation of home based training intervention (Chapter 3, 4 and 5), interactive cognitive-motor training system on a step plate with games training selective, divided attention were developed. Together with the app, this training system would fit the purposes for a cognitive-motor training program at home.

Providing feedback appeared to be an essential factor in enhancing adherence. The ActiveLifestyle app provided direct online feedback about training specifications such as performed sets and repetitions, perceived exertion, and specific comments through messaging. Programs including direct remote feedback during exercising at home presented similar effectiveness in physical functions to supervised exercising in a center [42]. A future version of the app should integrate the opportunity to provide direct remote feedback including information about correctness of exercise execution. Video analysis with three-dimensional motion tracking equipment or micro electromechanical systems (MEMS), or the Health Hub (HH) system that allows recognition and analysis of motion could be used as instruments to assist in this purpose [43].
References

7 Summary / Zusammenfassung / Danksagungen / Curriculum vitae

7.1 Summary

Age-related changes and their numerous negative consequences for our body systems often frighten young people of getting older. Knowing that these changes also – at least partly - result from lack of movement, and the huge body of literature indicating that there is a chance to fight these negative changes should give them hope. It gets even better: The dynamic aging process can be positively affected without medication or a huge investment, to be concrete; it can be achieved with exercising. The insight that regular exercise allows for health improvements is no ground breaking work. A challenge, however, is the successful implementation of an exercise program, which is reflected by an increasingly sedentary population.

Decreased muscle mass and balance deficits - factors that are strongly prone to the aging process - are amongst the most important risk factors for falls. Physical activity and, in particular, progressive strength and balance exercises, are therefore not surprisingly indispensable with the aim to enhance walking ability and to prevent falls. In reality, walking presents a challenging task for older adults. Several characteristics of an older persons walking pattern, such as longer gait initiation time or variability of step length, are associated to changes of our central nervous system. Possible obstacles require an instantaneous adaptation of the learned programs in these systems and walking, therefore, is no longer believed to present an automatic reflex-controlled process. Falls also occur due to cognitive decline. Falls prevention programs that include progressive strength and balance training should be supplemented by a cognitive challenge.

This thesis emphasizes how declined functioning of cognitive processes through aging or under use, especially executive functions, can be addressed by the use of a cognitive-motor approach. Since most of the current studies combining cognitive and motor exercise lack of statistical power or do not link cognitive component to prospective falls, research that analyses how the role of cognitive-motor interventions affecting physical and cognitive fall risk factors is needed to fill a gap. Chapter 2 describes a multicenter randomized controlled trial where 182 older adults from 14 homes for the aged performed twice weekly strength-balance training over twelve weeks. Half of the group additionally participated three times per week in a computerized cognitive training focusing on attention. The groups were compared in parameters of walking and, as the main part of it, the dual task costs of walking, physical performance, reaction time, executive functions, and divided attention. Additionally, fear of falling and retro- and prospective falls were assessed. Where both
The research described in this doctoral dissertation also focuses on the development and implementation of a training intervention for older adults living independently at home, aiming at promoting an independent and active lifestyle, and, to successfully affect fall risk factors. Successful implementation of such training interventions must pass several barriers: Older adults often lack of motivation, social support, or have problems in reaching a training center. Developing training programs that assist, support and motivate older adults being active is of great relevance to fight against the negative physical and cognitive changes resulting from an inactive lifestyle. The use of new technologies, i.e. tablet computers, plays a crucial role in reaching that goal. In collaboration with computer scientists of the University of Trento in Italy, we developed a tablet-based application – the ActiveLifestyle app. The app was created with the aim to help older adults starting and maintaining training autonomously at their homes.

**Chapters 3, 4, and 5** constitutes of two Experiments to test the ActiveLifestyle app. **Chapter 3** describes a two-week trial which assessed the feasibility and usability of the app. The results of a questionnaire indicated a strong intention to use and recommend the app. Motivational instruments were effective: whereas most of the participants did not feel motivated to exercise in general, 90% stated that it was fun to do so with the app. The two-week study was a foundational step in the preparation of the larger 12-week trial presented in **Chapters 4 and 5**. In the long-term trial two tablet groups (one group with and app that included individual motivation strategies and one with individual and social motivation strategies) were compared to a group that received a brochure as training guide. The effectiveness of IT-mediated motivation strategies, included in the app of the tablet-based intervention, and, how they impacted adherence is described in **Chapter 4**. One of the most remarkable findings of the study is the difference in attrition rate; 41% of the group training with the help of a brochure did not complete the study - mostly because of motivational reasons. **Chapter 5** presents the analysis of effectiveness of the training interventions on walking ability and physical performance. The tablet groups improved in all walking conditions and most parameters, whereas the brochure group failed to show positive results. The results largely depended on adherence to the training program. It can be concluded that training at home with a supportive...
tablet-based app enhances compliance to the training program and, through this, benefits physical performance and walking.

First of all, the results from the experiments described in this doctoral thesis strengthen the existing evidence that strength-balance training effectively improves physical and cognitive functions and reduces falls. Training at home can be facilitated with the use of new technologies such as tablet devices, which facilitate training motivators and optimize physical performance. Further research is needed to explore the additional effect of an implementation of a cognitive challenge in the tablet-app, since dual task costs of walking were not improved with the current version. That dual task costs of walking were minimized when strength-balance and cognitive training was combined substantiates recent evidence that cognitive-motor approaches are relevant for navigation in complex situation.
7.2 Zusammenfassung


7.3 Danksagung

Zum Schluss möchte ich einigen Personen Danke sagen, die mich während der Zeit meines Doktorats am Institut für Bewegungswissenschaften und Sport der ETH Zürich begleitet, motiviert und unterstützt haben.

Ganz speziell möchte ich mich bei PD Dr. Eling D. de Bruin bedanken. Du warst die Person, die mich für das Doktorat motiviert hat und warst nicht nur stark daran beteiligt die Motivation aufrecht zu erhalten, sondern du vermochtest sie gar fortlaufend zu erhöhen. Während den Jahren meines Doktorats hast du mich wissenschaftlich und emotional entscheidend unterstützt, was die Zeit für mich hochinteressant gestaltete. Es wurde wirklich nie langweilig. Du hast mich auch in komplizierten Situationen davon überzeugt, dass es eine Lösung gibt und immer dabei geholfen, diese zu finden. Deine innovativen Ideen haben mich immer beeindruckt. Ich freue mich sehr auf alle weiteren Projekte in Zukunft. Herzlichen Dank für alles!


Prof. Dr. David P. Wolfer möchte ich herzlich für die Bereitschaft danken, als Co-Referent für meine Doktorarbeit zu fungieren.


Dann möchte ich mich ganz herzlich bei meinen Weggefährten am Institut bedanken:


vermisst nachdem du als Dr. Giuseppe Pichierri austreten durftest. Danke für die lustige Zeit und deine kreativen Gedanken! Ich bin überzeugt, unsere Wege werden sich wieder kreuzen.


Bei Patrick und Rahel möchte ich mich ganz herzlich für die einerseits fachlich sehr hilfreichen Tipps und andererseits immer erfrischenden Gespräche bedanken.


Alle persönlichen Danksagungen für meinen Marco und unsere Sylvie, meine Eltern Mirta & Hans, Joris, Jan & Christina, Margrith & Pius, sowie all meinen Freunden die mich immer unterstützt haben, möchte ich gerne persönlich überbringen.
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