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Eeva Aartolahti

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JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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Finnish Summary
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High functional capacity of muscle strength and balance in older persons promotes independent mobility and prevents functional decline below the disability threshold. This dissertation explored the effects of strength and balance training (SBT) as part of a multimodal geriatric intervention on physical functioning and health-related factors associated with training participation in a community-dwelling population aged 75 years and over. This study is a part of the Geriatric Multidisciplinary Strategy for the Good Care of the Elderly (GeMS) project conducted from 2004 to 2007 in Kuopio, Finland. Participants were randomized into an intervention (n=339) and control group (n=312). The individualized multimodal intervention was based on comprehensive geriatric assessment, and included physical activity counselling and supervised SBT at the gym once a week for 28 months. Controls took part in the annual assessments but not in the intervention. Measurements of health, muscle strength, balance, and mobility were repeated annually.

In total, 54% of the intervention group participants started SBT. These SBT adopters (n=182) were younger and had better cognitive status and physical functioning than non-adopters (n=157). Long-term adherence to group-based training was possible for the older adults, despite hospital admissions, comorbidities and functional impairments. Adherence to SBT was 55% (SD 29, range 1-99%) and better physical functioning predicted higher adherence. Training adopters improved their muscle strength and mobility, and maintained their performance in balance. Among the non-adopters, who received physical activity counselling, muscle strength declined, while their balance and mobility performance remained unchanged during the intervention. Controls showed a decline in all the tested parameters. In addition, poor functional vision was related to weaker balance and poorer mobility performance. In conclusion, the results indicate that supervised strength and balance training is an important component of a comprehensive geriatric intervention to maintain independent mobility.

Keywords: Postural Balance, Muscle Strength, Resistance training, Vision, Aging, Geriatric Assessment

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Muurame, October 2016
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FIGURES

TABLES

LIST OF ORIGINAL PUBLICATIONS

The dissertation is based on the following original publications referred to in the text by Roman numerals I-IV. Some unpublished findings are also presented.

I Aartolahti E, Häkkinen A, Lönnroos E, Kautiainen H, Sulkava R, Hartikainen S. Relationship between functional vision and balance and mobility performance in community-dwelling older adults. Aging clinical and experimental research 2013; 25: 545–52

II Aartolahti E, Hartikainen S, Lönnroos E, Häkkinen A. Health and physical function predicting strength and balance training adoption: A community-based study among individuals aged 75 and older. Journal of aging and physical activity 2014; 22: 543–9

III Aartolahti E, Tolppanen A-M, Lönnroos E, Hartikainen S, Häkkinen A. Health condition and physical function as predictors of adherence in long-term strength and balance training among community-dwelling older adults. Archives of gerontology and geriatrics 2015; 61: 452-457

IV Aartolahti E, Lönnroos E, Hartikainen S, Häkkinen A. Effects of long-term training on muscle strength and mobility in adults aged 75 and older. 2016 submitted for publication.

ABBREVIATIONS

ACSM	American College of Sports Medicine
ADL	Activities of Daily Living
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
BBS	Berg Balance Scale
BMI	Body Mass Index
CGA	Comprehensive Geriatric Assessment
CI	Confidence interval
COPD	Chronic Obstructive Pulmonary Disease
ES	Effect size
FCI	Functional Comorbidity Index
GDS-15	Geriatric Depression Scale
GeMS	Geriatric Multidisciplinary Strategy for the Good Care of the Elderly
IADL	Instrumental Activities of Daily Living
ICC	Intraclass Correlation
ICF	International Classification of Functioning, Disability and Health
IQR	Interquartile range
LIFE	Lifestyle Interventions and Independence for Elders
m/s	Meters per second
MMSE	Mini-Mental State Examination
MNA	Mini Nutritional Assessment
MNA-SF	Mini-Nutritional Assessment - Short Form
N	Newton
NS	Non significant
OR	Odds ratio
RCT	Randomized controlled trial
RM	Repetition maximum
SBT	Strength and balance training
SD	Standard deviation
s	second
TUG	Timed Up and Go
VF-7	7-item functional vision questionnaire
WHO	World Health Organization

CONTENTS

1 INTRODUCTION

The ability to move around freely is essential to everyday life. In old age, independent and safe mobility is an important factor for maintaining one's quality of life and independence in the community (Brown & Flood 2013). Ageing affects physical functioning and reduces the reserve of functional capacity available to maintain high function into late life (Chatterji et al. 2015). Apart from age-related decline, older people are likely to experience multiple chronic conditions, and thus increasingly complex health needs (Marengoni et al. 2009). It has been shown that regular exercise can prevent and serve as an effective therapy for many chronic diseases and functional limitations (Nelson et al. 2007).

Impairments in muscle strength and balance can lead to mobility limitations and further disability (Rantakokko, Mänty & Rantanen 2013). Strength and balance training (SBT) has been demonstrated to improve physical functioning and prevent disability (Singh 2002), falls (Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society 2011) and the development and progression of frailty syndrome (Peterson et al. 2009) in older adults. The effects of strength and balance training on physical functioning and disability have been studied in several randomized controlled trials (Liu & Latham 2009, Howe et al. 2011, Liu & Latham 2011). However, the majority of these studies have been conducted as short-term interventions among either healthy older adults or among adults undergoing rehabilitation for specific clinical conditions. Older people are highly heterogeneous in health and functional ability. If the aim is to increase physical activity and health at the population level and among older populations, research evidence from extended follow-up periods among large populations with a wide variety of functioning and health is required.

The life expectancy of older people continues to rise worldwide with the effect that the world population is rapidly aging. Finland has one of the fastest aging populations in Europe and a particularly rapid increase in the number of people aged 80 years and older is expected. Maximizing the health, functional capacity and social participation of older people with the aim of extending independent living and quality of life has become a central objective of public health policies. In support of this objective, the promotion of physical activity in older adults has also become an important worldwide public health goal (World Health Organization 2010). Effective interventions to slow down further functional decline and delay care dependancy are needed. The present study examined physical functioning, participation in strength and balance training and the effects of training as part of a comprehensive geriatric intervention among community-dwelling population aged 75 years and over.

2 REVIEW OF THE LITERATURE

2.1 Health, physical functioning and disability in old age

2.1.1 Physical functioning and disability

The ability to undertake different functional activities is multifaceted. The International Classification of Functioning, Disability and Health (ICF) by the World Health Organization (WHO) provides a descriptive framework for functioning and disability (World Health Organization 2001). The ICF framework covers human functioning on three different levels: functioning at the level of the body or body parts (body functions and structures), the whole person (activities) and the whole person in their complete environment (participation). Disability arises at each of these levels, that is, as impairment, activity limitation, and participation restriction influenced by environmental and personal factors, respectively. Physical functioning is a term used to describe an individual's capacity to undertake the physical tasks of everyday living. In this dissertation, muscle strength describes body functions, mobility and balance performance describe activities and training adoption and adherence describe personal factors. A concept related to physical functioning is physical activity, defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen, Powell & Christenson 1985). Whereas physical functioning refers to the capacity to do something, physical activity refers to what one actually does.

Diverse conditions and diseases lead to disability, defined as a gap between individual capacity and environmental demands. Disability can affect people at any age. In older persons, in particular, the disablement process is often progressive and it may be a number of years before a disability manifests (Ferrucci et al. 1996). The dynamic disablement pathway from disease to disability, originally proposed by Nagi and subsequently revised by Verbrugge & Jette (Verbrugge & Jette 1994), clearly describes the steps along the pathway from disease to disability (Guralnik & Ferrucci 2009) and provides theoretical background for the study of preventive interventions among older adults. In the present research, the prevention of late life disability is explored by targeting specific impairments (muscle strength and postural balance) predisposing to functional limitations (functional balance, mobility). Environment plays a role at every stage of this process such that disability eventually manifests as a gap between individual capacity and environmental demands (independence in activities of daily living).

2.1.2 Functional decline in aging

The physiological changes related to aging are numerous. In the case of physical functioning, maximum function declines gradually. Functional declines are observed even in the absence of disease. Such age-related change affects various body structures and functions essential for safe and efficient functioning, such as the cardiovascular system (Strait & Lakatta 2012), respiratory system (Sharma & Goodwin 2006), sensory systems of vision and hearing (Heine & Browning 2002), central and peripheral nervous systems (Seidler et al. 2010) and muscle mass and strength (Mitchell et al. 2012).

Functional capacity across the life-course decreases and disability manifest itself when capacity declines below the disability threshold (Figure 1) (Kalache & Kickbusch 1997). Independent older adults living at or near the disability threshold have minimal functional capacity and need only a minor disruption to move into a dependent state (Young 1986). There is a clear trend towards increasing disability with age. When functional independence was evaluated by asking people about the activities of daily living (ADLs) and instrumental activities of daily living (IADLs), the proportion of respondents reporting ADL and IADL limitations rose with age (Chatterji et al. 2015). A large Australian population-based longitudinal survey study on physical functioning among women conducted between 1996 and 2005 (Peeters et al. 2013) found a curvilinear relationship between age and functioning, with decline occurring more rapidly at older ages. In addition, physical functioning already varied widely between individuals at younger ages and disability was developing at all ages.

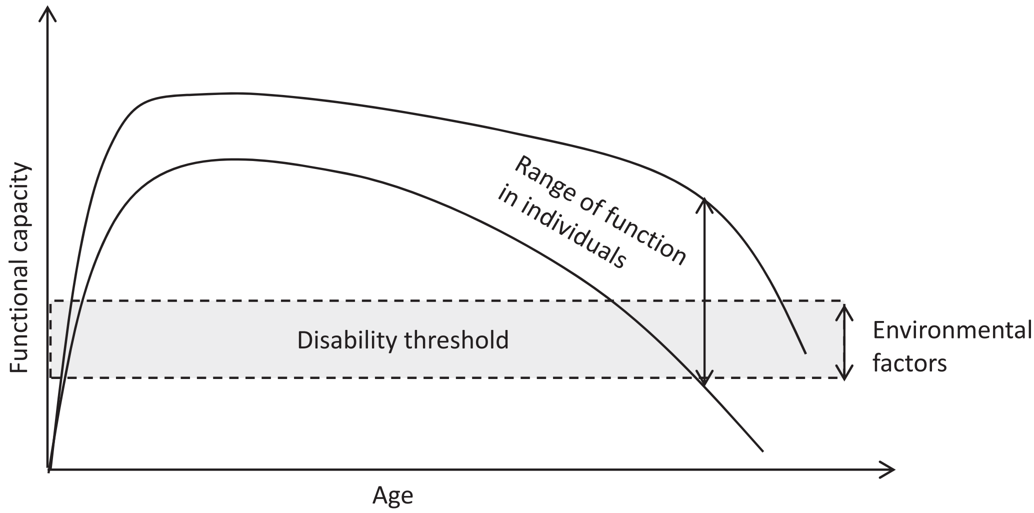

FIGURE 1 A life course approach to functional capacity, aging and disability, modified according to WHO (World Health Organization 2002).

2.1.3 Physical activity in the disablement process

The dynamic nature of disability is related to the finding that dependency in physical functioning may be reversible. This was shown among community-living older persons, aged 70 and older, monitored at monthly intervals for 5 years. When asked about mobility disability, inability to walk quarter of a mile or climbing a flight of stairs, participants frequently reported transitions in mobility disability between states of independency and disability (Gill et al. 2006). Among newly disabled older persons, habitual physical activity predicted a shorter recovery time from disability as well as longer duration of independence after recovery (Hardy & Gill 2005). The potential reversibility of the loss of physical functioning by participation in a physical exercise program was investigated in the Lifestyle Interventions and Independence for Elders (LIFE) study. A long-term structured physical activity program reduced the risk for major mobility disability among sedentary older adults aged 70–89 years and risk for disability over 2.5 years when compared to a health education program only (Pahor et al. 2014). The structured physical activity program included aerobic, resistance and flexibility training done in a center and at home (Fielding et al. 2011a).

When the disability threshold is defined as needing help from another person to carry out several daily activities, older people who reported being physically inactive reached disability 14 years earlier than those who reported being highly active (Peeters et al. 2013). Physical activity and physical fitness play important roles on the pathway to disability and have the potential to reduce or delay the onset of physical disability. Morey et al. found that individual components of fitness are associated with functional limitations (Morey, Pieper & Cornoni-Huntley 1998). Their study of men and women with mean age 72 showed not only an association between fitness and pathology, but also an association between fitness and functional limitations independent of pathology. Thus physical activity and physical fitness are not only mediators on the causal pathway from disease to disability but probably also independent risk factors for functional decline.

2.1.4 Morbidity as a risk factor for disability

Chronic diseases contribute variously to the burden of disability at the population level by their prevalence and disabling impact. For example, stroke has a highly disabling impact, arthritis and heart disease have a moderately disabling impact and high prevalence, and back pain has both high prevalence and a highly disabling impact (Klijs et al. 2011). The disabling impact of diseases has found to be high, especially among persons older than 80 years (Klijs et al. 2011).

Of the musculoskeletal disorders, osteoarthritis of knee and hip is one of the main causes of disability among aging people, especially women (Cross et al. 2014). Pain, instability, and stiffness in joints lead to limitations in mobility and ADLs (Fautrel et al. 2005). In severe cases, joint replacement surgery becomes an alternative. However, mobility limitations continue to affect the daily life of older adults after treatment of the original cause of the symptoms. Valtonen et al. (Valtonen et al. 2009) found that even 10 months after knee replacement surgery lower limb muscle size and function were affected such that the operated leg was weaker than the non-operated leg, causing limitations in stair negotiation.

Among older adults, cardiovascular burden, coincidence of cardiovascular diseases including ischemic heart disease, atrial fibrillation, heart failure and stroke increase the likelihood for mobility limitation, defined as having a walking speed below <0.8 m/s (Welmer et al. 2013). Women with diabetes have a greater prevalence of lower extremity disability, defined as mobility disability, basic ADL disability and severe walking disability (Volpato et al. 2002). This is explained by diabetes-related cardiovascular and peripheral vascular diseases, and complications such as peripheral neuropathy and visual limitation (Menz et al. 2004).

Cognitive disorders, such as mild cognitive impairment and dementia lead to inability to perform instrumental activities of daily living (Marshall et al. 2011). Impairments in cognition, such as attention, orientation and memory, affect mobility and persons with mild cognitive impairment have worse mobility test performance in (Pedersen et al. 2014). The accumulation of both physical and cognitive deficits predisposes older adults aged 75 or 80 years to a higher risk for institutionalization compared to persons with only a single limitation (von Bonsdorff et al. 2006).

Osteoporosis and falls are risk factors for hip fractures, an increasingly disabling injury among older populations (Panel on Prevention of Falls in Older

Persons, American Geriatrics Society and British Geriatrics Society 2011). People with a hip fracture history often, years after the fracture, continue to experience pain which restricts physical activity (Salpakoski et al. 2011). Low physical activity is an important modifiable risk factor for hip fracture and related excess disability (Marks 2011). Falls when considered as a geriatric syndrome among others, such as incontinence and delirium, have been shown to share the same risk factors when measured in older age: baseline cognitive impairment, baseline functional impairment and impaired mobility (Inouye et al. 2007).

Multimorbidity, i.e., having multiple chronic diseases concurrently, is a common feature in older persons (Fried et al. 1999). Among older populations aged 77 and older comorbidities are more prevalent than a single chronic disease occurring independently (Marengoni et al. 2009). The prevalence of comorbid conditions increases with age and heightens the risk for developing mobility disability (Fried et al. 2004). Among persons with knee osteoarthritis, coexisting chronic conditions, especially heart disease, pulmonary disease and obesity increased the risk for disability (Ettinger et al. 1994). Aging is also associated with the increasing prevalence of ocular diseases and decline in different aspects of vision and vision-related functioning (Brabyn et al. 2001). Arthritis and visual impairment are the most frequently co-occurring chronic conditions among older adults (Fried et al. 1999).

2.1.5 Comprehensive geriatric assessment

Multimorbidity and geriatric syndromes in older adults require special attention and knowledge when evaluating possible reasons and risk factors for disability. The risk factors for reduced physical functioning among older adults are diverse and addition to physical health and comorbidities are also related to psychosocial health, environmental conditions, social circumstances, nutrition, physical activity and other lifestyle factors (Stuck et al. 1995, Ayis et al. 2006). The diversity in risk factors emphasizes the need for interdisciplinary teamwork in aiming at preventing further functional decline and delaying care dependency. Comprehensive geriatric assessment (CGA) is defined as a "multidimensional interdisciplinary diagnostic process focused on determining a frail older person's medical, psychological and functional capability in order to develop a coordinated and integrated plan for treatment and long term follow up" (Rubenstein et al. 1991).

Geriatric screening and multidimensional individually tailored interventions have been shown to help older adults to continue living at home and to reduce the rate of falls (Beswick et al. 2008). In an inpatient setting, CGA for older adults admitted as an emergency increased patients' likelihood of remaining alive and living in their own home 12 months later when compared to general medical care (Ellis et al. 2011). In community-dwelling recently hospitalized frail older people a 12-month multifactorial intervention targeting frailty was more effective than usual care in reducing mobility disability (Fairhall et al. 2012). Among pre-frail and frail community-dwelling older adults a CGA-based intervention tended to improve frailty status and independency in ADLs (Li et al. 2010). In the in-home setting, a variety of multidimensional preventive home visit programs also have the potential to reduce the burden of disability when based on multidimensional assessment with a clinical examination (Huss et al. 2008). In an in-home intervention among older adults 75 years of age or older and living at home, three-year annual geriatric assessments, recommendations by a nurse and follow-up visits every three months delayed the development of disability and reduced permanent nursing home stays (Stuck et al. 1995). However, despite the in-home CGA intervention, gait and balance limitations were associated with significant decline in both ADLs and IADLs (Cho et al. 1998). Thus adequate balance and mobility performances would appear to be important factors to address in interdisciplinary assessments and tailored interventions.

2.2 Mobility in old age

Mobility can be defined as a person's ability to move him- or herself independently and safely from one place to another, and it includes all forms of movement, from transferring out of a bed through walking to driving a car or using public transportation (Satariano et al. 2012). Mobility is a fundamental feature of functioning and daily living. For example, among community-dwelling older adults with frailty or complex care needs walking and changing body position were reported to be the most relevant activities affecting functioning (Spoorenberg et al. 2015).

Walking ability is a complex neuromotor activity that is the sum of the functioning of multiple organ systems, and it can be considered a reliable measure of physical functioning and mobility disability. Walking ability predicts future health and mortality (Toots et al. 2013, Middleton, Fritz & Lusardi 2015, Liu et al. 2016). Walking ability is typically measured as a usual or maximal walking speed over a short distance, time taken to walk a longer distance, or self-reported ability to walk. Among the multiple parameters related to sarcopenia, walking speed has found to be the strongest variable discriminating the risk for incident ADL disability in community-dwelling older adults (Cesari et al. 2015). In an epidemiological study with a 4.9-year follow-up among well-functioning community-living older adults, slower 400-m walking speed or inability to walk 400 meters were associated with mortality, incident cardiovascular disease, mobility limitation and mobility disability (Newman et al. 2006). The relationship between gait speed and survival has been studied in different populations; among adults 65 years or older, walking speed faster than 0.8 m/s has predicted life expectancy beyond the median (Studenski et al. 2011). Mobility disability has a major impact on public health care expenditure. Total annual health care costs have found to be almost 50% higher for those who reported inability to walk 400 meters compared to those who had no difficulties (Hardy et al. 2011).

At the population level, perceived difficulties in mobility have declined over the last decade among Finnish older adults. The Health 2000 Survey (2000–2001) and Health 2011 Survey showed that among people 75 years and older the proportion of those who reported being able to walk up 1 flight of stairs without difficulties had increased from 57% to 75% among men and from 42% to 55% among women (Sainio et al. 2012). Similarly, the proportion of those with a maximal walking slower than 1.2 m/s had decreased among both men (54% to 33%) and women (73% to 57%) (Sainio et al. 2012). The time taken to rise five times from a chair had decreased by 1.1 seconds among men and 0.8 seconds among women (Sainio et al. 2012). Hence the physical functioning of Finnish people aged 75 years and older seems to have improved between 2000 and 2010. Differences between birth cohorts and various changes in population health may explain the improvements: cardiovascular and musculoskeletal health improved, obesity and smoking declined and level of education rose in Finland (Sainio et al. 2012).

Independent and effective mobility performance in old age requires proper functioning of the sensory, psychomotor and musculoskeletal systems. Poor muscle strength of the knee extensors has been reported to be the most crucial determinant of mobility and its decline (Sakari et al. 2010). In older women, the combined effect of muscle and balance impairment increased the risk of severe walking disability by 10-fold compared to having only one or other of these impairments (Rantanen et al. 1999a). Severe walking disability was defined as the inability to walk one-quarter mile and having a customary walking speed of ≤0.4 m/s. Thus balance problems and other co-impairments may change the functional threshold of a single factor of physical functioning. Vision also plays an important role in mobility performance (Salive et al. 1994), and hence it is not surprising that impaired vision has been reported to be a major risk factor for falls among older adults (Lord 2006).

2.2.1 Muscle strength

Declined muscle strength increases the risk for incident mobility limitations such as difficulties in walking or climbing stairs (Manini et al. 2007, Sallinen et al. 2010). Moreover, loss of muscle strength is a substantial predictor of physical disability and mortality (Rantanen et al. 1999b, Rantanen et al. 2000, Manini et al. 2007). Progressive loss of muscle mass and strength are associated with the aging process. Muscle strength decreases with age, beginning at approximately 35 years of age, and longitudinal studies show that at 75 years of age the rate of strength lost is approximately 3–4% per year (Mitchell et al. 2012). At present, age associated loss of muscle strength is included in the definition of sarcopenia, that is, "the age associated loss of skeletal muscle mass and function" (Fielding et al. 2011b). Function denotes either muscle strength or functional performance. Originally, in 1988, the term sarcopenia was defined by Irwin Rosenberg as loss of muscle mass associated with aging (Rosenberg 1997). The age-associated decline in muscle strength is steeper than the decline in muscle mass. In healthy

70– to 79-year-old adults, the loss of knee extension strength was 3-fold greater than the loss of leg lean mass over a 3-year follow-up (Goodpaster et al. 2006).

The etiology of sarcopenia is multi-causal and complex. The loss in muscle strength may be an outcome of the aging process, changing endocrine function, disuse of muscles, chronic diseases, inflammation, insulin resistance, and malnutrition. The interaction of disease and age across the multiple systems inducing sarcopenia are incompletely understood and exact causes remain unknown. Therefore, it has been proposed that sarcopenia be recognized as a geriatric syndrome (Cruz-Jentoft et al. 2010). According to a recent review, the prevalence of sarcopenia varies widely, from 1 to 33 % across different older adult populations living in the community, long-term care or institutions (Cruz-Jentoft et al. 2014).

Decreasing physical activity accelerates the progression of sarcopenia and the loss of muscle strength, especially after age 75. The etiology of sarcopenia varies with age. At age 70 and older the potential causes are further reduction in physical activity and inactivity due to illness and hospitalization and increased body fatness (Fielding et al. 2011b). Hospitalization is associated with changes in body composition and strength. Among well-functioning 70- to 79-year-old adults, strength decline has been shown to occur especially among persons hospitalized for 8 or more days during the previous year (Alley et al. 2010). Even short-term immobilization decreases muscle function and structure in both young and old persons, but older adults may need a longer time than young adults for muscles to fully recover (Hvid et al. 2010).

In a 12-year longitudinal study among healthy sedentary men around 65 years at baseline, strength loss was more rapid in the lower than upper limbs (Frontera et al. 2000). This leads to difficulties, especially in weight bearing tasks such as getting out of a chair or climbing stairs. The faster decline in lower than upper extremity strength is even more evident among women (Hughes et al. 2001). The relationship between muscle strength and mobility has found to be curvilinear, so that high levels of muscle strength are thought to offer a reserve buffering future losses in muscle strength (Buchner et al. 1996, Manini et al. 2007). Sufficient muscle strength is needed to perform functional tasks such as walking, although above a certain level of performance an increase in muscle strength does not increase walking speed (Buchner et al. 1996, Rantanen et al. 1998).

Peak muscle power (force x velocity of muscle contraction) may be an even more influential predictor of physical functioning than muscle strength (Reid & Fielding 2012). In a cross-sectional analysis, older adults with low muscle power had 2–3-fold greater risk for significant mobility impairments compared to peers with low muscle strength (Bean et al. 2003).

2.2.2 Postural balance

Despite the common use of term balance among health professionals, a universally accepted and concise definition of balance is not available. Balance is often referred to as stability or postural control, owing the need to control the position or posture of the body in different situations (Pollock et al. 2000). Defined biomechanically, balance is the ability to maintain the body's center of mass above the manageable limits of the base of support when remaining still or moving (Winter 1995). In this dissertation, the term postural balance refers to the ability to move efficiently and effectively in a different situations and environments safely without falling.

Postural control of stance and locomotion is a complex skill that requires coordination of the sensory, motor and cognitive systems (Pollock et al. 2000, Shumway-Cook & Woollacott 2001, Horak 2006). The visual, vestibular and somatosensory systems give information about the movement and position of the body in relation to gravity and the environment. The central nervous system integrates this sensory information and directs the peripheral motor system. In response to these sensory inputs, the neuromuscular and musculoskeletal systems produce volitional, automatic or reactive movements. Thus, movement results from dynamic interplay between the perception, cognition, and action systems (Woollacott & Shumway-Cook 1990). Balance in turn is maintained by different proactive visual and predictive mechanisms and with reactive processes in response to unexpected perturbations or if proactive processes fail (Patla 1997).

The role of cognition in postural balance has become more evident with increasing understanding of psychomotor processing, problem-solving, the attention and awareness of self and surroundings as requirements of motor control (Alexander & Hausdorff 2008). It is, therefore, unsurprising that persons with mild cognitive impairment have gait dysfunction (Verghese et al. 2008) and higher incidence of falls (Delbaere et al. 2012) than those with normal cognitive function.

Substantial decline in all the systems involved in postural control occur with advancing age, and hence limitations in balance may be caused by impairments in the cognition, vision, vestibular, sensory or motor systems (Woollacott & Shumway-Cook 1990, Horak 2006). Vision provides the nervous system with information regarding the position and movements of body segments in relation to each other and the environment. The visual system plays a role both in reactive and proactive postural control of locomotion. With the help of vision, we determine our speed of locomotion and also identify potential obstacles in the environment and navigate around them (Patla 1997). The role of vision in the maintenance of balance on a compliant surface becomes even more important under challenging conditions where proprioceptive information from the musculoskeletal system is reduced (Lord & Menz 2000). Despite age-related ocular diseases and changes in different aspects of vision (Brabyn et al. 2001), the importance of vision in the maintenance of postural control seems to increase with age (Woollacott 2000).

Difference in balance performance was assessed very early on by measuring body sway (Sheldon 1963). Sheldon found differences between age groups: sway in a quiet stance was more difficult to minimize in younger (6–14 years) and older (50–80 years) age groups than those in between. Computerized dynamic posturography has been used to study individuals' ability to use visual, proprioceptive and vestibular cues to maintain postural stability under altering sensory conditions (Ford-Smith et al. 1995). Laboratory measures of postural control have also been conducted to understand the associations between different sensorimotor factors when maintaining balance not only in quite standing but also in dynamic situations such as walking. Due to the complexity of balance ability, methods in these assessments have varied widely from measuring the acceleration patterns of the head and pelvis during walking on level and irregular surfaces (Menz, Lord & Fitzpatrick 2003, Menz et al. 2004) to measuring gait variables such us step length, the double support phase and step width (Lord, Lloyd & Li 1996, Callisaya et al. 2009).

In clinical use, performance in different functional task has been used to assess balance and falls risk. Correlation between functional clinical balance tests and static laboratory tests has been low, suggesting that these two types or measures partly assess different aspects of balance (Nguyen et al. 2012). Clinical balance tests can be classified according to the stability of the base of support (stationary or moving) and the form of perturbation (unperturbed, self-generated, external or sensory) (Huxham, Goldie & Patla 2001). The systems approach argues that it is critical to recognize that movement emerges from interaction between the individual, the task, and the environment in which the task is being carried out (Woollacott & Shumway-Cook 1990). From systems approach point of view, functional balance tests could be a more accurate measure of balance ability in daily living than laboratory tests.

2.2.3 Functional vision

Assessment of visual functioning has been approached from different perspectives. A clear distinction has been drawn between objectively measured visual functions, i.e., how the eye functions, and functional vision, i.e., how vision deficits may affect functioning in daily and social activities (Colenbrander 2010). Among older adults, measuring visual acuity alone may underestimate the degree of disability related to vision impairment as considerable changes may occur in vision functions other than acuity (Brabyn et al. 2001). In addition, measurements of visual acuity do not take into account the role of environmental factors. For many older adults, daily functioning often takes place under less-than-optimal lighting conditions (Sinoo, van Hoof & Kort 2011). Furthermore, research findings on the importance of different vision function components associated with balance and mobility performance in older adults are conflicting (Brabyn et al. 2001, Patel et al. 2006).

Full-scale ophthalmic examination of visual functions would include tests for visual acuity, visual field, color vision, contrast sensitivity and dark adaptation (Colenbrander 2010). It would nevertheless be difficult to tell how various combinations of suboptimal test results affect balance and mobility. In addition, individual and environmental demands on vision may vary in daily life situations. Vision-related functional impairment has been measured with different subjective questionnaires (Mangione et al. 1992, Steinberg et al. 1994, Uusitalo et al. 1999). These provide information not conveyed by objective ophthalmic examinations and might help reveal visual disabilities affecting everyday life. Several visual function questionnaires have been developed to measure vision impairment caused by cataract (Massof & Ahmadian 2007). Later assessments of self-rated functional vision were proposed to be useful for vision screening in community-dwelling older adults (Valbuena et al. 1999) and for assessing their risk for falls (Kamel, Guro-Razuman & Shareeff 2000). Thus far, however, the relationship between self-rated functional vision and physical functioning has not been evaluated using well established physical performance tests (Hidalgo et al. 2009).

2.3 Exercise among older adults

The role of physical activity and exercise on the aging process has received substantial interest. To date, among interventions for sarcopenia, exercise has been demonstrated to be the only intervention to show moderate quality evidence for improved muscle mass and function (Cruz-Jentoft et al. 2014). Strength and power gains in older age result more from neural adaptation than muscle cross-sectional area (Häkkinen et al. 1998). One of the eminent studies demonstrating the efficacy of high intensity strength training in frail older adults was conducted among nursing home residents aged 70 years or older (Fiatarone et al. 1994). The 10-week training intervention improved lower extremity strength, walking speed, and stair climbing power (Fiatarone et al. 1994). In older women with osteopenia, supervised strength, balance and impact exercise for 30 months had a long-term positive effect on physical functioning and seemed to decrease the risk for hip fracture (Korpelainen et al. 2010). Various systematic reviews have also compiled RCT studies conducted among older adults on progressive resistance training interventions to improve physical functioning (Liu & Latham 2009), balance (Howe et al. 2011) and for fall prevention (Gillespie et al. 2012).

In some of the multimodal exercise interventions conducted among older adults, aerobic exercise has played a substantial role. Among community-dwelling older adults, the Otago Exercise Programme, including long-term strength and balance training as well as encouragement to walk outside the home, reduced falls and injuries (Campbell et al. 1999). More recently, the LIFE study, combining walking, strength and balance training, has been the first large-scale RCT to show the effect of exercise on the prevention of incident mobility disability (follow-up 2.6 years) (Pahor et al. 2014).

2.3.1 Strength and balance training guidelines

Growing evidence has confirmed the place of strength and balance training (SBT) in health-enhancing exercise and physical activity guidelines. SBT has become a particularly important component of guidelines in older adults regarding fall prevention, mobility limitations and disability (Nelson et al. 2007). The recommendation for aerobic exercise in older adults is either moderate-intensity activities for at least 30 minutes per day (total of 150 minutes per week), or vigorous–intensity activities for at least 20 minutes per day (total of 75 minutes per week). In addition to aerobic exercise, older adults are recommended to engage in moderate to vigorous resistance training at least 2 times per week. Potential exercise modes are progressive weight training or weight bearing calisthenics, stair climbing, and other strengthening activities that use the major muscle groups. Similar doses of muscle-strengthening activities are recommended in the WHO's Global Recommendations on Physical Activity for Health (World Health Organization 2010).

The strength training as an isolated intervention has not been shown to be uniformly effective in improving balance performance (Orr, Raymond & Fiatarone Singh 2008), while functional exercise in addition to machine-driven resistance training improves functional task-specific performance compared to strength training only (de Bruin & Murer 2007). Those at risk for falls are recommended to perform balance exercises. In addition, flexibility exercises should be performed for at least 10 minutes at least two days a week (Nelson et al. 2007). Balance exercise is also recommended for frequent fallers or individuals with mobility problems in falls prevention guidelines (Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society 2011). Muscle strengthening and balance activity may need to precede aerobic training activities among very frail individuals. Walking may not be a safe mode of exercise for persons at high risk for falls (Sherrington et al. 2011). In Finland, health enhancing physical activity recommendations are described in a so called Physical Activity Pie by the UKK Institute for Health Promotion Research (UKK Institute 2009). In this Finnish version, performance of muscle strength, balance and flexibility activities is recommended at least two times a week.

Older adults aged 65 years and over are a highly heterogeneous group of people with a very diverse disease aetiology and level of physical functioning, and therefore global recommendations may be difficult to follow. It is recommended that "when chronic conditions preclude activity at minimum recommended level of prevention, older adults should engage in physical activity according to their abilities and conditions" (Nelson et al. 2007). To ensure training effects, exercises need to be performed progressively and near the limits of an individual's capacity (American College of Sports Medicine, Kaminsky & Bonzheim 2006). In strength training, the quantification of exercise intensity can be measured by the 1-repetition maximum (RM) method (Knutzen, Brilla & Caine 1999). Reduction in the base of support and limitations on sensory input may be used to increase the difficulty of balance exercise (Muehlbauer et al. 2012). However, the methods used to quantify the intensity of the challenge posed to the individual's balance system by the balance exercises administered in randomized trials have not been clearly reported (Farlie et al. 2013).

In Finland, less than 10% of the population aged ≥75 years participate in strength training (Hellda´n & Helakorpi 2014) at the level recommended in health-enhancing exercise and physical activity guidelines. Similarly, in Australia, 12% of persons aged >65 years participate in strength training, and 6% participate in balance training (Merom et al. 2012). In the United Kingdom, a study using accelerometers in 70- to 93-year-olds found that only 15% men and 10% women meet the guideline of moderate-intensity exercise for 150 minutes per week (Jefferis et al. 2014).

2.3.2 Literature review of training interventions

Given the target group of this study, the following systematic literature review focuses on community-dwelling older adults. The entire cohort of the study had to be 75 years or older to be included in this review. The exercise interventions had to include progressive strength training, alone or combined with other exercise forms. Only trials with performance-based measures of physical functioning as outcomes were included. A full text article published in English was a further criterion for inclusion. To focus more on preventive than rehabilitative interventions, trials targeting participants after an acute medical condition, with specific conditions (e.g. Parkinson's Disease, pulmonary or cardiac disease) or immediately after hospital discharge were excluded.

First, the studies in this literature review were selected from three previous systematic reviews (Liu & Latham 2009, Howe et al. 2011, Gine-Garriga et al. 2014). The trials with a participant mean or median age of 80 years or over were in the minority in the systematic reviews. In the Cochrane review of progressive resistance training in older adults (Liu & Latham 2009), only 20 out of 129 trials concerned this oldest age category. Moreover, only three (n=3) matched all the aforementioned inclusion criteria (Judge, Whipple & Wolfson 1994, Sipilä et al. 1996, McMurdo & Johnstone 1995). Participants living in sheltered accommodation or long-term care facilities and being under age 75 were the commonest reasons for exclusion from the present review. From the Cochrane review of exercise and balance (Howe et al. 2011) seven (n=7) research articles with progressive strength training were included (Skelton et al. 1995, Wolfson et al. 1996, Campbell et al. 1997, Helbostad, Sletvold & Moe-Nilssen 2004, Liu-Ambrose et al. 2004b, Lord et al. 2005, Vestergaard, Kronborg & Puggaard 2008). A recent systematic review among frail older adults (Gine-Garriga et al. 2014) contributed a further four (n=4) research articles on combined exercise training (Binder et al. 2002, Gill et al. 2004, Rydwik et al. 2008, Gine-Garriga et al. 2010). Altogether, 14 articles from the previous three systematic reviews were included.

Further, to detect more recently published studies, a systematic online search was carried out in August 2015 using keywords adapted from the Cochrane review (Liu & Latham 2009) (Appendix 1). The database searched was Medline (2008 to August 14 2015). Updated online retrieval complemented the review with four (n=4) articles (Caserotti, Aagaard & Puggaard 2008, Kalapotharakos, Diamantopoulos & Tokmakidis 2010, Kim et al. 2012, Idland et al. 2014). Details of all the included (n=18) intervention studies are presented in Table 1. The participants of these studies were either relatively healthy or had functional limitations or were frail. Due to the strict age limit of 75 years, the average age of participants ranged between 79 and 84 years. One study focused solely on nonagenarians (≥90 years) (Idland et al. 2014).

Training was mainly home-based in five studies (McMurdo & Johnstone 1995, Campbell et al. 1999, Gill et al. 2004, Helbostad, Sletvold & Moe-Nilssen 2004, Vestergaard, Kronborg & Puggaard 2008). In addition, weekly supervised training at a clinic and unsupervised training sessions at home were combined in one study (Skelton et al. 1995). Home-based training most often combined strength, balance, aerobic and flexibility exercises. Resistance requisites in home-based trials were most often elastic bands and cuff-weights. Supervision was partly provided in the home-based interventions, most often by a physiotherapist. One study included video-tape showing the exercises (Verbrugge & Jette 1994). Helbostad et al. (Helbostad, Sletvold & Moe-Nilssen 2004) aimed to study the effectiveness of home training with motivating group meetings and found that the additional group exercise did not have any extra effect on home training. Thus training intensity and motivation to persist in exercising were regarded as key factors for the success of the intervention irrespective of the setting or training environment (Helbostad, Sletvold & Moe-Nilssen 2004).

Other trials incorporated supervised group-based training in outpatient clinics or gyms. These trials included multicomponent programs, most often addressing both strength and balance as a primary intervention, and single-component strength training programs. These included a variety of physical parameters as a co-intervention or control condition. The single-component programs focused on lower extremity strength (Judge, Whipple & Wolfson 1994, McMurdo & Johnstone 1995, Skelton et al. 1995, Wolfson et al. 1996, Sipilä et al. 1996, Idland et al. 2014) and the use of resistive machines was reported in all these studies. Resistive machines were used also in two multicomponent interventions (Binder et al. 2002, Rydwik et al. 2008). Progression of intensity was monitored by RM or by the resistance grade of the elastic bands. In multicomponent training programs, the Borg perceived scale of exertion (RPE) (Borg 1982) was also used to ensure intensity progression (Lord et al. 2005, Gine-Garriga et al. 2010, Kim et al. 2012).

In the included trials, the intervention most typically continued for 12 weeks. Only 3 out of 18 studies reported an intervention that continued for over 6 months (Campbell et al. 1997, Binder et al. 2002, Caserotti, Aagaard & Puggaard 2008). In the short-term studies, training adherence varied between 65–90%. Three of the interventions continuing for 6 months or longer did not report adherence (McMurdo & Johnstone 1995, Campbell et al. 1997, Caserotti, Aagaard & Puggaard 2008). High adherence for a 6-month intervention was reported by Liu-Ambrose (83%) and Gill (73–79%) (Gill et al. 2004, Liu-Ambrose et al. 2004b). Lord, in contrast, reported a median adherence 27% for a 6-month intervention (Lord et al. 2005). In the study by Binder et al., 100% adherence was achieved because completion of 36 training sessions in each of three phases was required as a criterion for finishing the intervention (Binder et al. 2002). However, 33% of the participants in the exercise training group did not complete the trial and the actual adherence for the entire group was not reported. Variation in reporting adherence complicates reliable comparison between studies.

The intensity of training interventions was even less reported than adherence. Prescribed intensity progression was described as a percentage of 1RM in a few studies. In long-term interventions, the frequency of progression would need to be reported. In addition to progression, more detailed information on the loads, sets and repetitions actually used would be needed to evaluate intervention intensity and to compare it between studies.

The effects of the training interventions on muscle strength, balance and mobility were evaluated with a variety of outcome measures. Muscle strength gains in the lower extremities, most often in knee extension, were clearly found in several trials (Judge, Whipple & Wolfson 1994, Skelton et al. 1995, Wolfson et al. 1996, Binder et al. 2002, Rydwik et al. 2008, Gine-Garriga et al. 2010, Kalapotharakos, Diamantopoulos & Tokmakidis 2010). In two home-based interventions (Campbell et al. 1997, Vestergaard, Kronborg & Puggaard 2008), two group-based multicomponent exercise interventions (Kim et al. 2012, Lord et al. 2005) and two supervised strength training interventions (Sipilä et al. 1996, Liu-Ambrose et al. 2004a) lower body strength did not improve compared to control values. In addition, three studies were carried out to assess the effect of exercise in reducing either risk for falls or number of falls or injuries related to falls (Campbell et al. 1997, Liu-Ambrose et al. 2004a, Lord et al. 2005).

In some studies, an effect was found on both muscle strength and functional outcomes in walking speed, chair rise and balance tests. However, studies among relatively healthy (Judge, Whipple & Wolfson 1994, Skelton et al. 1995) as well as more frail persons (Rydwik et al. 2008) reported a positive effect on muscle strength but less clearly marked effect on mobility or balance. Due to the differences in the study participants' baseline level of physical functioning, the intervention contents and outcome measures used, summarizing the effects of all the strength and balance training interventions included becomes complicated. However, a positive effect on different components of physical functioning both in home-based and center-based exercise interventions was found among community-dwelling older adults aged 75 years or over. On the other hand, the length of the interventions was most often not more than 6 months and, in general, no follow-up after the training intervention was reported. Of the included trials only Kalapotharakos et al. (Kalapotharakos, Diamantopoulos & Tokmakidis 2010) also studied the detraining effect, where they found that the positive strength training effects on muscle strength and functional performance started to decline during a short detraining period of 6 weeks.

TABLE 1 Studies reporting strength training effects on physical functioning in older community-dwelling adults aged ≥75 years.

Studies	Participants, N Mean age (SD)	Intervention	Duration, volume and adherence	Effects
Home-based interventions				
Campbell et al. 1997	233, New Zealand Women >80 IG: 84 (3.4) CG: 84 (3.1)	IG: Individual strength and balance training, outdoor walking (PT supervised 4x+telephoned regularly) CG: Social visits Ankle cuff weights (0.5 and 1 kg)	1 year 30' 3x/week Adherence NR	In favour of IG at 6 months Knee extension strength NS Chair rise + Stair climb up and down NS Walking speed NS Functional reach NS 4 test balance scale +
Gill et al. 2004	188, USA ≥75, physically frail IG: 83 (5.0) CG: 84 (5.2)	IG: Partly supervised individualized physical therapy program: ROM, balance, muscle conditioning and strengthening exercises CG: Health educator home-visits Elastic bands	6 months balance daily, conditioning 3x/week 10 rep, 2 sets, progressive resistance Adherence 73–79%	In favour of IG at 7 months: Chair rise NS Rapid walking speed + Performance oriented mobility assessment POMA + Physical Performance Test NS IADL +
Helbostad et al. 2004	77, Norway ≥75, fallen during the past year + uses a walking aid HT: 81 (4.3) CT: 81 (4.7)	HT: Home-training, twice-daily functional balance and strength exercises and 3 group meetings CT: Supervised, combined training including progressive strength training and the same home exercises. Ankle weights, elastic bands	12 weeks 60' 2x/week 3 sets, 10 rep Adherence : HT 1.29 (0.54) x/day CT 1.35 (0.51) x/day, strength training 88%	No difference between groups: Knee extension strength NS Chair rise + Walking speed + Figure of eight walk + Maximum step length + TUG + Timed pick up +

(Continues)

TABLE 1 (Continues)

Studies	Participants, N Mean age (SD)	Intervention	Duration, volume and adherence	Effects
McMurdo et al. 1995	86, Scotland, UK, ≥75 mobility and ADL limitations IG1: 81 (3.4) IG2: 83 (4.4) CG: 82 (4.7)	Home-based, PT supervised monthly IG1: Individual strength exercises IG2: Flexibility training CG: Health education Elastic bands, progressive thickness	6 months 15' daily 30' supervision every 3-4 week 5-10 rep Adherence NR	No between group differences TUG NS Chair rise NS Grip strength NS Functional reach NS
Skelton et al. 1995	52, England, UK ≥75 healthy IG: med 80, range 76–93 CG: med 80, range 75–90	IG: Supervised group and home-based progressive strength training CG: No intervention, regular PA Elastic bands (6 resistances) and rise bags (1-1.5 kg)	12 weeks 60' 1x/week supervised group AND 2x60' unsupervised home 3 sets, 4-8 rep Sessions completed: -supervised, median 10.5 -home, median 35.5	In favour of IG Knee extension strength + Elbow flexion strength + Leg extension power + Grip strength + Chair rise NS Box stepping + Kneel rise + Stair walking NS Walking speed NS Functional reach NS
Vestergaard et al. 2008	61, Denmark ≥75 women receiving home care IG: 81 (3.3) CG: 83 (3.8)	Home-based video exercise IG: flexibility, balance, strength and aerobic training + biweekly motivation by telephone call CG: regular PA, controlled by biweekly telephone call Elastic bands and exercise video	5 months 26' 3x/week video supported no progression in intensity/resistance Adherence 89%	No comparison between groups IG: Leg extension power NS Biceps strength + Grip strength + Chair rise + Walking speed + Standing balance NS Physical Performance Test +

(Continues)

TABLE 1 (Continues)

Studies	Participants, N Mean age (SD)	Intervention	Duration, volume and adherence	Effects
Center-based multicomponent interventions				
Binder at al. 2002	115, USA >78, sedentary men and women with mild to moderate physical frailty IG: 83 (4) CG: 83 (4)	IG: Supervised intensive exercise training: First 3 months, flexibility, light strength, and balance training; next 3 months, strength training was added; next 3 months, endurance training was added. CG: Low intensity home exercise. Weightlifting machines	9 months 60-90' 3x/week initially 1-2 sets, 6-8 rep, 65% 1RM -> 3 sets 8-12 rep, 85-100% of the initial 1RM Adherence 100% (=2.2 x/wk)	In favour of IG Knee extension strength + Knee flexion strength + Single limb stance time + BBS + Physical Performance Test + ADL+
Caserotti et al. 2008	44, Denmark ≥75 male IG: 80 (11.2) CG: 82 (10.9)	Supervised IG: Multicomponent aerobic, muscle strength, endurance, postural control, flexibility, and reaction exercises CG: Non-exercise control. Elastic bands and body weight	36 weeks 60' 2x/week repetitions and intensity continuously increased Adherence NR	Chair rise + Walking speed + Physical Performance Test +
Giné-Garriga et al. 2010	51, Spain 80-90 frail men and women IG: 84 (2.8) CG: 84 (3)	IG: Supervised functional circuit training for balance and lower body strengthening CG: Health education and social meetings Ankle weights	12 weeks 2x/week 6-15 rep, 1-2 sets, 0.5-2 kg weight, 12-14 RPE Adherence 90%	In favour of IG Knee extension strength + Chair rise + Walking speed + modified TUG + Standing balance + ADL +

(Continues)

TABLE 1 (Continues)

Studies	Participants, N Mean age (SD)	Intervention	Duration, volume and adherence	Effects
Lord et al. 2005	620 (153 in IG1), Australia ≥75 IG1: 80 (4.3) IG2: 81 (4.6) CG: 80 (4.6)	IG1: Supervised individualized strength, flexibility, coordination, and balance exercise and strategies for maximising vision and sensation IG2: Minimal brief advise CG: No intervention Ankle cuffs, weight belts, elastic bands	during 6 months 4x 10- to 12-week term with 2-week breaks 60' 2x/week initial 8 reps, increased based on RPE Adherence: median 21 out of 78 offered sessions (=27%)	IG1 and IG2 compared with CG Chair rise + Knee extension NS Ankle dorsiflexion NS Balance NS Reaction NS IG1 compared with CG Knee flexion strength +
Kim et al. 2012	155, Japan ≥75 sarcopenic women IG1: 80 (2.9) IG2: 79 (2.9) IG3: 79 (2.8) CG: 79 (2.8)	IG1: Supervised strength, balance and gait exercise program + amino acid supplementation IG2: Exercise program without amino acid supplementation IG3: Amino acid supplementation CG: Health education Ankle-weights (0.5-1.5 kg), elastic bands and chair	3 months 60' 2x/week 12-14 Borg RPE Adherence: IG1:70%, IG2: 81%	IG2 compared to CG Knee extension strength NS Usual walking speed + Maximal walking speed + Muscle strength increased only in IG1
Rydwik et al. 2008	96, Sweden ≥75 frail, low PA IG1: 83 (4.5) IG2: 84 (3.7) IG3: 83 (4) CG: 83 (4)	Group-based aerobic, strength and balance training IG1: Diet counselling IG2: Training IG3: Training + diet counselling CG: General PA and diet advice Stationary strength training equipment, weight belt	12 weeks 60' 2x/week, 1 set, 8 rep, 60 -> 80%, in functional strength 2 sets, 10 rep Adherence 65%	In favour of IG2 and IG3 compared with CG Strength + Chair rise NS Walking speed NS Balance NS TUG NS

(Continues)

TABLE 1 (Continues)

Studies	Participants, N Mean age (SD)	Intervention	Duration, volume and adherence	Effects
Centre-based strength training interventions				
Idland et al. 2014	8, Norway ≥90 range 90-93	Individually supervised progressive strength training Training machines (Technogym)	12 weeks 60' 2x/week 2-3 sets, 8-12 rep Adherence 57–95%	Walking speed + Chair rise + TUG +
Judge et al. 1994	110, USA ≥75, relatively healthy IG1: 80 (4.0) IG2: 79 (2.8) IG3: 80 (4.1) GG: 81 (4.5)	IG1: Supervised strength training IG2: Balance exercise IG3: Combined strength and balance CG: Control, 5 educational sessions) Cuff-weights (up to 14 kg) and resistive machines	12 weeks 45' 3x/week 2 sets, 10 rep for cuff weight exercises, 3 sets, 12 rep 60-75% 1RM for resistive machines Adherence 82%	In favour of strength training IG1 and IG3 Isokinetic lower extremity strength + Walking speed NS Chair rise NS
Kalapotharakos et al. 2010	22, Greece 80-88 men, no limitations in cognition, ADL or IADL IG1: 82 (2.2) IG2: 83 (2.8) CG: 83 (3)	Supervised strength training IG1: Exercise 8wk-detraining 6wk IG2: Exercise 14wk CG: Non-exercise control Kettler multi-machine	14weeks 60' 2x/week 3 sets 10 rep at 70% of 3RM Adherence: 90% (8-week), 85% (14-week)	In favour of IG1 and IG2 Lower body strength + chair rise + TUG + 6 min walk distance + Strength gains of IG1 declined during detraining period
Liu-Ambrose et al. 2004	98, Canada 78-85 women with low bone mass IG1: 80 (2.1) IG2: 79 (2.8) CG: 80 (3.2)	IG1: Supervised strength training IG2: Agility training CG: Stretching (sham exercise) Kaiser machines, free weights	25 weeks 50' 2x/week target 2 sets, 6-8 reps 75-85% of 1RM Adherence 83%	In favour of IG1 and IG2: Postural sway + Quadriceps strength NS Balance and mobility NS

(Continues)

TABLE 1 (Continues)

Studies	Participants, N Mean age (SD)	Intervention	Duration, volume and adherence	Effects
Sipilä et al. 1996	42, Finland age range 76–78 no severe diseases or functional impairments	Supervised IG1: Strength training IG2: Endurance training CG: Control Resistance machines (Hur)	18 weeks 60' 3x/week 3-4 sets/8-10 reps, 60-75% 1RM Adherence 71–86%	Both IG1 and IG2 improved strength and walking speed. No difference compared to CG.
Wolfson et al. 1996	110, USA ≥75 healthy IG1: 79 (2.8) IG2: 80 (4.1) IG3: 80 (4.1) CG: 81 (4.5)	Supervised IG1: Balance training IG2: Strength training IG3: Balance and strength CG: Fall prevention and stress management education sessions Resistive machines and sand bags	13 weeks 45' 3x/week strength +45' 3x/week balance max 13 rep, 70-75% of 1RM Adherence: IG1 74%, IG2 82%, IG3 82%	In favour of IG2 and IG3 Lower extremity strength + In favour of IG1 and IG3 Balance + Walking speed NS for all groups

IG, intervention group; CG, control group; HT, home training group; CT, combined training group; NR, Not reported; + positive effect, NS, non-significant effect; rep, repetitions; ROM, range of motion; rep, repetitions; RM, Repetition Maximum; RPE, Rate of Perceived Exertion; PA, Physical activity; PT, physical therapist

2.3.3 Adherence to training interventions

Typically, less than half of those invited to take part in falls prevention activities agree to participate, and nearly half decline invitations to attend SBT groups (Yardley et al. 2008). Low adherence to exercise interventions threatens the wide range of health benefits. Interventions aiming at increasing physical activity in older adults have had larger positive effects on physical activity level among healthier than among chronically ill populations (Chase 2015). An important issue when implementing exercise interventions is whether the recruited participants can continue the training for a relatively long time and with reasonable frequency.

Previous reviews have reported high adherence rates in randomized controlled trials (RCT), where participants have completed more than 70% of their prescribed exercise sessions (Martin & Sinden 2001, Nyman & Victor 2012). The determinants predicting better exercise adherence for older adults have been better physical condition, a previous physically active lifestyle, non-smoking and higher exercise self-efficacy (Martin & Sinden 2001). However, as material for RCTs, these study populations were rather limited compared with real-world community settings, where multiple morbidities and functional limitations are common. A more recent review revealed that the evidence on the determinants of physical activity and exercise in healthy adults aged >55 years was insufficient (Koeneman et al. 2011). Barriers to physical activity among older adults, especially those over 80 years of age with regard to SBT, have been studied even less frequently (Baert et al. 2011).

In an Australian sample aged ≥62 years and living in retirement villages, poor balance, multiple medication use and impaired cognition were found to predict poor adherence to exercise programs (Tiedemann, Sherrington & Lord 2011). Previous studies among older community-dwelling adults have reported adherence to shorter-term (Fielding et al. 2007, Sjösten et al. 2007) or home-based exercise interventions (Jette et al. 1998) and assessed self-report measures such as self-efficacy (Koeneman et al. 2011), attitudes (Hawley-Hague et al. 2014) or socioeconomic characteristics (Chevan 2008) as potential determinants of training adherence. Poor health has been described as a significantly greater barrier to general physical activity after age 80 than at younger ages (Moschny et al. 2011).

2.4 Summary of the literature

A large body of research has been carried out on the effects of strength and balance training on physical functioning. Different kinds of SBT modalities have been used, mostly, however, in short term interventions and among relatively healthy older adults. Evidence on the effect of long-term supervised strength training is scarce. In addition, studies on the effects of health and physical functioning on the initiation of exercise among community-dwelling older adults with a wide variety of functional limitations and comorbidities are very few. It is less clear how strength and balance training can be adapted for older adults with multiple functional limitations and morbidities. Despite the recognized health benefits, relatively few older adults participate in supervised SBT. The role of health- and physical functioning-related factors in predicting long-term SBT adherence has not been reported previously in ≥75-year-old adults. Information regarding the barriers to beginning a training program may improve the design and implementation of exercise programs in community settings (Glasgow, Vogt & Boles 1999). In addition, the relationship between subjective functional vision impairment and measured balance and mobility has not previously been evaluated in a population-based sample of older persons.

3 AIMS OF THE STUDY

This study is part of the Geriatric Multidisciplinary Strategy for the Good Care of the Elderly (GeMS) project, which included a multi-intervention based on a comprehensive geriatric assessment. The purpose of this dissertation was to explore physical functioning, participation in strength and balance training, and the effects of training in older community-dwelling people aged 75 years and over.

The specific aims were to study:

1. Relationships between functional vision, balance and mobility in older adults. (Study I)

2. The associations of health and physical functioning with participation in a strength and balance training program. (Studies II and III)

3. The effects of a long-term strength and balance training intervention on muscle strength, balance and mobility in training adopters. (Study IV)

4. Muscle strength, balance and mobility in training adopters, non-adopters and controls. (unpublished data)

4 MATERIAL AND METHODS

4.1 Study design and participants

This intervention study is part of the larger GeMS project. It was a multi-disciplinary population-based health intervention study with the aim of evaluating the effects of geriatric assessment and the optimization of health and functioning. The study was conducted in the city of Kuopio, Eastern Finland between November 2003 and December 2007. A random sample of 1 000 persons (Figure 2) was taken from all persons aged ≥75 years and resident in the city of Kuopio (88 253 inhabitants, of whom 5 615 (6%) were aged ≥75 years). Contact information was based on the Finnish population register. The population-based sample of 1 000 individuals was randomly assigned (computerized random numbers) into an intervention or a control group before the baseline examination. Simple randomization was stratified by age and sex. The allocation sequence was not concealed. Of these subjects, 188 refused to participate in the study or in the physical functioning measurements, 68 died before the baseline examination, 81 were living in institutional care facilities, 10 were unable to participate in the physical functioning measurement due to poor health and 2 had moved out of the area. Finally, only the community-dwelling participants with baseline data on physical functioning were included in this study (n= 651; 339 in the intervention group and 312 in the control group). The intervention effects of the GeMS project on physical performance and mobility limitation have been published previously (Lihavainen et al. 2011, Lihavainen et al. 2012). In this dissertation the main interest is in the secondary analyses of the community-dwelling participants in the intervention group who started the supervised training program (n=182). The data used and the participants in the original articles and dissertation are summarized in Table 2. An annual examination over a three-year period was conducted both for the intervention and control groups.

The GeMS study protocol was approved by the Research Ethics Committee of Northern Savo Hospital District and Kuopio University Hospital. Written informed consent was obtained from all participants or from their closest proxy if the participant had advanced cognitive impairment.

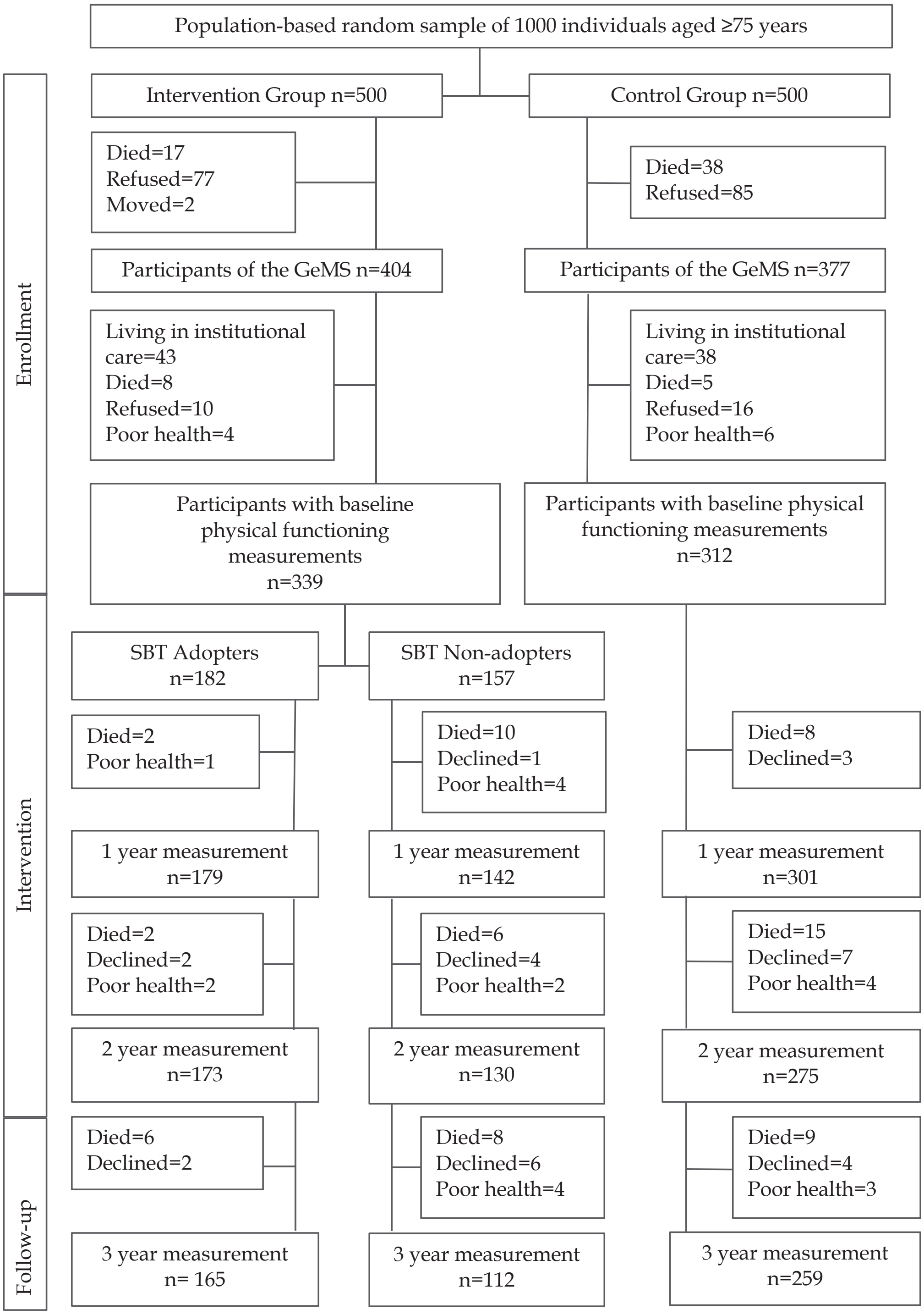

FIGURE 2 Flow chart of the study with reasons for dropouts.

TABLE 2 Content of data presented in the original articles and dissertation.

Study	Design	Participants N	Age mean (SD)	Primary outcome
I	Observational Cross sectional	576 functional vision groups by VF-7: 95 poor 222 moderate 259 good	81(4)	Mobility and balance
II	Observational Prospective	339 182 adopters 157 non-adopters	81 (5)	SBT adoption
III	Intervention	182 adopters	80 (4)	SBT adherence
IV +additional unpublished data	Intervention and follow-up	651 182 adopters 157 non-adopters 312 controls	81 (5)	Muscle strength, mobility and balance

SD=Standard deviation, MMSE= Mini Mental State Examination, SBT= Strength and balance training, VF-7=7-item functional vision questionnaire

4.2 Data collection and measurements

Three trained nurses, two physiotherapists, and two physicians were responsible for the data collection. They assessed the participants in the intervention and control group annually (2004–2007). Only those in the intervention group were medically examined by a physician (2004–2006). In follow-up year 2007, the physicians did not examine the participants but instead collected data from medical records. If a participant was unable to visit the outpatient clinic, the measurements and interviews took place in the participant's home. Data collection was supplemented by a caregiver or a nurse interview if a participant had difficulty answering the questions. Such difficulties were mainly due to cognitive impairment. Each participant's medical history from the primary health care provider (City of Kuopio) and Kuopio University Hospital was available to the research team.

4.2.1 Measurements of physical functioning and activity

The muscle strength, balance and mobility measurements were performed by the physiotherapists. They were not blinded to the group assignments. Performance measurements were always done in the same order. Each participant was annually assessed by the same therapist. If the participant didn't seem to fully understand the instructions, the tester repeated them once.

Muscle strength was measured by maximal isometric knee extension and flexion strength and maximal grip strength. Unilateral maximal isometric knee extension and flexion strength was measured in a sitting position using an adjustable dynamometer chair (Good Strength; Metitur Oy, Jyväskylä, Finland) with the ankle attached by a belt above the malleolus to a strain-gauge system and the knee angle set at 60° from full extension. Participants were allowed three maximal efforts for each leg, and the best performance with the highest value was accepted as the result. Grip strength was measured in seated position, with the elbow flexed at 90°, using a dynamometer (Saehan Corp, South Korea). One maximal effort for each hand was allowed, and the result from the stronger hand was used in the analyses.

Each balance and mobility test was performed once per year as part of the annual test battery. The flooring was standardized so that all the balance and mobility tests were conducted on a rigid floor surface. The participants wore shoes except for the BBS test. For all of the timed tests, time was measured with a stopwatch, and use of a walking aid was allowed in the TUG and maximal walking speed tests.

A *chair rise test* was used to assess participants' ability to perform five repeats of sit-to-stand and stand-to-sit tasks as fast as possible. As a modification of the original test (Guralnik et al. 1994), hands were held to side and participants were allowed to help with their hands if needed. First, physiotherapists demonstrated the test to the participants and then instructed verbally. The test-retest reliability of the test has been shown to be good, with Intraclass Correlations (ICC) ranging from 0.64 to 0.96 (Bohannon 2011). Inability to perform the test in 17 seconds has been found to predict high risk for severe lower extremity functional limitation among well-functioning women aged 70 to 79 years over a 6.9-year follow-up (Cesari et al. 2009). In the Health 2011 study conducted among a Finnish population aged 75 years and over, average performance time was 14.2 seconds for men and 16.1 seconds for women (Koskinen, Lundqvist & Ristiluoma 2012).

Maximal walking speed (m/s) was measured over a 10-m distance. Two markers were used to indicate the start and finish of the 10-m path. Participants started walking 2 m before the first mark and were instructed to continue walking past the end mark for a further 2 m, so that they were walking at maximal pace within the timed 10-m section. A review of different walking speed tests found them to have high reliability and validity (Rydwik et al. 2013). Maximal walking speed has been reported to have high test-retest reliability over distances of both 6 (ICC=0.96) (Steffen, Hacker & Mollinger 2002) and 10 meters (ICC=0.98) (Pohjola 2006).

The Berg Balance Scale (BBS) was used to assess balance by observing the participant performing 14 different functional tasks: standing up, standing unsupported, sitting down, sitting unsupported, transferring from one chair to another, standing with eyes closed, standing with feet together, reaching forward with outstretched arm, retrieving object from floor, turning to look behind, turning around 360 degrees, placing alternate foot on step, standing in a tandem position and standing on one foot. Depending on the degree of success in performance, each task is scored from zero to four. The sum score ranges between 0 (severely impaired) and 56 points (excellent) (Berg et al. 1992, Bogle Thorbahn & Newton 1996). The BBS has reported to have high inter-rater reliability (0.88) among community-dwelling older adults (Bogle Thorbahn & Newton 1996). It has also been recommended as one of a core set of standing balance measures in clinical research and practice (Sibley et al. 2015).

A *timed up and go test (TUG)* was used to assess balance and basic mobility skills (Podsiadlo & Richardson 1991). The patients were instructed to stand up from a chair, walk for a distance of 3 m at maximal speed, turn, walk back, and sit down on the chair. Among community-dwelling women aged 65 to 85 years a TUG test time of 12 seconds has been proposed to be a practical cut-off point for normal performance and it has shown high validity in discriminating between community-dwelling and institutionalized residential status (Bischoff et al. 2003).

Ability to walk 400 m was assessed by asking whether respondents could walk 400 m (yes; yes, with difficulty, but without help; not without help; or no). In the analysis, the categories "yes" and "yes, with difficulty, but without help" were combined under the single category "yes independently". Self-reported difficulties in walking have been found to be reliable and valid measures to assess mobility disability (Sayers et al. 2004, Mänty et al. 2007).

Fear of falling was investigated by asking a question "Does fear of falling restrict your everyday locomotion?" The possible answers were: no; yes, outdoors in slippery conditions; yes, outdoors in winter; yes, outdoors year-round; or yes, indoors). In the analysis, the "yes" responses were combined under the single response "yes."

Level of previous physical activity, at a different period of life, was asked by a questionnaire. The question was "How much leisure-time physical activity did you have when you were 10–19, 20–64 or over 64 years old?" There were three response categories: no regular physical activity; regular physical activity; and sports. The categories regular physical activity and sports were combined under the single category 'active'.

The level of current physical activity was assessed by physiotherapists using a modified version of the Grimby scale (Grimby 1986). The participants were categorized on the basis of their self-rated physical activity into the low (no other exercise beyond light walking 1–2 times/wk), moderate (light walking or other light exercise several times/wk or moderate exercise 1–2 times/wk), or high (moderate or vigorous exercise several times/wk) activity group.

Types and frequency of current physical activity were assessed by asking "What kind of exercise do you do to improve your fitness and health?" The answering options were walking or Nordic walking, home exercise, swimming, cycling, skiing, dancing, strength training at the gym, supervised exercise groups, ball games, and something else. Participants also reported their frequency of each activity: not at all, less than once a month, 1 to 2 times per month, once a week, 2 to 3 times per week, almost daily. Categories 1 to 2 times per month or more often were combined in a single category.

Perceived importance of physical activity was assessed by asking "How important is physical activity for you?" The answering options were: unnecessary, waste of time, not very important, no opinion, quite important, very important. Physiotherapists also asked about the main motives for physical activity: "What are the main motives for your physical activity?" The answering options were: maintaining health, pleasure of physical activity, social causes, psychological causes, health care professionals' advice or referral, something else, what?

4.2.2 Assessments of health and daily functioning

Cognitive function was assessed using the Mini-Mental State Examination (MMSE) (Folstein, Folstein & McHugh 1975). The MMSE score was categorized as normal (30–25) or impaired (24–0) (Crum et al. 1993). *Depressive symptoms* were assessed using the 15-item Geriatric Depression Scale (GDS-15) (Sheikh & Yesavage 1986) with scores ≥5 considered to be indicative of possible depression. Body mass index (BMI, kg/m2) was calculated from body weight and height measured by the study nurses. The short version of the Mini Nutritional Assessment (MNA-SF) was used to assess *the risk of malnutrition* (Rubenstein et al. 2001). The maximum score on the MNA-SF is 14; scores of 12–14 indicate normal nutritional status, scores of 8-11 indicate a risk of malnutrition, and scores of 0–7 indicate malnutrition.

Self-rated health was assessed with the following question: "How would you rate your health at the moment?" The participants selected one of five response alternatives. In the analyses, alternative 3 (moderate) formed one category and alternatives 1 and 2 (good or very good) as well as 4 and 5 (poor or very poor) were combined.

Comorbidity was computed using a modified functional comorbidity index (FCI), which is a validated scale that predicts physical functioning in older adults (Groll et al. 2005). The FCI takes into account the number of medical conditions, with higher scores indicating greater comorbidity. In this study, data on the following medical conditions were available: rheumatoid arthritis and other connective tissue diseases, osteoporosis, chronic asthma or chronic obstructive pulmonary disease (COPD), coronary artery disease, heart failure, myocardial infarction, Parkinson's disease or multiple sclerosis, stroke, diabetes, depression, visual impairment, hearing impairment, and obesity (BMI > 30). Patient diagnoses obtained from the Special Reimbursement Register were used to screen for the presence of rheumatoid arthritis and other connective tissue diseases, chronic asthma or COPD, Parkinson's disease, and multiple sclerosis. Other conditions of the FCI were ascertained via participants' medical records. For the purposes of Study I, the FCI item of visual impairment (i.e., presence of an eye disease that could potentially impair eyesight) was omitted.

Use of medicines was elicited during the nurse interviews. Participants were asked to bring their prescription forms and drug containers to the interviews. Regular and as-needed drugs were recorded. *The Sedative Load Model* was used to quantify the cumulative effect of taking multiple drugs with sedative properties (Linjakumpu et al. 2003, Taipale et al. 2011). Sedative load score ≥1 was used to describe participants who used one or more drugs with sedative properties on a regular basis.

Functional vision was assessed by a 7-item vision function questionnaire, the VF-7, a modified version of the VF-14 (Steinberg et al. 1994). The VF-7 comprises seven activities dependent on functional vision and is validated for use in patients with cataracts (Uusitalo et al. 1999). Patients are asked how much difficulty they have doing each activity, with or without glasses. The activities are reading small print; seeing steps, stairs, or curbs; reading traffic, street, or store signs; doing fine handwork; cooking; watching television and driving in darkness. Each question is scored as follows: 4, 3, 2, or 1, respectively, if the subject has no, little, moderate, or a great deal of difficulty performing the activity, and 0 if the subject is unable to perform the activity due to poor vision. If a patient does not do an activity for reasons other than his or her vision, the item in question is not included in the scoring. The final score is obtained by averaging responses across all the relevant activities and multiplying by 25. Scores range from 0 (representing maximum impairment) to 100 (representing no impairment). The response rate varied between 97% and 100% for all the VF-7 questions, except cooking (n = 519, 90%) and driving in darkness (n = 99, 17%). Only 114 participants had a valid driving license, and the gender distribution of the respondents (n=99) for the question about driving in darkness was uneven (16 women and 83 men). Thus, the question was dropped out from the final scoring of the VF-7 index.

For analytical purposes, participants were categorized into three groups according to their VF-7 results: (1) poor functional vision, VF-7 score ≤75; (2) moderate functional vision, scores between 75 and 100; and (3) good functional vision, the score of 100. The cut-off value between the poor and moderate functional vision groups (VF-7 score = 75) represented a sum score in a theoretical situation in which participants reported little difficulty (score 3) in performing all of the activities in question.

Independence in activities of daily living was assessed using questionnaires. Basic activities of daily living (ADLs) (e.g. toileting, dressing, transfers) were assessed using the 10-item Barthel Index (Mahoney & Barthel 1965, Collin et al. 1988). The index is scored in units of 5 points from 0 to 100, with higher points indicating better function. The Barthel Index has been validated as a measure of neurologic physical disability (van der Putten et al. 1999, Hobart et al. 2001). Participants with an ADL score ≤80 were defined as having ADL disability. The ability to perform instrumental activities of daily living (IADL) (e.g. using a telephone, preparing food, taking responsibility for one's own medications and finance) was assessed using the 8-item Lawton & Brody Instrumental Activities of Daily Living Scale (Lawton & Brody 1969). Scoring ranges from 0 to 8, with higher scores indicating better functioning. For the purpose of the present study, participants with an IADL score ≤6 were defined as having impaired IADL.

4.3 Interventions

4.3.1 Comprehensive geriatric assessment

The intervention was based on the CGA and focused individually on participants' health- and physical functioning-related problems (Lihavainen et al. 2011). The intervention was planned by a multidisciplinary team together with the participants.

Two physicians who were trainees in geriatrics conducted the structured clinical examination and medication assessment. Nurses carried out the case management or health counselling annually and arranged services for participants in need. For those at risk of malnutrition (MNA-SF ≤11) in 2005, a full MNA assessment was performed by study nurse (Nykänen et al. 2013). If the MNA score was 24 or less, nutritional counselling by a nutritionist was offered. The nutritional intervention included two meetings with a nutritionist, the first in 2005 and the second in 2006 (Nykänen et al. 2014). Telephone calls between the visits every two months and special leaflets were used to reinforce the dietary advice. The intervention aimed to help participants improve the wholesomeness of their diet in line with Finnish recommendations by increasing the frequency of meals and adding energy and proteins to meals without nutritional supplements.

An ophthalmologist examined all the participants in the intervention group (n=304) in 2006 and, when needed, referred them to specialist care (e.g. cataract surgery). Oral health was examined at least twice during the study period by two dentists (Komulainen et al. 2012). An oral health-promoting intervention was carried out for a random sample of the intervention group. Controls used their usual health care services and they did not receive any additional intervention.

4.3.2 Physical activity counselling

The physical activity component of the intervention consisted of physical activity counselling and an opportunity to participate in supervised muscle strength and balance training at the study gym. The aim was to optimize participants' physical activity level. The counselling was conducted by a physiotherapist and started with a semi-structured interview that charted the participants' current and prior physical activity. During the counselling session, practical and detailed goals for future physical activity were set together, and both the participant and the physiotherapist signed the written plan outlining goals and ways of increasing physical activity. The session took approximately 1.5 hours and was repeated annually, when revisions and adjustments were made to the plan.

4.3.3 Strength and balance training

The intervention group had an opportunity to participate in group-based SBT once a week between September 2004 and December 2006. Training was organized in the city center and arranged every workday. The intervention did not include transportation to the gym, but the participants received help in finding community transportation services or arranging transportation with family members or neighbors. Training was free of charge. Eligibility for the SBT was based on clinical examination by a study physician. The training could be commenced later if the participant had permanent or transient contraindications for training, such as an unstable acute or chronic medical condition or was recovering from an operation. An inclusion criterion was the ability to move independently or with minimal help in the gym. The gyms were also accessible for participants with assistive devices.

The training was supervised in small groups by a trained physiotherapist. Participants with poorer physical functioning were in smaller groups (<5) and those with high physical functioning in bigger (>10) groups. Each training session started with a 15-minute warm-up including balance exercises. These included different kinds of static and dynamic, standing, walking, turning and reaching exercises where challenge was adjusted by changing the size or stability of the base of support. Also dual task and eyes-closed situations were applied.

This was followed by 60 minutes of strength training which included knee extension and flexion, leg press, hip adduction, abduction and extension and abdominal crunches with resistive machines (Technogym SpA, Cesena, Italy). The intensity of the strength training was determined individually by the one-repetition maximum (RM): 60–85% of 1 RM. After a couple of introductory training sessions, the prediction of 1 RM was done using 3–6 repetitions to failure. Abdominal muscles were trained without RM measurement. The resistance was adjusted throughout the intervention, and progression accomplished by increasing the load while maintaining the same number of repetitions. Participants were instructed to perform the exercises in two to three sets with 8–12 repetitions per set. Muscle stretching was to be done at home after each training session.

4.4 Training adoption and adherence

Participation in SBT was monitored by the three study physiotherapists and recorded on the training logs at the gym. The criterion for *SBT adoption* was taking part at least once in training at the gym during the study period. *Non-adoption* is used here as a synonym for not taking up, initiating or starting training. The total length of training was 28 months, including gym closures on midweek holidays and for summer vacations. Thus the number of training sessions offered per participant varied from 94 to 104. Training *adherence* was measured by the number of training sessions attended relative to the number of training sessions offered, and expressed as a percentage. For the statistical analysis, the participants were categorized according to their adherence level: (1) ≤33.3%, low adherers, (2) between 33.3 and 66.6%, moderate adherers, and (3) ≥66.6%, high adherers.

Major adverse events (falls, cardiovascular-related episodes and musculoskeletal-related events) (Liu & Latham 2010), directly related to the training, were monitored by physiotherapists during the supervised training. Minor adverse events were not systematically documented. *Hospital admissions* during the study period were identified from the Finnish National Hospital Discharge Register maintained by the National Institute for Welfare and Health (Sund 2012).

4.5 Statistical methods

Variables with normal distribution descriptive values were expressed by means and standard deviations (SD) or 95% confidence intervals (95% CI); statistical comparison between the groups was made by using analysis of variance (ANOVA) or t-test. Variables with ordinal descriptive values were expressed by median and interquartile range (IQR); statistical comparison between groups was made by using a Kruskal-Wallis test or a Mann-Whitney U test when appropriate. Measures with a discrete distribution were expressed as counts with percentages (%) and analysed by Chi-Square. The α-level was set at 0.05.

Study I: Owing to violation of the distribution assumptions, statistical significance for the hypotheses of linearity (orthogonal polynomial on the level of the functional vision group values, linear trends) for physical performance was evaluated by bootstrap-type analysis of covariance (ANCOVA). Age, gender, FCI and MMSE scores were used as covariates in the ANCOVA analyses. The normality of the variables was tested using the Shapiro–Wilk W-test.

Study II: Logistic regression models were used to study the factors associated with non-adoption (i.e., not initiating training). The bivariate analyses were adjusted for age and sex. In the second phase, the independent variables that were significantly related to non-adoption in the bivariate analysis were used as predictors in the multivariate analysis. To avoid multicollinearity, the BBS and TUG test scores were omitted from the multivariate model because they were strongly correlated with the IADL score. If the 95% CI did not include 1, the result was regarded as statistically significant.

Study III: With the low SBT adherence group as a reference, multinomial logistic regression analyses were conducted to estimate the odds ratios (OR) for determinants of moderate and high adherence levels. The analyses were run for each variable with age and/or sex as covariates.

Study IV: As an exploratory analysis, secondary to the main GeMS study, the effects of the training intervention were analyzed separately for women and men due to differences in baseline characteristics and performance level. The statistical significance of mean longitudinal change between the baseline and two-year measurements and two-year and follow-up measurements was assessed using t-test for paired-samples with bias-corrected accelerated bootstrap type tests (2 000 repetitions). Participants with missing data on two year functional measurements were excluded from the analyses of specific measurements. The proportion of missing cases among training adopters was 13% in knee extension and flexion strength, 12% in chair rise, 10% in walking speed, 8% in TUG, and 8% in BBS.

The effect sizes (ES) were calculated as the mean difference between the two measurements divided by the pooled standard deviation of the two measurements. The 95% Confidence Intervals (CI) for ES were obtained by bias-corrected bootstrapping. An effect size of <0.20 was considered negligible, 0.2-0.49 small, 0.50-0.79 medium, and ≥0.80 large (Cohen 1988).

Additional data: Finally, a linear mixed model was used to examine the effect of intervention in physical functioning over time in training adopters, non-adopters and controls. An unstructured covariance matrix was used to estimate the variance of the random intercepts. The mixed model approach used all available data on each subject and was the method which best accounted for observations missing at random. An interaction term, group by time, was used to estimate the effect of the intervention on the annual rate of change in physical functioning over time. First, the analyses were carried out for the 2-year intervention, after which the 1-year follow-up was included in the analyses. Age, years of education, cognition, IADL, depressive symptoms and physical activity were used as covariates in the model. In addition, time effect within each group was estimated with age and sex adjusted models.

Statistical software: Stata statistical software, release 12.1 (StataCorp, College Station, Tx, USA), was used for the analyses in Study I. In Study IV, Stata statistical software, release 13.0 was used to conduct the effect size calculations. In all other analyses, the latest available statistical version (19.0 or 20.0) of SPSS for Windows (SPSS Inc., Chicago, Il, USA) was used.

5 RESULTS

5.1 Characteristics of participants

The participants' demographic, health and physical functioning characteristics are presented in Table 3. The intervention group had shorter education and fever depressive symptoms than controls. They also had higher independence in the instrumental activities of daily living and were more often able to walk 400 m independently than controls.

The participants' previous and baseline physical activity characteristics are described in Table 4. No differences in their physical activity during the previous age stages were observed. The proportion of those reporting being active at both ages 10–19 and 20–64 years was 56% in the control group and 63% in the intervention group. Activity was highest after age 64, when 84% of the participants in both groups reported being active.

At baseline, the participants in the control group had a low physical activity level more often than those in the intervention group. At baseline, the most commonly reported form of exercise was walking or Nordic walking, with a higher proportion of walkers in the intervention than control group. Home gymnastics was the second most common exercise form in both groups. The control group reported skiing more often than the intervention group. One-fifth of the participants took part in a supervised exercise group, but strength training in a gym was equally rare in both groups.

TABLE 3 Baseline characteristics of the study participants.

Variable		Population sample			Intervention group		
		Control group (n=312)	Intervention group (n=339)	*p*	SBT adopters (n=182)	SBT non-adopters (n=157)	*p*
Demographics							
Female, n (%)		212 (68)	244 (72)	0.26	130 (71)	114 (73)	0.81
Age, years, mean (SD)		81.4 (4.7)	80.9 (4.5)	0.15	79.7 (3.9)	82.3 (4.8)	<0.001
Years of education, mean (SD)		7.7 (3.3)	7.1 (3.3)	0.03	7.6 (3.6)	6.5 (2.9)	0.001
Living alone, n (%)		176 (58)	183 (54)	0.53	93 (51)	90 (58)	0.25
Health status							
Functional Comorbidity Index, mean (SD)		2.5 (1.7)	2.4 (1.7)	0.37	2.1 (1.5)	2.6 (1.8)	0.011
Geriatric Depression Scale-15 ≥5, n (%)		32 (11)	20 (6)	0.03	10 (6)	10 (6)	0.74
BMI, mean (SD)		26.4 (4.3)	26.7 (4.2)	0.38	27.3 (4.0)	26.7 (4.7)	0.22
Sedative load ≥1, n (%)		89 (29)	102 (30)	0.66	38 (21)	64 (41)	<0.001
Mini-Mental State Examination ≤24, n (%)		74 (24)	73 (22)	0.51	18 (10)	55 (35)	<0.001
Mini Nutritional Assessment-SF ≤11, n (%)		46 (15)	41 (12)	0.33	13 (7)	28 (18)	0.002
Self-rated health, n (%)	good or very good	133 (43)	151 (45)	0.83	79 (43)	72 (46)	0.003
	moderate	138 (44)	142 (42)		88 (48)	54 (34)	
	poor or very poor	40 (13)	45 (13)		15 (8)	30 (19)	
Physical functioning							
Knee extension force (N)	women	250 (77)	256 (79)	0.48	263 (79)	243 (79)	0.087
mean (SD)	men	397 (98)	396 (104)	0.94	405 (108)	382 (98)	0.31
Knee flexion force (N)	women	111 (42)	109 (39)	0.67	113 (40)	103 (37)	0.069
mean (SD)	men	200 (57)	197 (55)	0.73	200 (56)	194 (54)	0.62
Chair rise (s), mean (SD)		16.7 (8.6)	16.7 (7.0)	0.98	15.8 (5.3)	18.0 (8.7)	0.010
Walking speed (m/s), mean (SD)		1.28 (0.5)	1.24 (0.4)	0.31	1.31 (0.4)	1.15 (0.4)	<0.001
TUG (s), mean (SD)		14.2 (9.7)	13.5 (8.9)	0.38	11.5 (5.7)	16.0 (11.2)	<0.001
BBS, mean (SD)		47 (9.4)	48 (8.8)	0.11	50 (6.9)	46 (10.2)	<0.001
IADL, mean (SD)		6.3 (2.2)	6.7 (1.8)	0.02	7.2 (1.4)	6.1 (2.1)	<0.001
Unable to walk 400 m independently, n (%)		39 (13)	25 (7)	0.03	4 (2)	21 (13)	<0.001
Use of a walking aid, n (%)		109 (35)	101 (30)	0.16	39 (21)	62 (39)	<0.001

BMI, Body mass index; BBS, Berg Balance Scale; IADL, Instrumental activities of daily living; SBT, strength and balance training; TUG, Timed up and go

TABLE 4 Physical activity characteristics of the study participants.

	Population sample			Intervention group		
	Control group (n=312)	Intervention group (n=339)	*p*	SBT adopters (n=182)	SBT non-adopters (n=157)	*p*
Previous						
Active at age of, n (%)						
10-19 years	174 (56)	213 (63)	0.091	118 (65)	95 (61)	0.41
20-64 years	173 (56)	214 (63)	0.064	126 (69)	88 (56)	0.012
>64 years	260 (84)	285 (84)	0.98	161 (88)	124 (79)	0.017
Baseline						
Physical activity level, n (%)			0.002			0.009
Low	139 (45)	118 (35)		51 (28)	67 (43)	
Moderate	106 (34)	162 (48)		93 (51)	69 (44)	
High	67 (21)	58 (17)		38 (21)	20 (13)	
Forms of physical activity, n (%)						
No form of physical activity reported	38 (12)	29 (9)	0.13	10 (5)	19 (12)	0.034
Walking or Nordic walking	218 (70)	263 (78)	0.025	153 (85)	111 (71)	0.003
Home gymnastics	214 (69)	224 (66)	0.52	134 (74)	93 (59)	0.005
Supervised exercise classes	60 (19)	72 (21)	0.52	45 (25)	28 (17)	0.124
Cycling	34 (11)	40 (12)	0.72	22 (12)	18 (12)	0.86
Swimming	17 (5)	28 (8)	0.16	19 (10)	9 (6)	0.12
Skiing	40 (13)	21 (6)	0.004	14 (8)	7 (5)	0.22
Strength training in a gym	21 (7)	17 (5)	0.35	9 (5)	9 (6)	0.75

SBT, Strength and balance training

5.2 Functional vision and physical functioning (Study I)

The mean (SD) VF-7 score was 88.2 (18.7) for the whole study group; for men, it was 88.4 (20.9) and for women 88.1 (20.1). Participants were categorized according to their VF-7 scores into groups of poor (n=95), moderate (n=222), and good (n=259) functional vision. The mean (SD) VF-7 score was 53.5 (22.3) for the poor and 89.3 (5.6) for the moderate functional vision groups, while all the participants in the good functional vision group had the maximum score of 100.

The characteristics of the participants, grouped by level of functional vision, are shown in Table 5. Groups differed significantly in all the demographic, health and activity characteristics except sex. The participants in the poor functional vision group were older and their years of education were fewer compared to those with moderate or good functional vision. Participants with poor functional vision had higher FCI scores and were more likely to have a lower limb endoprosthesis or history of hip fracture. They also had lower MMSE and higher GDS-15 scores. Additionally, participants in the poor functional vision group were less physically active, less often able to walk 400 m independently, and more often had a fear of falling and physical disability in ADLs or IADLs compared to those with moderate or good functional vision.

TABLE 5 Characteristics of participants (n=576) by their functional vision (VF-7) scores.

Characteristic	Functional vision by VF-7 score						p
	Poor ≤75 (*n* = 95)		Moderate 75<and< 100 (*n* = 222)		Good 100 (*n* = 259)		
Demographics							
Female, N (%)	65	(68)	167	(75)	170	(66)	0.070
Age, mean (SD)	84	(5)	81	(4)	80	(4)	<0.001
Education years, median (IQR)	6	(4 , 8)	7	(6 , 10)	7	(6, 10)	0.004
Health status							
FCI, median (IQR)	2	(1 , 4)	2	(1, 3)	2	(1, 3)	0.001
Lower limb endoprosthesis, N (%)	29	(31)	41	(18)	45	(17)	0.018
Hip fracture, N (%)	8	(8)	9	(4)	4	(2)	<0.001
MMSE, mean (SD)	26	(3)	27	(3)	27	(3)	<0.001
GDS-15, mean (SD)	2.5	(2.5)	1.7	(1.9)	1.1	(1.5)	<0.001
Activity N (%)							
Physical activity							<0.001
Low	50	(53)	70	(31)	80	(31)	
Moderate	36	(38)	95	(43)	110	(42)	
High	9	(9)	57	(26)	69	(27)	
Able to walk 400 m independently	79	(83)	207	(93)	246	(95)	<0.001
Fear of falling	49	(52)	57	(26)	58	(22)	<0.001
ADL ≤80	18	(19)	7	(3)	7	(3)	<0.001
IADL ≤6	58	(61)	65	(29)	84	(32)	<0.001

BMI, body mass index; FCI, functional comorbidity index; med, median; MMSE, Mini-Mental State Examination; GDS-15, geriatric depression scale; ADL, Barthel Index; IADL, Instrumental Activities of Daily Living

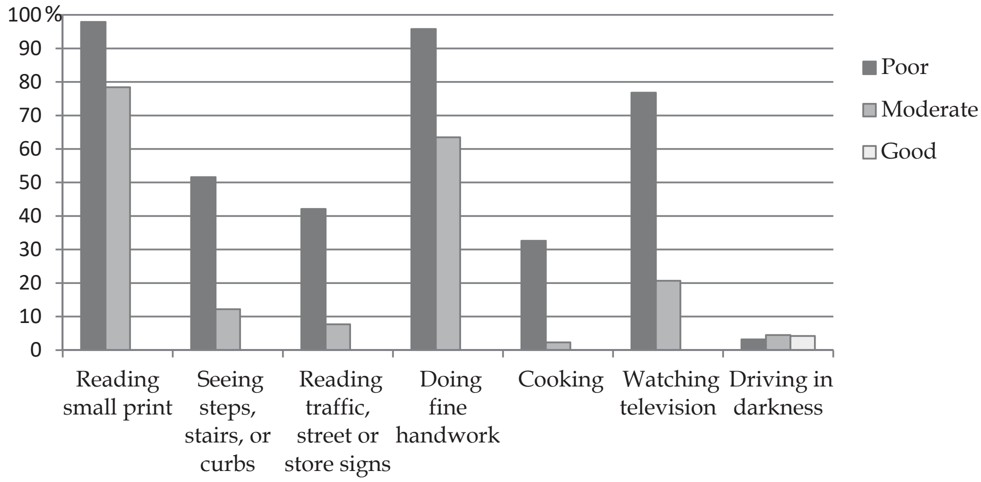

FIGURE 3 Percentages of persons with limitations in different VF-7 items in the poor, moderate and good functional vision groups. Only 17% (n=99) of the participants responded to the item on driving in darkness.

Participants with poor functional vision reported difficulties in all the VF-7 items apart from 'driving in darkness' more often than those with moderate functional vision ($p<0.001$) (Figure 3). For participants with poor functional vision, difficulties were most commonly reported in the activities reading small print and doing fine handwork. Participants with good functional vision only reported difficulties in 'driving in darkness'.

The proportion of persons with more severe vision-related functional limitations was higher in the poor functional vision than moderate functional vision group in all the VF-7 items ($p<0.001$). For example, in response to the item 'seeing steps, stairs, or curbs', an important item for assessing mobility, 14% vs. 12% reported little difficulty, 16% vs. 0% moderate difficulty and 22% vs. 1% reported having great deal of difficulty or being unable to do the activity due the lack of vision.

Performance in the balance and mobility tests is presented in Figure 4. The poor functional vision group performed worst in the tests, and the good functional vision group best. The linear relationships between self-rated functional vision and BBS ($p<0.001$), TUG ($p<0.001$), walking speed ($p<0.001$) and chair rise ($p<0.01$) were statistically significant. After adjusting for gender, age, FCI, and MMSE scores, the linearity remained statistically significant between functional vision and BBS ($p<0.05$), TUG ($p<0.05$) and walking speed ($p<0.01$), but not between functional vision and chair rise (NS).

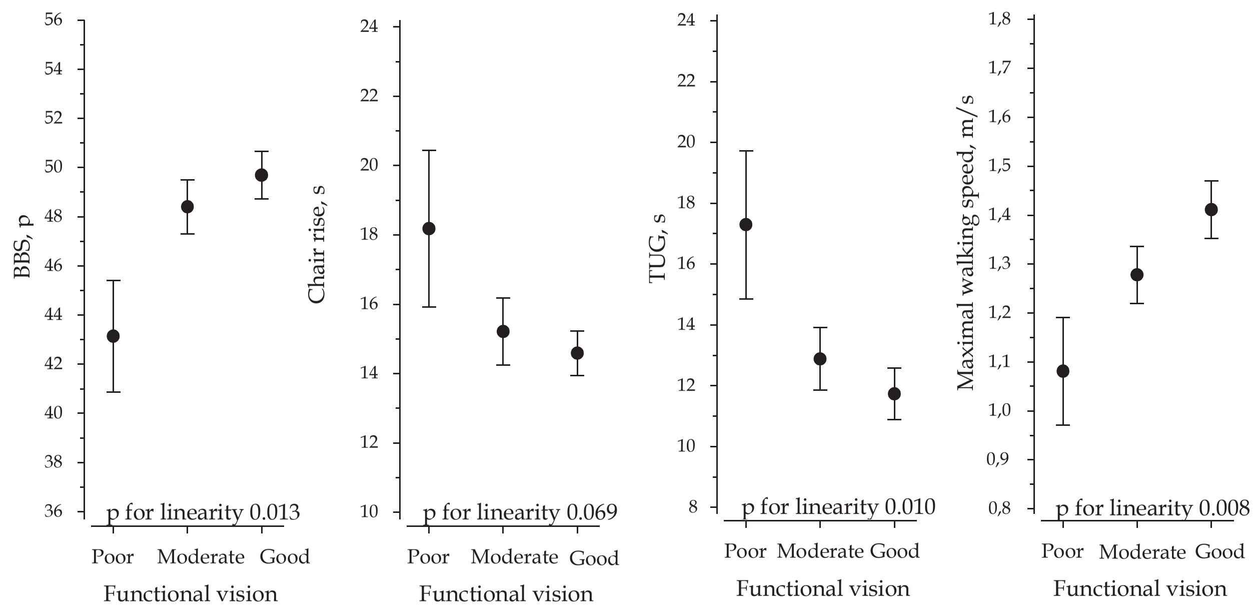

FIGURE 4 Balance and mobility performance according to functional vision. Higher score on the Berg Balance Scale (BBS) indicates better performance. Note: Black circles = mean; Bars = 95% CI

5.3 Strength and balance training participation

5.3.1 Adoption of training (Study II)

All the community-dwelling participants in the intervention group who received the physical activity counselling by a physiotherapist at baseline (n=339) had an opportunity to participate in group-based strength and balance training at the gym once a week. 157 (46%) did not adopt SBT during the intervention. The characteristics of the training adopters and non-adopters are presented in Table 3 and Table 4.

Non-adopters were older ($p<0.001$) and had shorter education ($p<0.01$) than adopters (Table 3). With regard to health status, non-adopters had more comorbidities ($p<0.05$), lower cognition ($p<0.001$), more often sedative load ($p<0.001$) or risk of malnutrition ($p<0.01$), and poorer self-reported health ($p<0.01$) than the SBT adopters. In self-reported functioning, non-adopters reported more difficulties with IADLs ($p<0.001$) and walking 400 m ($p<0.001$). In addition, a higher proportion of them used a walking aid ($p<0.001$). In measured physical performance, non-adopters showed more balance and mobility problems according to the BBS ($p<0.001$) and the TUG ($p<0.001$) than adopters. In addition, non-adopters had lower grip strength than adopters [women 16 (7.4) kg vs. 21 (5.3) kg, $p<0.001$; men 31 (6.9) kg vs. 35 (9.9) kg, $p<0.05$].

Adopters reported higher adulthood physical activity both before and after 64 years as well as at baseline than non-adopters. Walking and home exercise were the most common forms of exercise in both groups and were more often reported among adopters. Participation in supervised exercise classes or strength training in a gym was seldom reported. Only 4% of adopters and 6% of non-adopters reported gym training as a current form of exercise at baseline. (Table 4).

Physical activity was experienced as very (68% vs. 64%) or quite (30% vs. 33%) important for both adopters and non-adopters, respectively. Adopters and non-adopters did not differ in their most frequent motives for physical activity: maintaining health was most often reported by both adopters (78%) and non-adopters (77%), followed by pleasure in physical activity (14% vs. 12%).

In the bivariate logistic regression analysis, non-adoption of strength and balance training was associated with higher age, lower education, sedative load, lower levels of cognition, risk of malnutrition, more dependence in IADLs, lower performance in BBS and TUG, and grip strength in the two weakest quartiles (Table 6). In the multivariate analysis, higher age, a lower MMSE score and lower grip strength were independently associated with non-adoption. A one-point decrease in the MMSE score increased the odds for non-adoption by 14%.

TABLE 6 Factors associated with non-adoption of strength and balance training (n=339).

Characteristic	Bivariate*	Multivariate
	Odds Ratio (95% Confidence Interval)	
Female	0.95 (0.58-1.57)	0.93 (0.53-1.61)
Age	1.15 (1.09-1.22)	1.08 (1.02-1.15)
Years of education	0.92 (0.85-0.99)	
Functional Comorbidity Index	1.15 (1.00-1.32)	
Sedative load ≥1	2.16 (1.31-3.57)	1.66 (0.96-2.88)
Mini Mental State Examination†	0.82 (0.76-0.89)	0.86 (0.79-0.94)
Self-reported health		
Good or very good	1	
Moderate	0.71 (0.44-3.98)	
Poor or very poor	1.94 (0.94-3.98)	
Mini Nutritional Assessment-SF ≤11	2.84 (1.42-5.71)	2.09 (0.97-2.88)
IADL†	0.74 (0.64-0.85)	0.90 (0.76-1.07)
Use of a walking aid	1.67 (0.99-2.81)	
Berg Balance Scale†	0.96 (0.93-0.99)†	
Timed Up and Go	1.06 (1.02-1.10)†	
Physical activity by Grimby		
High	1	
Moderate	1.10 (0.58-2.11)	
Low	1.79 (0.90-3.55)	
Grip strength quartile		
4 strongest	1	1
3	1.90 (0.98-3.66)	1.59 (0.76-3.32)
2	2.79 (1.42-5.46)	2.48 (1.05-4.50)
1 weakest	4.63 (2.30-9.34)	3.28 (1.16-5.74)

*Age- and sex-adjusted bivariate odds ratios.
†On the MMSE, IADL and BBS, a higher score represents better performance
Note: To avoid multicollinearity, BBS and TUG scores were omitted from the multivariate model because they were strongly correlated with the IADLS.

5.3.2 Training adherence (Study III)

The average adherence to SBT was 55% (SD 29, range 1-99%). Adherence was low for 31%, moderate for 25% and high for 44% of the participants (Table 7). Mean (SD) adherence in these three groups was 18 (10), 53 (9) and 82 (7) % for the low, moderate and high adherers, respectively. Seven low adherers died and 6 participants (4 low, 2 moderate adherers) moved to institutional care facilities during the intervention.

The average (SD) length of the individual training periods was 19 (9) months (range 1-120 weeks) (Figure 5). Low adherers started training more gradually, and their mean length of participation in SBT was 7 (6) months. High and moderate adherers continued training for 26 (1) and 22 (5) months, respectively. By month 24 of the training intervention, 123 participants (68%) were still participating in SBT.

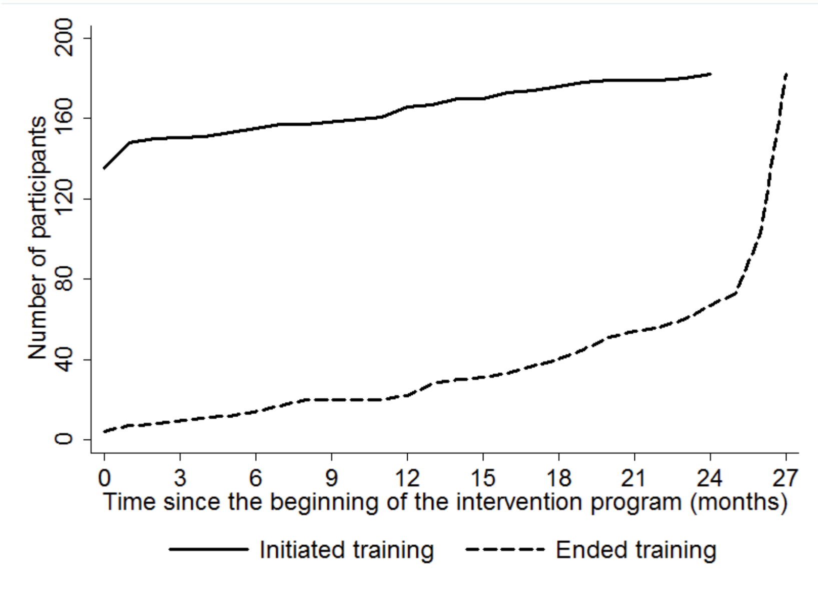

FIGURE 5 Initiation and cessation of training in all training adopters (n=182).

Compared to low and moderate adherers, high adherers were younger, had longer education, fewer comorbidities, better self-rated health and higher MMSE scores (Table 7). The proportion of participants with cognitive impairment (MMSE≤24) was 16% in the low, 11% in the moderate and 5% in the high adherence group (NS). Men in the high adherence group had the highest grip and knee extension strength levels, while in women no differences in strength levels between the adherence groups was observed. High adherers performed better in IADLs and all the balance and mobility tests except the chair rise test.

TABLE 7 Characteristics of participants (n=182) by level of adherence to the strength and balance training.

	Low (n=56)	Moderate (n=46)	High (n=80)	p-value
Demographics				
Female, N (%)	35 (63)	32 (70)	63 (79)	0.11
Age, years, mean (SD)	81 (4.7)	80 (4.1)	79 (2.7)	0.001
Education years, median [IQR]	6 [6 , 7]	7 [7 , 9]	7 [7 , 11]	0.02
Health status				
FCI, mean (SD)	2.1 (1.6)	2.9 (1.7)	1.7 (1.1)	<0.001
MMSE, mean (SD)	27 (3.2)	27 (2.1)	28 (2.0)	0.02
Self-rated health, N (%)				0.03
poor/very poor	10 (18)	3 (7)	2 (3)	
moderate	24 (43)	24 (52)	40 (50)	
good/ very good	22 (39)	19 (41)	38 (48)	
Physical functioning				
Physical activity, N (%)				0.66
low	18 (32)	15 (33)	18 (23)	
moderate	27 (48)	23 (50)	43 (54)	
high	11 (20)	8 (17)	19 (24)	
Grip strength (kg), mean (SD)				
men	33 (11)	33 (7)	41 (9)	0.02
women	21 (6)	20 (5)	22 (5)	0.13
Knee extension strength (N)*, mean (SD)				
men	359 (102)	410 (73)	457 (120)	0.02
women	248 (88)	253 (91)	276 (65)	0.19
IADL, mean (SD)	6.6 (1.7)	7.2 (1.1)	7.6 (0.9)	<0.001
Walking speed (m/s), mean (SD)	1.2 (0.4)	1.3 (0.4)	1.4 (0.3)	0.002
Berg Balance Scale (p), mean (SD)	48 (8.4)	49 (8.0)	53 (3.0)	<0.001
Timed Up and Go (s), mean (SD)	14.0 (7.8)	11.9 (5.3)	9.7 (3.0)	<0.001
Chair rise (s), mean (SD)	16.8 (5.9)	15.9 (5.8)	15.0 (4.5)	0.18
Uses a walking aid, N (%)	18 (32)	14 (30)	7 (9)	0.001

*missing value n=2

FCI, Functional Comorbidity Index; MMSE, Mini-Mental State Examination; IADL, Instrumental Activities of Daily Living

Comorbidity was highest among the moderate adherers, who were also hospitalized more often during the SBT intervention than the low and high adherers: 83% of the moderate adherers had one or more periods of inpatient care compared to the high (43%) and low adherers (70%) ($p<0.001$). However, the number of inpatient days during the training intervention was highest among the low adherers. In this group, the median [IQR] number of inpatient days was 21 [6, 62] compared to 13 [2, 40] and 5 [2, 9] in the moderate and high adherer groups, respectively. No direct training-related major adverse events occurred.

In the age- and sex-adjusted regression analysis with low adherence as the reference, a higher comorbidity index (OR 1.38, 95% CI 1.05 to 1.8) and IADL score (1.31, 0.96 to 1.78) predicted moderate adherence to SBT. High adherence was predicted by female sex (2.83, 1.30 to 6.58), a higher MMSE score (1.21, 1.03 to 1.42), greater knee extension strength (1.01, 1.00 to 1.01), a higher IADL score (1.67, 1.17 to 2.37), faster 10-m walk time (0.77, 0.65 to 0.90), higher BBS score (1.22, 1.10 to 1.35) and faster TUG test performance (0.82, 0.73 to 0.92). Higher age (0.81, 0.73 to 0.90), poor or very poor self-rated health (0.13, 0.03 to 0.68) and the use of a walking aid (0.24, 0.09 to 0.67) lowered the probability of high adherence.

5.4 Effects of long-term training on physical functioning

5.4.1 Average training effects in men and women (Study IV)

At baseline, women (n=130) had lower grip strength than men (n=52) (21.4 (SD 5.3) vs. 35.4 (9.9) kg) ($p<0.001$). They also had higher independence in instrumental activities of daily living (IADLs) (7.5 (0.9) vs. 6.4 (1.9)) ($p<0.001$), and they more often used a walking aid (26% vs. 12%) ($p<0.05$) compared to men. Mean (SD) training adherence was 57 (28) % for women and 49 (28) % (NS) for men.

The effects of the training intervention were analyzed separately for women and men. Among women, knee extension strength improved by 14.7 N [ES 0.18, 95% CI (-0.03 to 0.29)] and knee flexion strength by 16.7 N [ES 0.40, (0.26 to 0.56)] during the 2-year intervention. During the post-intervention follow-up knee flexion strength in women declined by 4.4 N [ES -0.10, (-0.19 to -0.01)]; however, values for both extension (5.3%) ($p<0.01$) and flexion (13.2%) ($p<0.001$) strength were higher at the follow-up. Men’s strength levels did not change during the training period or over the subsequent follow-up.

During the training period Chair rise performance improved in women by 2.6 seconds [ES -0.48, (-0.72 to -0.15)] and in men by 1.5 seconds [ES -0.40, (-0.68 to 0.09)]; no further changes occurred during the subsequent follow-up (Table 8).

TABLE 8 Mean changes and effect sizes with 95% Confidence Intervals (CI) in muscle strength, balance and mobility for men and women during the two-year training period and post intervention follow-up.

	Baseline	Training period		Post intervention follow-up	
	Mean (SD)	Change (95% CI) from 0 to 2 years	Effect size (95% CI)	Change (95% CI) from 2 to 3 years	Effect size (95% CI)
Knee extension strength (N)					
men	407 (111)	-4.8 (-19.4 to 9.3)		-0.9 (-15.2 to 12.7)	
women	266 (79)	14.7 (3.6 to 24.5)	0.18 (0.03 to 0.29)	-5.5 (-12.0 to 1.1)	
Knee flexion strength (N)					
men	198 (57)	0.1 (-9.6 to 9.9)		-7.4 (-16.4 to 2.0)	
women	114 (40)	16.7 (11.2 to 22.9)	0.40 (0.26 to 0.56)	-4.4 (-8.2 to -0.7)	-0.10 (-0.19 to -0.01)
Chair rise (s)					
men	14.3 (3.7)	-1.5 (-2.4 to -0.5)	-0.40 (-0.68 to -0.09)	1.0 (-0.03 to 2.3)	
women	15.8 (5.1)	-2.6 (-3.5 to -1.5)	-0.48 (-0.72 to -0.15)	0.2 (-0.3 to 0.7)	
Walking speed (m/s)					
men	1.50 (0.38)	-0.03 (-0.11 to 0.04)		-0.02 (-0.08 to 0.03)	
women	1.24 (0.36)	0.08 (0.04 to 0.12)	0.21 (0.11 to 0.32)	-0.01 (-0.05 to 0.02)	
Timed Up and Go (s)					
men	10.7 (5.7)	0.3 (-0.4 to 1.0)		1.3 (0.3 to 2.6)	0.17 (0.05 to 0.35)
women	11.9 (6.0)	-0.2 (-0.9 to 0.6)		1.1 (0.03 to 2.6)	0.11 (-0.01 to 0.19)
Berg Balance Scale (points)					
men	51.4 (5.2)	-0.7 (-1.9 to 0.3)		-1.5 (-3.2 to -0.2)	-0.20 (-0.33 to -0.05)
women	50.3 (6.6)	0.3 (-0.4 to 1.0)		-1.1 (-1.9 to -0.4)	-0.15 (-0.26 to -0.07)

In women, walking speed improved by 0.08 m/s [ES 0.21, (0.11 to 0.32)] during the intervention and the improvement was maintained over the follow-up. In men, walking speed remained unchanged during the training period and one year follow-up. TUG and BBS performance did not change from the baseline level during the intervention. However, TUG declined over the post-intervention follow-up by 1.1 s [ES 0.11, (-0.01 to 0.19)] in women and 1.3 s [ES 0.17, (0.05 to 0.35)] in men. At the same time, BBS declined by 1.1 points [ES -0.15, (-0.26 to -0.07)] in women and 1.5 points [ES -0.20, (-0.33 to -0.05)] in men.

5.4.2 Individual training effects

For the analysis of individual training effects after the two-year intervention, both sexes were analyzed together, although Figures 6–8 also show the results by sex. Large individual differences in absolute change in muscle strength, mobility and balance were observed. The proportion of those whose performance improved varied across the adherence groups ($p \leq 0.01$) in all the tests except the BBS (NS). The highest proportion of participants showing improved performance was found in the high adherence group. In knee extension and flexion strength, the change was positive for 74 and 73% of the high adherers, respectively, while in the low adherence group 32 and 42% of individuals showed improved performance. In the chair rise test, 95% of the high adherers performed faster than at baseline. 70% of the high adherers showed improved walking speed. In the low adherence group, walking speed improved and declined for an equal number of individuals. Low adherers showed the largest individual increases and decreases in both the TUG and BBS scores. A number of individuals, including 33% of the participants the high adherence group, remained at their baseline level in the BBS.

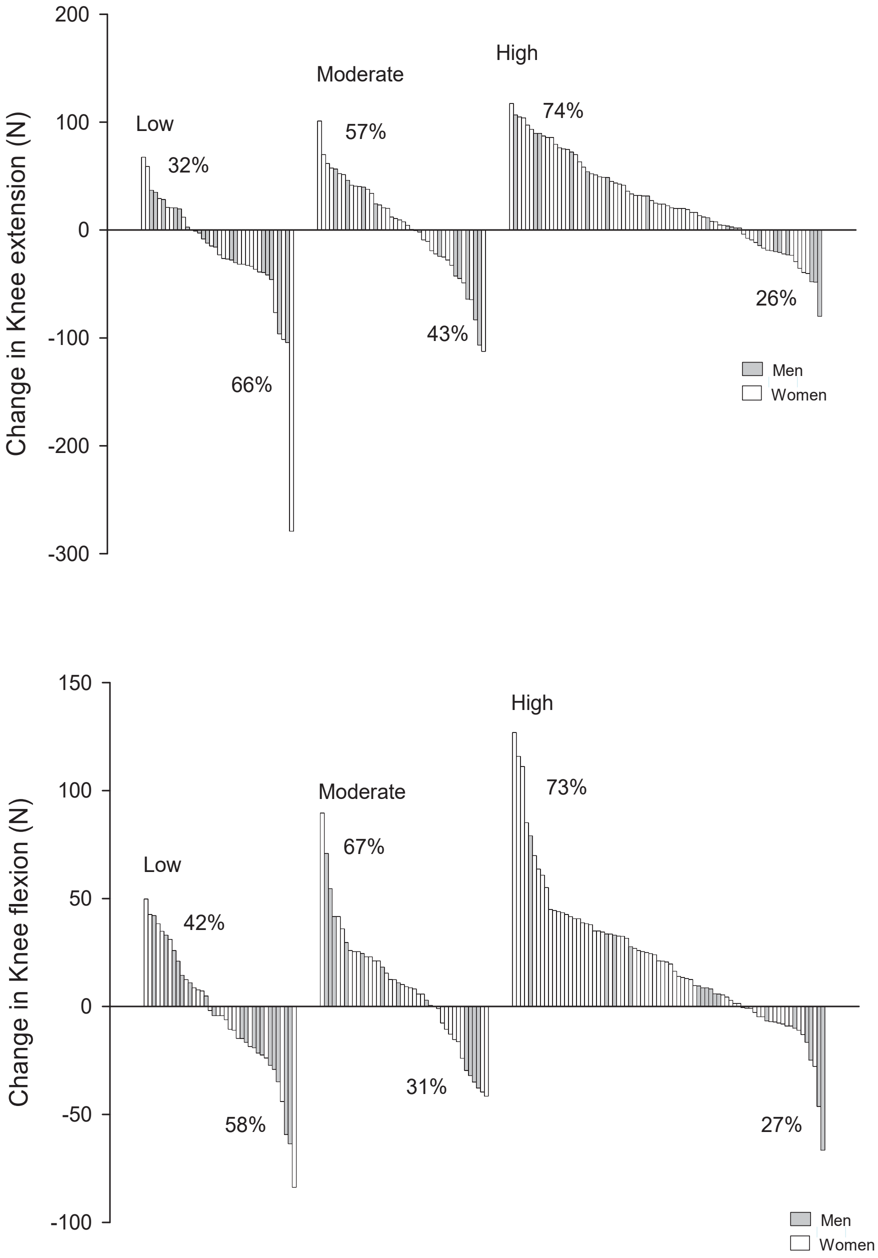

FIGURE 6 Absolute (Newton) individual changes in men and women and proportion (%) of participants in each SBT adherence group who showed improvement or decline in knee strength after 2 years of intervention.

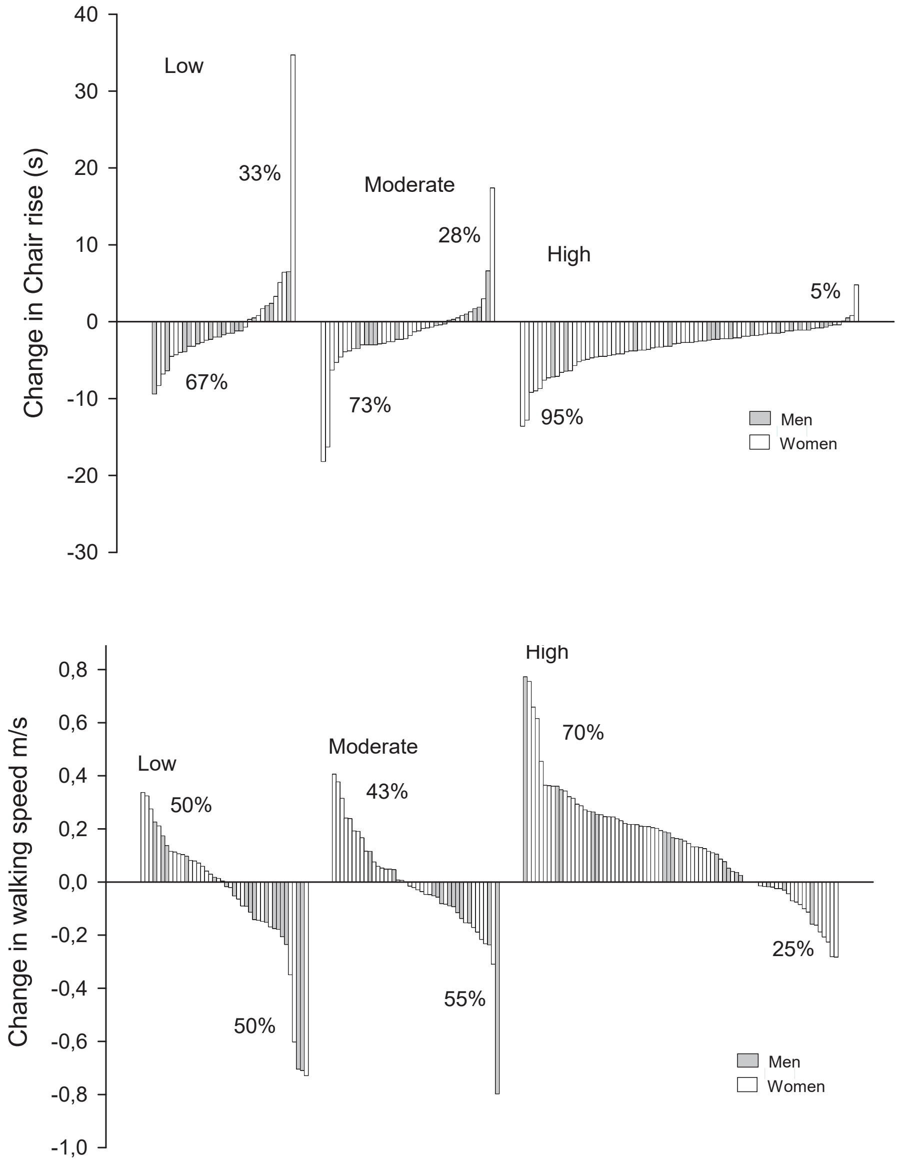

FIGURE 7 Absolute individual changes in men and women and proportion (%) of participants in each SBT adherence group who showed improvement or decline in mobility performance after 2 years of intervention. Negative change in Chair rise and positive change in walking speed indicates improvement.

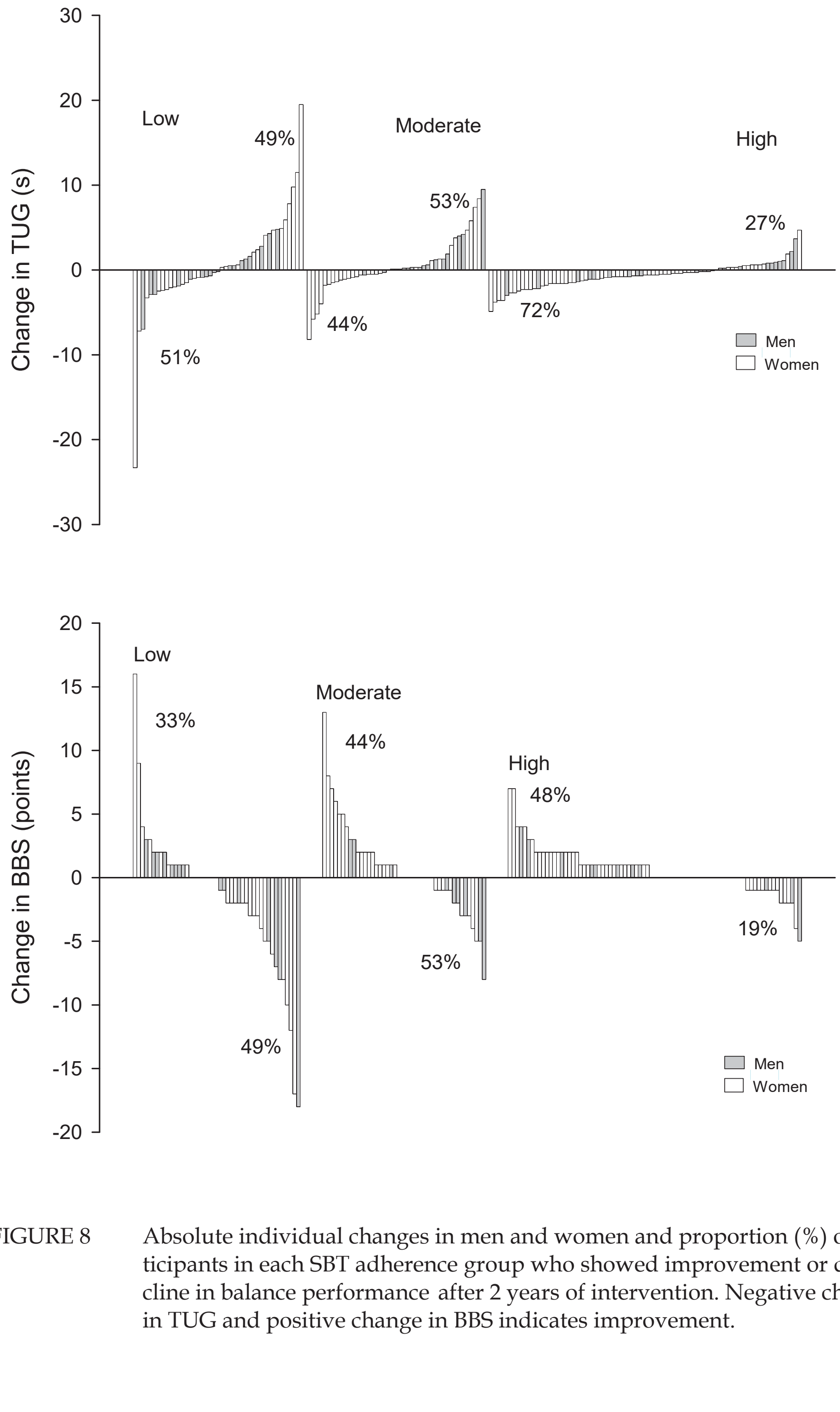

FIGURE 8 Absolute individual changes in men and women and proportion (%) of participants in each SBT adherence group who showed improvement or decline in balance performance after 2 years of intervention. Negative change in TUG and positive change in BBS indicates improvement.

5.4.3 Training effects in adopters, non-adopters and controls

Finally, the changes in physical functioning were examined in training adopters and non-adopters compared to controls, who had not received physical activity counselling or any additional intervention besides the usual healthcare services during the follow-up. These results are exploratory, as the participants self-selected their own grouping as adopters or non-adopters, thereby eliminating the randomised assignment. The results of the study groups over time are listed in Table 9. Changes in physical functioning between the study groups over the 2-year intervention were significantly different. In all the measured physical functioning outcomes the difference was in favour of the training adherers when compared to controls. Adopters improved their performance in all tests ($p<0.05$) except BBS (NS) and TUG (NS) in which their performance remained unchanged. Controls showed a decline in all tests ($p<0.05$). Non-adopters showed a decline in performance in knee extension strength ($p<0.05$) but no change in all the other tests. However, the difference in changes was in favour of non-adopters in TUG and BBS when compared to controls.

When the post-intervention follow-up was included in the analyses, the differences in the changes in physical functioning over time between adopters and controls remained significant. The differences in TUG and BBS between non-adopters and controls did not remain significant.

TABLE 9 Means and standard deviations (SD) of observed physical functioning outcomes, and linear mixed model estimates (interactions) for change in physical functioning over 2-years intervention, and post-intervention by training adopters, non-adopters and controls.

	Baseline	1 year	2 year	Estimated change from baseline to 2 years		Follow-up	Estimated change from baseline to 3 years	
	Mean (SD)	Mean (SD)	Mean (SD)	β (SE)	*p*-value	Mean (SD)	β (SE)	*p*-value
Knee extension strength (N)								
Adopters	304 (109)	320 (115)	317 (109)	28.1 (4.25)	p<0.001	312 (106)	35.7 (4.74)	p<0.001
Non-adopters	287 (107)	286 (98)	292 (94)	9.1 (5.38)	p=0.09	296 (100)	8.8 (6.19)	p=0.16
Controls	300 (110)	293 (107)	290 (106)	Ref		287 (110)	Ref	
Knee flexion strength (N)								
Adopters	138 (60)	149 (57)	151 (56)	24.7 (4.37)	p<0.001	148 (57)	23.6 (3.38)	p<0.001
Non-adopters	132 (60)	131 (58)	135 (55)	10.7 (5.46)	p=0.05	136 (58)	7.1 (4.43)	p=0.11
Controls	141 (64)	132 (61)	134 (61)	Ref		135 (61)	Ref	
Chair rise (s)								
Adopters	15.8 (5.3)	13.4 (4.7)	13.1 (5.2)	-3.13 (0.61)	p<0.001	12.9 (4.4)	-3.02 (0.59)	p<0.001
Non-adopters	18.0 (8.7)	17.8 (9.9)	16.3 (8.2)	-1.23 (0.70)	p=0.08	15.2 (6.8)	-1.32 (0.71)	p=0.06
Controls	16.7 (8.6)	15.7 (5.1)	17.1 (9.5)	Ref		16.5 (7.4)	Ref	
Walking speed (m/s)								
Adopters	1.31 (0.37)	1.40 (0.40)	1.35 (0.42)	0.11 (0.03)	p<0.001	1.37 (0.45)	0.15 (0.039	p<0.001
Non-adopters	1.15 (0.41)	1.16 (0.49)	1.16 (0.52)	0.06 (0.03)	p=0.06	1.15 (0.52)	0.06 (0.03)	p=0.08
Controls	1.28 (0.46)	1.25 (0.49)	1.23 (0.50)	Ref		1.22 (0.51)	Ref	
Timed Up and Go (s)								
Adopters	11.5 (5.7)	11.1 (7.4)	11.9 (7.8)	-2.94 (0.70)	p<0.001	12.9 (11.5)	-3.36 (1.11)	p=0.003
Non-adopters	16.0 (11.2)	15.1 (9.7)	16.6 (12.7)	-1.63 (0.79)	p=0.04	18.0 (17.2)	-0.95 (1.29)	p=0.46
Controls	14.2 (9.7)	14.6 (9.2)	15.6 (11.7)	Ref		15.6 (15.0)	Ref	
Berg Balance Scale (points)								
Adopters	50.4 (6.9)	50.8 (6.3)	50.6 (6.6)	2.28 (0.52)	p<0.001	49.7 (8.4)	2.11 (0.66)	p=0.001
Non-adopters	46.0 (10.2)	45.8 (9.9)	46.0 (9.7)	1.87 (0.57)	p=0.001	44.5 (10.9)	1.01 (0.74)	p=0.17
Controls	47.3 (9.4)	45.9 (11.1)	45.9 (10.5)	Ref		45.8 (11.1)	Ref	

6 DISCUSSION

This study of a population-based sample of Finnish community dwelling older adults aged ≥75 years showed that physical functioning was possible to improve among those participated in a long-term supervised SBT program as part of an individualized geriatric intervention that also included physical activity counselling. Among those in the intervention group who did not adopt SBT, muscle strength decreased over the two-year follow-up. Among controls, who received no intervention, all the performance-based physical functioning parameters declined. Adoption of supervised SBT was affected by several health-related factors. Nevertheless, despite of morbidity and hospital admissions, many older adults were capable of long-term regular training adherence. Female sex, younger age, better cognition and physical functioning predicted high adherence to training. Poor functional vision was related to worse performance in the balance and mobility tests and often coexisted with other health problems.

6.1 Methodological considerations

A major strength of this study is that it included large population sample of home-dwelling men and women aged 75–99 years. As few exclusion criteria as possible were set, so that the sample also included oldest-old individuals with several comorbidities, thereby reflecting real-world situations. Furthermore, the sample was probably more representative of the general population of people aged ≥75 years than similar samples in some previous studies, as the interviews and measurement were done in the participants' homes, if they were unable to travel to the study clinic. Thus, more frail community-dwelling subjects were included in the study than is generally the case. However, the generalizability of the results on the effects of SBT may be limited, as the analyses excluded both the frailest community-dwelling participants, who were unable to perform the balance and mobility tests, and participants resident in institutional care facilities. In describing successful aging, the ICF includes not only the absence of disease, but also the ability to be active and participate in different life situations. The emphasis in the ICF is on enabling function and promoting participation rather than a focus on disability and dysfunction. The promotion of mobility thus means addressing several targets in an individual's health and physical functioning as well as environmental and personal characteristics (Wilkie et al. 2007). In the GeMS study, the participants underwent a CGA, and their health conditions and medical history were carefully assessed and documented by health care professionals. Objective measures of physical functioning as along with valid and reliable measures of health determinants were used annually. The different multi-disciplinary assessments used in this dissertation are described in the ICF framework (Figure 9). Following the ICF classification, versatile aspects of health and functioning were taken into account. The relevant health-related problems among community-dwelling older adults were addressed in the CGA. Similar health related problems are included in the recently published Geriatric ICF Core Set as well (Spoorenberg et al. 2015).

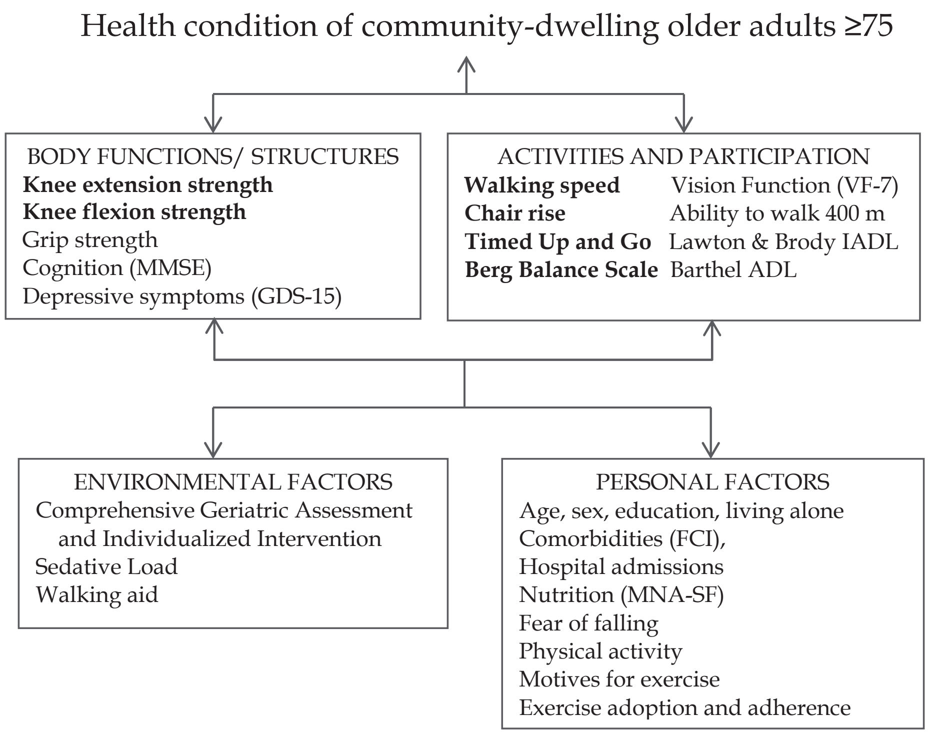

FIGURE 9 Outcome measures (bolded) and central confounding factors described in the ICF domains.

To our knowledge, this is one of the first studies to explore SBT adoption and adherence in a community setting after a multidisciplinary CGA and physical activity counselling. SBT adoption and adherence were assessed according to actual participation in the training program, and not solely by self-report or willingness to take part. This study was not a single intervention study but also included other health promoting interventions, such as optimizing medication and nutrition. This multi-intervention promoted the safe implementation of long-term strength training in a heterogeneous population sample. The intervention program was tailored to individuals based on CGA and major adverse events (falls, cardiovascular-related episodes and musculoskeletal-related events) (Liu & Latham 2010) directly related to the training intervention did not occur. Adverse events should be reported more detailed and the lack of reporting minor adverse events and adverse events not directly related to training, are limitations to this study.

Typically, previous studies have reported SBT adherence and effects for interventions lasting less than one year. The long intervention period in this study enabled assessment of both adherence to and the effects of long-term training as part of a multimodal intervention. The effects of a single intervention cannot be reported wholly in isolation from other accompanying interventions. In addition, physical activity outside the gym sessions was not controlled for with objective measurements in this study despite the fact that the focus of the annual physical activity counselling was on total physical activity. The adherence analyses were not the primary purpose of the GeMS. This study is a secondary analysis and also exploratory as the groupings of the training adopters and non-adopters were self-selected, eliminating randomized assignment. The differences between the study groups have been taken into account in the analyses by using appropriate covariates. Nevertheless, the results of the effect of training are considered to be hypothesis-generating.

According to earlier studies, multiple interacting factors determine exercise participation. These factors have been categorized as personal characteristics, program-related factors and environmental factors (King et al. 1992). The present study focused on health-related factors and aspects of physical functioning that potentially affect SBT adoption; neither behavioral and psychological barriers or motivators, nor genetic factors were addressed. In order to improve exercise intervention and physical activity adherence in the future, extensive observation of both health-related, psychological (Koeneman et al. 2011, Hawley-Hague et al. 2014), socioeconomic (Chevan 2008), genetic and epigenetic (Herring, Sailors & Bray 2014) factors is needed.

Supervised strength and balance training was utilized in the intervention as it was considered to be a feasible safety measure with a population-based random sample of older adults. However, there is a growing literature on the importance of power and power training (Tschopp, Sattelmayer & Hilfiker 2011) as well as aerobic training (Pahor et al. 2014) for slowing functional decline in older adults, suggesting that more than one approach may be effective.

The recommended frequency of strength training, i.e. twice-weekly, was not followed in this study. This training intervention was not the only primary intervention in the study and the resources available in terms of gym facilities and the ability of some of the participants to cope with higher amount of supervised exercise in the course of their daily lives were found to be limited.

The physical functioning measures were conducted by two physiotherapists who were familiar with and well educated to conduct the tests. Each participant was annually assessed by the same therapist. The fact that inter-rater reliability was not assessed can be regarded as a limitation of this study.

The Berg Balance Scale has a ceiling effect and relatively low sensitivity to change and responsiveness among community-dwelling elderly populations (Pardasaney et al. 2012). This was also true in this study, where the participants' BBS scores were already high at baseline, thus preventing the registration of significant improvement. More challenging measures of balance would be needed to detect training effects in older adults with higher levels of functioning. The ability to walk 400 meters was self-reported in this study, whereas the change in walking ability was examined using objectively measured walking speed over a distance of 10 m. An objective measurement of 400 m walk capacity would have enabled better comparison of the outcomes of this study with more recently published data, for example the Health ABC (Perera et al. 2014) and LIFE (Pahor et al. 2014) studies.

Owing the cross-sectional design in Studies I and II, causal inferences cannot be made. The data for Study I were not collected at the baseline of the intervention study, but 1 year later. The multi-intervention had started, gradually, during the preceding year. However, the assessment of functional vision and the physical functioning measurements were done cross-sectionally without any disparity in time.

Cognition had some impact on the reliability of the self-assessments and on understanding and retaining the instructions. To minimize the confounding effect of cognitive impairment on participants' self-ratings of their functional vision in Study I the participants with the lowest MMSE scores (≤17) were excluded and the analysis adjusted for the MMSE scores.

Population-based cut-off scores for VF-7 have not yet been established, and therefore it was needed to base the grouping on theoretical cut-off scores. The VF-7 and the original VF-14 questionnaires were designed to allow severely impaired populations to be assessed in clinical practice. In this community-based sample, 45% of the participants had no difficulties in functional vision (full score on VF-7); thus, the ceiling effect was notable. In population-based studies, questionnaire items that are seldom answered need to be re-considered (Valbuena et al. 1999); in our study, this applied to the driving at night question, which was dropped from the final index. The present findings suggest that the relevance of the separate items of the VF-7 to community-dwelling older adults might need to be pondered.

The wide variety in health and physical functioning of the participants makes full reproducibility of this intervention study difficult. In this population both the progression of strength training and the content of the balance training had to be individualized, which limits the full reproducibility of the training intervention in the future. The selection of individuals with a moderate degree of mobility limitation and ADL difficulties could yield larger treatment effects than in this study, as individuals with no disabilities are less likely to show improvements, while individuals with severe disabilities may have a high burden of co-morbid conditions and risk for mortality, thus limiting improvement (Ferrucci et al. 2004). The feasibility and effectiveness of trials in general among older people is much more complicated than in efficacy trials where the intervention effect is studied under optimal conditions. However, the present study finds SBT to be effective as part of a comprehensive geriatric intervention in an older population under real-world conditions.

6.2 Functional vision

Poor functional vision was associated with worse performance in the balance and mobility tests, and, when sex age, cognition, and comorbid conditions were controlled for, a linear association was found between functional vision and the balance and mobility test results. Decreased balance and mobility performance have harmful consequences for older adults. In earlier studies, older adults with BBS scores of <46 were more likely to develop ADL difficulty over an 18-month period (Wennie Huang et al. 2010), and were at increased risk for multiple falls if their BBS score was <45 (Muir et al. 2008). For the TUG test, a previous study reported that the cut-off time of 14 seconds (Shumway-Cook, Brauer & Woollacott 2000) was predictive of higher risks for falls. In addition, a walking speed of at least 1.2 m/s is generally required to cross the road safely during a green light (Finnish Road Administration 2005). In our study, the participants with poor functional vision performed below all of these cut-off points.

In contrast with the results of the other physical performance tests, after adjustments, no relationships between functional vision and mobility were found for the chair rise test. In a previous Finnish Health 2000 study, the population aged 55 years and older had difficulties in performing the chair rise test only in the case of more severe visual impairment, whereas the walking speed, stair climbing, and tandem standing tests were already affected by less severe visual impairment (Laitinen et al. 2007). Although the chair rise is partly influenced by visual function, several other factors are associated with the test time, of which the most important is quadriceps strength (Lord et al. 2002).

In the present study the balance and mobility tests used— BBS, TUG, chair rise and walking speed — were not highly vision-demanding. The tests required little or no use of the visual component of proactive balance control (Huxham, Goldie & Patla 2001), such as obstacles to be stepped over or around, planning a course to move safely on different surfaces or in low or bright lightning conditions. Half of the participants with poor functional vision had some difficulties seeing steps stairs or cubes and 22% reported having great deal of difficulty or being unable to performing the activity due to poor vision. Quantifying vision-related impairment cannot fully predict balance function. According to the system theory, function also depends on the strategies that individuals use to achieve the stability needed for a particular task (Woollacott & Shumway-Cook 1990). The Dynamic Gait Index could be used to evaluate ability to adapt gait to changes in the environment and in task demands, such as dual-task situations (Shumway-Cook & Woollacott 2001). A Finnish version of Dynamic Gait Index has recently become available (Tuomela, Paltamaa & Häkkinen 2012).

The higher prevalence of comorbidities, such as depressive symptoms, among older adults with poor functional vision is consistent with the findings of Iliffe et al. (Iliffe et al. 2005). Likewise, the present finding of lower MMSE scores in the poor functional vision group is in accord with the findings of a previous longitudinal study, in which poor visual acuity was associated with greater odds of cognitive decline (Lin et al. 2004). Postural control of stance and locomotion requires function of the motor, sensory, and cognitive systems, all of which are subject to age-related changes (Woollacott 2000). In addition to these physiological changes, decline in other health parameters were common in the poor functional vision group; thus, possibilities to use compensatory strategies for the effects of vision impairment were limited (Horak 2006). This suggests that the role of vision in balance and mobility performance may be even more critical in old age than previously thought.

Low physical activity and fear of falling among the participants with poor functional vision was in line with the cross-sectional findings of Kempen et al. (Kempen et al. 2009). They found that self-reported vision impairment was associated with greater fear of falling and avoidance of activity among community-living older people aged ≥70 years. Poor vision is a well-established risk factor for falls among older adults (Lord 2006). The Activities of Daily Vision Scale, a functional vision index, has been reported to be a useful tool for fall risk assessment in older adults (Kamel, Guro-Razuman & Shareeff 2000). While the cross-sectional design of the present functional vision analyses does not allow conclusions to be drawn of the possible causal relationship between poor functional vision and fall risk, previous longitudinal studies support the default hypothesis that poor functional vision is a predisposing factor for development of the fear of falling (Murphy, Dubin & Gill 2003), and it is known that fear-related avoidance of a physical activity predicts declines in balance and mobility performance (Deshpande et al. 2008). In this study, a history of hip fractures, fear of falling, impaired ability to walk 400 m, and low physical activity were more prevalent among participants with poor functional vision. Given the possible consequences of vision impairment for independent mobility, vision impairments should be comprehensively prevented, recognized and treated among the aging population.

6.3 Training adoption and adherence

Over half (54%) of the community-dwelling older adults took up the invitation to participate in the SBT program at the gym. Compared to the results of a previous survey in the UK, in which 41% of the population aged ≥54 years reported that they would definitely not attend group-based SBT for falls prevention (Yardley et al. 2008), the degree of non-participation in the present study with a far older population seems moderate. Conversely, a review of RCTs falls prevention exercise trials for older people found notably higher (70%) participation rates (Nyman & Victor 2012). The participants in these RCTs were recruited differently, and often had better health and a higher level of functioning than the older adults in this community-based intervention study.

After the initial adoption of training, approximately two-thirds of the SBT-initiators continued the training for over two years. High adherers comprised almost half of the SBT initiators, attending on average three of four monthly SBT sessions. Moderate adherers attended a half and low adherers one-fifth of sessions. These results reflect both the possibilities and challenges in implementing long-term exercise programs for older adults with great disparities in health and physical functioning.

The mean adherence, 55%, in this population-based study is lower than that reported the majority of RCTs included in the recent reviews of class-based fall prevention (73–89%) (Nyman & Victor 2012) or strength and flexibility exercise (87%) programs (Martin & Sinden 2001). RCTs of longer-duration (12 months) have shown lower adherence rates than shorter trials (2–4 months) (Nyman & Victor 2012). However, long-term interventions among Finnish older adults have also reported higher adherence than found in this study. In a recent multimodal exercise intervention lasting 24 months, an adherence rate of 74% was reported for supervised training sessions (Patil et al. 2015). Participants were 70- to 80-year-old female fallers and training was offered twice or once a week. Similarly, in a previous population-based exercise intervention which combined 30 months round-the-year daily home exercises with three annual 6-month periods of one group exercise per week, the 70- to 73-year-old women participants showed adherence of at least 74% in each supervised 6-month period (Korpelainen et al. 2006). Differences in study populations and exercise modalities may partly explain the lower adherence in the present study, where the participants were older and the exclusion criteria for the exercise intervention were minimal. Furthermore, the present mean adherence (55%) is comparable to the adherence (50%) reported among sedentary 70- to 89-year-old adults who participated in a center-based physical activity intervention offered once a week as part of the LIFE pilot trial (Fielding et al. 2007).

Although comorbidities and functional limitations were common in the present community-based sample, the dropout rate due to death or institutionalization was low. Given that the participants were community dwelling ≥75-year-old adults, the fact that 68% of them continued training for over two years may be considered fairly promising. Annual physical activity counselling with supervised exercise intervention seems an effective means for persuading at least some older adults to acquire a new regular physical activity habit. However, several health and physical functioning characteristics associated with training adoption and adherence need to be taken into account when designing and implementing SBT interventions for older populations.

Previous research has reported that physical activity decreases with aging (Cohen-Mansfield, Shmotkin & Goldberg 2010), which is in line with the present finding that higher age was independently associated with SBT non-adoption and also with lower long-term adherence. Female sex was not associated with training adoption. Nevertheless, women had higher odds than men for long-term training adherence. This is in contrast to previous findings that female sex was an independent predictor of lower participation rate in strength training activities among US adults (Chevan 2008). However, a similar difference between sexes was not found in a Finnish older population: among 75- to 79-year-olds, 22% of men and 23% of women reported engaging in muscle-strengthening activity at least once a week and at age 80–84 years the proportion was 18% for men and 14% for women (Hellda´n & Helakorpi 2014). For older women, group-based training may have been even more motivating owing to its social component (King 2001).

In addition to more advanced age, the non-adopters had more co-morbidities and poorer self-perceived health. More of them used drugs with sedative properties and were more often at risk of malnutrition compared with the SBT adopters. This result indicates that the non-adopters had a greater accumulation of health problems. One clinical implication of these results is that many of these barriers, such as the risk of malnutrition and sedative load are treatable. Sedative load may prevent participation in SBT by increasing tiredness and dizziness and impairing attention. Furthermore, the safety and effectiveness of SBT are questionable if energy or protein intake is insufficient (Carlsson et al. 2011). Thus, medication and nutritional assessments along with further interventions might be necessary before SBT initiation. However, people should not be excluded from training solely because of characteristics such as malnutrition, dementia, depression or physical impairment - these did not have a negative effect on balance following high-intensity functional weight-bearing training in residential care facilities (Littbrand et al. 2011).

Of the physical functioning measures, low grip strength was a significant independent predictor of non-adoption. Grip strength predicts major mobility disability (Marsh et al. 2011) and it has been proposed as a surrogate measure of sarcopenia (Cruz-Jentoft et al. 2010). The functional impairments, chronic diseases and malnutrition detected among the present non-adopters are signs and symptoms of frailty and core elements in the cycle of frailty (Fried et al. 2009). Sarcopenia is a key pathophysiological feature in this cycle, as it decreases muscle strength, power and walking speed and leads to disability and dependency (Fried et al. 2009). In the present study, higher independence in IADLs predicted high adherence. These findings suggesting that those with disabilities in daily activities or presenting with many risk factors for frailty had problems in adopting or adhering to long-term SBT at the gym.

Non-adopters also demonstrated reduced balance and mobility as assessed by the BBS and the TUG. These objective measures of balance and mobility support the previous finding that self-rated mobility limitations prevent the initiation of weight training among older community-dwelling adults (Rasinaho et al. 2012). Slow walking speed, balance problems and the use of a walking aid also decreased the probability of long-term high adherence. Return to a physical activity program after acute illness or hospitalization may be difficult, especially for sedentary older adults with mobility limitations (Phillips et al. 2010). Simple measures of physical functioning, such as walking speed, BBS and TUG may thus be used to identify older adults who need more individualized guidance and support to maintain SBT. In this study, a higher proportion of non-adopters (39% vs. 21%) used a walking aid. The use of a walking aid or a fall during the past year has been shown to limit older adults' participation in strength training or balance-challenging activities (Merom et al. 2012). These factors also make it challenging to go to the gym, especially when combined with the inability to walk 400 meters independently, a self-rated functional limitation significantly more common among the SBT non-adopters than adopters.

To some extent, in this study, disease management and health promotion may have served as motivators for exercise, as in the study by Rasinaho et al. (Rasinaho et al. 2007). The baseline multidisciplinary comprehensive geriatric assessment by health professionals as well as the annual follow-ups and supervised training may have encouraged older adults with comorbid conditions to participate. This support may partly explain why those with a moderate level of adherence had a higher average number of comorbidities than those with low adherence. Thus, clinicians should not allow the mere number of medical conditions to determine who could or could not participate in SBT. Instead, self-rated health has been reported to play more important role in SBT adherence than the number of comorbidities (Dogra 2011). Also in the present study, poor self-rated health decreased the probability of high SBT adherence by 87%.

One third of the non-adopters in this study had cognitive impairment (MMSE≤24), and lower cognitive status independently predicted SBT non-adoption. This result accords with a previously reported finding that better cognitive function predicts exercise initiation in older adults (Cohen-Mansfield, Shmotkin & Goldberg 2010). Previous studies have also reported that older adults with cognitive impairment had lower maintenance of participation in exercise programs, with only 25% continuing exercise longer than one year (Tak et al. 2012). In the present study, better cognition predicted high SBT adherence. Although cognitive impairment might present some challenges to SBT participation, the promotion of exercise among these older adults deserves special attention because of its potential benefits. According to systematic reviews, exercise interventions enhance mobility (Pitkälä et al. 2013a) and may also improve the ability to perform activities of daily living (Forbes et al. 2015) among people with dementia. In a recently published RCT, high intensity supervised progressive resistance training improved cognition among participants with mild cognitive impairment (Fiatarone Singh et al. 2014). Among patients with Alzheimer's disease a tailored, supervised home-based exercise could result in higher adherence and a more favorable effect on physical functioning than group-based exercise at a day center (Pitkälä et al. 2013b).

The results of this longitudinal intervention study confirm the recently reported finding that persons with functional limitations less likely perform strength training (Kraschnewski et al. 2014). Therefore, additional support and alternative training options are needed to serve older adults with limiting conditions, such as cognitive or mobility impairments. Various techniques can be used to optimize adherence. In this study, the semi-structured interview and physical activity counselling shared similarities with the LIFE study, including topics such as motives, looked-for benefits, barriers, self-efficacy, goals and values, (Rejeski et al. 2013), although these were not followed through as systematically. In addition, in the more recently conducted LIFE study a unique web-based intervention tracking system offered clinicians data enabling them to monitor, provide regular feedback on, and tailor the intervention to meet individual needs. Offering transportation could help those experiencing challenges in travelling to the gym to adopt and adhere to training. In addition to supportive telephone contacts, info mailings, videos or other mobile contacts could be used to support physical activity counselling (Müller & Khoo 2014).

To realize the great potential of exercise as a medicine for older adults with functional limitations will also require action by health professionals. It can be speculated that the proportion of older adults physically incapable of participating in SBT would be minor, taking into account the previously shown feasibility and effectiveness of high-intensity training even among frail nursing home residents (Fiatarone et al. 1994) and demented older adults living in residential care facilities (Toots et al. 2016).

6.4 Training effects

The findings of this study suggest that multimodal intervention, including long-term strength and balance training, improves or maintains muscle strength and mobility in older adults. Both men and women improved their chair rise performance, and women improved their walking speed and muscle strength. The changes achieved were partially maintained during the post-intervention follow-up. Taking into account the mean participant age of 80 at baseline and the nearly three-year study period, the results are encouraging and support the implementation of SBT in older community populations to promote their independent mobility. The decline in older adults' physical functioning appears not to be linear but to accelerate with increasing age. Physical exercise is currently the only intervention that has been shown to effectively improve muscle strength in old age (Waters et al. 2010). Thus, the main findings of this long-term intervention study among a community sample of older adults aged 75 to 98 years are noteworthy.

In this study, women's knee extension strength improved by 5.5%, and knee flexion strength improved by 14.6% during the intervention. The absolute average changes were small (~ 1.5 kg). At the same time, men's strength levels remained at the baseline level. However, even the maintenance of strength may be seen as a positive treatment effect in this age group. At the age of 75 years, strength loss per year occurs at a rate of 3-4% for men and 2.5-3% for women (Mitchell et al. 2012). In addition to muscle strength, a positive training effect was found on physical functioning. A previous meta-analysis found a large positive effect of progressive resistance training on muscle strength in older people (Liu & Latham 2009). The effect also appears to be positive on measures of balance and mobility, though the evidence is weaker than that on the muscle strength (Liu & Latham 2009). In our study the largest improvement on physical functioning was found in the chair rise test. One of the most important factors associated with chair rise capacity is quadriceps strength (Lord et al. 2002). In our study, the training was centered on muscle strengthening in the lower extremities, and therefore it is consistent that the effect was greatest for this parameter.

Lower limb muscle strength is also a central factor for walking speed (Tiedemann, Sherrington & Lord 2005). The relationship between walking speed and muscle strength has previously been found to be non-linear and stronger among weaker people and at slower walking speeds (Buchner et al. 1996, Tiedemann, Sherrington & Lord 2005). The men who initiated SBT had good average walking speed (1.50 m/s) at baseline and large muscle strength gains would have been needed to induce a notable increase in walking speed (Tiedemann, Sherrington & Lord 2005). In women, walking speed improved (6%) over the two years despite an average walking speed at baseline of 1.24 m/s. This result is important as it indicates a reserve capacity in physical functioning above the disability threshold, and hence the possibility for independent and safe mobility. The association between muscle strength and power is different in the case of habitual walking speed, where leg power explains more of the variance than strength (Bean et al. 2003). In our study, where the training did not include power training in addition to strength and balance training, this may partly explain the smaller effect on walking speed than on the chair rise test.

Owing to the different outcome measurements of walking ability, a conclusive comparison between the effects of this study and the LIFE study is not possible. However, in the LIFE study the physical activity intervention focused on aerobic walking exercise together with strength, flexibility, and balance training. The effects of the intervention on walking, i.e., the ability to walk 400 meters independently, were positive among vulnerable older adults (Pahor et al. 2014). Thus, the potential effectiveness of different forms of exercise should be taken into account when seeking to prevent mobility disability among older adults.

The baseline performance in strength and timed functional tests is not comparable between men and women. However, women used walking aids more often. This suggests that women had higher frequencies of mobility limitation and were on a lower functional level than men. Based on the effect sizes, women benefited more than men from the weekly training. This is consistent with the findings of a previous study according to which those with lower baseline strength and function benefited more from training (Chandler et al. 1998).

The TUG and BBS results remained at the baseline level during the intervention. In a previous systematic review, only weak evidence was found to support the theory that exercise is effective in improving balance outcomes (Howe et al. 2011). This may be related to the "specific effect of training". The present strength training occurred primarily in a sitting position, aside from the balance warm-up sessions. Therefore, it was possible that the training was not challenging enough for postural balance. Strength training as an isolated intervention has not been shown to be uniformly effective in improving balance performance (Orr, Raymond & Fiatarone Singh 2008). Previously, in a short-term intervention, strength training alone improved walking speed, but not had any effect on standing balance or chair rise performance in active, community-dwelling older adults (Schlicht, Camaione & Owen 2001). More recently, in a meta-analysis by Sherrington et al., a total exercise dose of more than 50 hours was reported as effective for falls prevention (Sherrington et al. 2011). For a 6-month period this would mean 2 hours of training per week, whereas in our study the training dose was substantially lower. It should also be borne in mind that while in the present long intervention period it was possible to make the strength training component progressive and more challenging, this was less easy in the balance training. One reason for this is that methods for quantifying the level of the challenge to the individual's balance system are lacking (Farlie et al. 2013).

The individual physical functioning adaptive responses to the SBT intervention showed considerable heterogeneity in. In this study, SBT can be seen as a mainly preventive method to maintain physical functioning and prevent disability. However, owing to the multi-comorbidity in population-based sample, it may be that the long-term intervention also included aspects of rehabilitation, as one or more hospital admissions occurred for the majority of the participants during the intervention period. The wide variation in individual training effects may partly be explained by the dynamic nature of functioning and disability. It has been shown that individuals are moving from a state of independency to disability and vice versa (Gill et al. 2006). Some participants may be in the recovery phase of a transient health condition at the times when the annual measurements were conducted. Among frail older people, who are ADL-dependent, the presence of fluctuation in day to day functioning will be reflected in the BBS (Conradsson et al. 2007) and TUG (Nordin, Rosendahl & Lundin-Olsson 2006) results. However, large heterogeneity in adaptive responses to resistance-type exercise was also present among >65-year-old adults during a training intervention lasting 12–24 weeks (Churchward-Venne et al. 2015). In the present study, the age-related decline in physical performance can be expected to be greater due to the higher age of the participants and greater length of the intervention phase.

During the long-term intervention, the mean adherence of 55% indicates that the average training frequency was once every two weeks. Although the American College of Sports Medicine recommends that strength training be done two times per week for adults aged 65 and over (American College of Sports Medicine et al. 2009), there is some evidence to support the idea that training once per week might be effective in increasing strength and preventing sarcopenia, i.e., loss of muscle mass and strength, among older adults (DiFrancisco-Donoghue, Werner & Douris 2007, Sousa et al. 2013). At baseline, only 5% of the intervention group participants reported that they had been engaged in strength training at the gym during the preceding month. Therefore, even once-weekly training represented a substantial increase in their weekly physical activity for most of them and could reasonably be expected to help in the prevention of age-related loss of muscle strength and mass. At the population level, training two days per week would have demanded a considerable increase in gym capacity as well as in the number of competent instructors.

Despite the relatively low training frequency in this study, the intensity was planned to be on a level (60–85% 1RM) conforming with the American College of Sports Medicine recommendations (American College of Sports Medicine et al. 2009). Improvement in lower limb strength requires higher training intensities (70–89% of 1RM), while interestingly, improvement in functional performance might be induced by moderate (50–69% of 1RM) or even low (≤50% of 1RM) training intensities (Raymond et al. 2013). However, the dose-response relationship between training intensity and gains in strength and physical functioning shows that high intensity training would be more effective than low intensity training (Seynnes et al. 2004). In this study, the proportion of participants who showed improved performance was greatest in the high adherence group. However, even they did not adhere totally to the once-a-week training offered. Taken together, for very old and frail populations, the effect of different training volumes and frequencies, as well as the dose-response relationship, remains in need of confirmation (Steib, Schoene & Pfeifer 2010). Additional research is also warranted to assess the advantage of implementing power training versus strength training among older adults (Tschopp, Sattelmayer & Hilfiker 2011). Interestingly, power training has the potential to elicit similar improvements in muscle power and physical functioning whether performed with light or high external resistance (Reid et al. 2015).

In the present study, no major adverse events, related to training, occurred among training adherers during the intervention, although breaks from training occurred due to hospital admissions and other personal reasons. This confirms the previous findings that high to moderate intensity strength training is feasible and safe for older adults. However, in future clinical trials, to help practitioners to modify interventions and avoid the incidence of adverse events when implementing interventions among different patient groups, adverse events should be reported in more details.

The strength gains partially remained after the intervention ended. In women, both knee extension (5.3%) and flexion (13.2%) strength was higher at the end of the post-intervention follow-up than at baseline. In older adults, gains in muscle mass decrease rapidly after the end of training, while the strength gains are reported to partially remain after 12 weeks of detraining (Correa et al. 2013). When detraining is prolonged to 24 weeks, both strength and muscle size decrease, but, with regular physical activity, walking speed and explosive jumping remain elevated among middle-aged and older adults (Häkkinen et al. 2000). The magnitude of the detraining effect obviously differs according to the frequency, volume and intensity of the training as well as the types of physical activity performed during the detraining. However, the BBS and TUG test results declined during the post-intervention detraining. Continuing SBT would be important to prevent decline in physical functioning at the age of 75 and older.

The control group in the GeMS study used the usual health care services but did not receive any additional intervention, and thus can be seen here as representing the effects of ageing and comorbidities on physical functioning. The performance of the control group declined during the two years of the intervention in all the physical functioning measurements. Due to differences in the baseline characteristics of training adopters and non-adopters, the intervention effects between these groups are not directly comparable despite controlling for confounders. However, it is notable that the level of performance of non-adopters remained unchanged in all the measured physical functioning components except knee extension strength. The risk factors for reduced physical functioning among older adults are diverse, including comorbidities, psychosocial health, environmental conditions, social circumstances, nutrition, physical activity and other lifestyle factors (Stuck et al. 1995, Ayis et al. 2006). For instance, different mental, sensory and neuromuscular functions are relevant to standing balance activity (Thomas et al. 2014). Therefore, it is evident that good care, based on the CGA, and physical activity counselling of older adults could have helped to maintain mobility and balance among non-adopters without a specific supervised exercise intervention. From the physical reserve point of view, only the training adherers increased their functional capacity, including muscle strength.

6.5 Practical implications and future directions

The results of the present study indicate that it is possible to implement long-term supervised strength and balance training as part of a multimodal intervention in a community-dwelling population aged 75 years and older showing wide range of health and physical functioning. However, several factors need to be taken into consideration when promoting exercise among older populations.

The variation in training adherence was wide, and a substantial proportion of the older community-dwelling population did not adopt training offered or were unable or unwilling to continue it for an extended period. Therefore, different individualized exercise modalities are needed to increase adherence to activities challenging strength and balance among older people. For this reason, effective ways to implement either home-based training or other physical activities should be devised, tried out and the effects evaluated. Power training could have the potential to increase exercise effects, at least among those already used to moderate intensity strength training. Aerobic exercise would be an effective component of exercise strategies aimed at the prevention of mobility disability as well offering a wider variety of possibilities for individualized physical activity counselling in older adults. Long-term exercise adherence is an important behavioural change. Therefore, physical activity counselling strategies should be studied and optimized for implementation in real life settings among older adults (Rejeski et al. 2013).

Follow ups are called for to assess outcomes and, if needed, to ensure appropriate progression or modification of exercise programs. In future trials, the inclusion of more exercise physiological data, such as ratings of perceived exertion, would help to describe what people actually did. In future, the development of digital technologies may be used in physical activity counselling and rehabilitation. Special attention should be paid to physical activity promotion as part of a good home care services among the rising proportion of community-living older adults with limitations in mobility or cognition.

In this study, training initiation was preceded by a multidisciplinary assessment, physician's referral and physical activity counselling. This protocol enabled participants to adopt training despite multi-morbidity and different impairments, and health challenges such as vision impairment, malnutrition, declining cognition and using of a walking aid. To guarantee safe and effective training, the professionals responsible for the training of older adults should be aware of these possible limitations in functioning.

In sum, the training implemented in this study had a positive effect, especially on muscle strength and strength-demanding activities such as the walking speed and chair rise tests. The dose-response relationship in strength and balance training, however, needs to be studied among older populations. The identification of possible training adherers and responders at the individual level and of the factors and mechanisms underlying adherence and the willingness to take up training would promote the use of exercise as medicine. What intensity, frequency, duration and progression among older population are optimal should be clarified. In physical activity counselling, it is also important to accept smaller increments in physical activity to potentially reap the benefit of maintaining one's independent mobility.

For policy making purposes, the cost effectiveness of CGA-based multi-interventions, including their impact on health care services, such as hospitalization, the need for long-term care or assisted-living facilities and home care services remains to be clarified in future studies.

Although muscle strength declined among the training non-adherers, physical activity counselling and other targeted interventions based on the comprehensive geriatric assessment may have helped this group to maintain balance and mobility even without additional training. If so, this underlines the importance of comprehensive health assessments and individualized interventions among older populations to prevent functional impairments and maintain independent mobility. Physical activity monitoring should be an established component of health assessments for older adults. Optimizing the ability to be independently mobile among the frailer participants requires multi-professional teamwork. Promoting physical activity and mobility along with serving other basic needs and proper treatment of diseases should be a priority of all health care professionals working with older adults.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings of the present dissertation can be summarized as follows.

1. Supervised strength and balance training (SBT) once a week as part of a multimodal geriatric intervention for over two years improved or maintained muscle strength, balance and mobility unchanged in a community-dwelling older population. The effects gained partially decreased after the intervention. Women benefitted more from training than men.

2. Long-term adherence to group-based strength and balance training is possible for older adults, despite hospital admissions, comorbidities and functional impairments. However, lower age, better cognitive status and better physical functioning promote older adults to initiate and adhere to long-term training.

3. Physical functioning declined among the participants in the non-intervention control group. Among the participants in the individualized geriatric intervention with physical activity counselling, physical functioning was maintained in those who participated in the SBT, while in those in this group who did not participate in the SBT muscle strength declined.

4. Poor functional vision was related to weaker balance and mobility performance in the community-dwelling older adults.

In conclusion, the results of the present study indicate that it is possible to implement supervised strength and balance training as part of a multimodal geriatric intervention in a 75- to 98-year-old population showing wide range of health and physical functioning. Training is an important component of a comprehensive geriatric intervention to prevent age-related decline in muscle strength and related activities such as walking speed and chair rise. Muscle strength declines in the absence of training while physical activity counselling and other targeted interventions based on a comprehensive geriatric assessment delay balance and mobility decline. Thus training should be broadly promoted among older populations to maintain independent mobility in the long term.

YHTEENVETO (FINNISH SUMMARY)

Pitkäkestoisen tasapaino- ja voimaharjoittelun toteutuminen yli 75-vuotiailla henkilöillä sekä harjoittelun vaikutukset liikkumiskykyyn

Liikkumiskyky on tärkeää iäkkäiden henkilöiden kotona selviytymisen ja elämänlaadun kannalta, sillä itsenäinen suoriutuminen päivittäisistä toiminnoista edellyttää kykyä liikkua tehokkaasti ja turvallisesti. Iäkkään väestön liikkumiskyvyn heikentymisen taustalla on monia tekijöitä. Ikääntyessä tasapainon säätely vaikeutuu, näkökyky huononee ja lihasvoima heikentyy. Monet sairaudet yleistyvät iän myötä. Myös monisairastavuuden todennäköisyys kasvaa. Iäkkäiden terveyteen ja toimintakykyyn kohdistuvilta toimenpiteiltä edellytetään tämän vuoksi monialaisuutta. Ennaltaehkäisyssä ja hoidossa tulee huomioida kokonaisuus yksittäisten oireiden ja rajoitteiden lisäksi. Esimerkiksi laaja-alaisen geriatrisen arvioinnin perusteella interventiot on mahdollista kohdistaa yksilöllisesti. Useimmat elimistön vasteet liikunnalle säilyvät myöhäiseen ikään. Lihasvoimaa ja liikkumiskykyä voidaan lisätä nousujohteisella voimaharjoittelulla vielä hyvin iäkkäänäkin. Aiempi tutkimustieto kuitenkin painottuu 75-vuotiasta väestöä nuorempiin ja terveempiin henkilöihin sekä kestoltaan vain muutamien viikkojen tai kuukausien mittaisiin kokeisiin. Vähemmän on tietoa siitä, kuinka pitkäkestoinen harjoittelu toteutuu iäkkään väestön kohdalla, ja millaisia vaikutuksia sillä on liikkumiskykyyn ja sen osatekijöihin.

Tässä tutkimuksessa selvitettiin voima- ja tasapainoharjoittelun vaikutuksia 75-vuotiaan ja sitä vanhemman väestön toimintakykyyn sekä harjoittelun toteutumiseen yhteydessä olevia tekijöitä. Lisäksi selvitettiin toiminnallisen näön yhteyttä tasapainoon ja liikkumiskykyyn. Aineisto on osa laajaa väestöpohjaista Hyvän Hoidon Strategia -tutkimusta. Alkumittauksiin osallistui 651 kotona-asuvaa henkilöä, jotka oli satunnaistettu koe- (n=339) ja kontrolliryhmään (n=312). Terveyden ja toimintakyvyn arviointi toistettiin vuosittain 2004–2007. Kontrolliryhmä jatkoi normaalia elämää mittauksia lukuun ottamatta. Koeryhmä sai laaja-alaisen geriatrisen arvioinnin ja siihen perustuvan yksilöllisen intervention kohdistuen mm. lääkitykseen, ravitsemukseen, suun terveyteen ja näkökykyyn. Lisäksi kaikki koeryhmäläiset osallistuivat fysioterapeutin liikuntaneuvontaan ja heistä 54 % (n=182) lähti mukaan tarjottuun tasapaino- ja voimaharjoitteluun kuntosalilla. Edellytyksenä osallistumiselle oli, että henkilö pystyy liikkumaan kuntosalilla itsenäisesti tai pienen avun turvin. Harjoittelu jatkui 28 kuukauden ajan.

Kuntosaliharjoittelu toteutettiin kerran viikossa fysioterapeutin ohjaamana. Reilun tunnin kestävään harjoitteluun kuului 15 minuutin alkulämmittely vaihtelevalla tasapainoradalla. Nousujohteinen voimaharjoittelu tapahtui vastuslaitteilla ja painottui alavartaloon. Harjoitusmäärän ja -intensiteetin tavoitteeksi määriteltiin 3 sarjaa, joissa 8–12 toistoa 60–85 %:n vastuksella yhden toiston maksimista. Nousujohteisuus toteutettiin kuorman lisäämisellä ja harjoittelun toteutumista seurattiin henkilökohtaisten päiväkirjojen avulla.

Kuntosaliharjoittelun valinneet koeryhmäläiset olivat nuorempia ja heillä oli parempi kognitiivinen ja fyysinen toimintakyky verrattuna tutkittaviin, jotka eivät aloittaneet harjoittelua (n=157). Harjoittelun aloittaneet koeryhmäläiset osallistuivat keskimäärin 55 %:in tarjotuista harjoittelukerroista. Pitkäaikainen ohjattuun kuntosaliharjoitteluun sitoutuminen oli mahdollista myös iäkkäille henkilöille huolimatta sairauksista, sairaalahoitojaksoista ja toiminnanvajauksista. Parempi liikkumiskyky kuitenkin lisäsi osallistumisaktiivisuutta.

Harjoittelun aloittaneiden lihasvoima lisääntyi, liikkumiskyky parani ja tasapaino pysyi yllä kahden vuoden harjoittelun aikana. Parantunut suorituskyky näkyi polven ojennus- ja koukistusvoimassa sekä kävelyn ja tuolista ylösnousemisen nopeudessa. Suorituskyky alkoi heikentyä intervention päätyttyä. Harjoitteluun osallistumattomilla koeryhmäläisillä, jotka saivat kuitenkin interventioon sisältyneen liikuntaneuvonnan, liikkumiskyky ja tasapaino säilyivät kahden vuoden seurannassa, mutta heidän lihasvoimansa heikentyi. Sen sijaan liikkumiskyky, tasapaino ja lihasvoima heikentyivät kontrolleilla, jotka eivät saaneet mitään interventiota. Lisäksi tutkimustulokset osoittivat, että heikentynyt toiminnallinen näkö oli yhteydessä huonompaan tasapaino- ja liikkumiskykyyn.

Tasapaino- ja voimaharjoittelu kuntosalilla lisää lihasvoimaa ja ylläpitää liikkumiskykyä kotona asuvilla yli 75-vuotiailla henkilöillä verrattuna harjoitteluun osallistumattomiin koe- tai kontrolliryhmiin. Suorituskyky alkaa kuitenkin heikentyä pian harjoittelun päätyttyä, joten harjoittelun tulisi olla jatkuvaa. Laaja-alaisen geriatrisen arvioinnin ja sen perusteella yksilöityjen interventioiden rinnalla pitkäkestoinen kuntosaliharjoittelu oli mahdollista myös monisairaille iäkkäille henkilöille. Tutkimuslöydökset korostavat ongelmien tunnistamisen ja monipuolisesti puuttumisen tärkeyttä. Yhteenvetona voidaan todeta, että tasapaino- ja voimaharjoittelu on tärkeä osa laaja-alaista geriatrista hoitointerventiota. Liikunnalla on keskeinen merkitys ikääntyneiden toiminta- ja liikuntakyvyn ylläpitäjänä, ja se on myös olennainen osa ikääntyneiden hyvää hoitoa.

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APPENDIX: ONLINE SEARCH CRITERIA

MEDLINE (OVID)

1. ((strength$ or resist$ or weight$) adj3 training).tw.
2. progressive resist$.tw.
3. 1 or 2
4. Exercise/
5. Exercise Therapy/
6. exercise$.tw.
7. 4 or 5 or 6
8. (Resist$ training or strength$).tw.
9. and/7-8
10. or/3,9
11. limit 10 to ("all aged (65 and over)" or "aged (80 and over)")
12. (elderly or senior$).tw.
13. and/10,12
14. or/11,13
15. randomized controlled trial.pt.
16. controlled clinical trial.pt.
17. Randomized Controlled Trials/
18. Random Allocation/
19. Double Blind Method/
20. Single Blind Method/
21. or/15-20
22. Animals/ not Humans/
23. 21 not 22
24. clinical trial.pt.
25. exp Clinical Trials as topic/
26. (clinic$ adj25 trial$).tw.
27. ((singl$ or doubl$ or trebl$ or tripl$) adj25 (blind$ or mask$)).tw.
28. Placebos/
29. placebo$.tw.
30. random$.tw.
31. Research Design/
32. or/24-31
33. 32 not 23
34. 33 not 23
35. or/23,34
36. and/14,35

ORIGINAL PUBLICATIONS

I

RELATIONSHIP BETWEEN FUNCTIONAL VISION AND BALANCE AND MOBILITY PERFORMANCE IN COMMUNITY-DWELLING OLDER ADULTS

by

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ORIGINAL ARTICLE

Relationship between functional vision and balance and mobility performance in community-dwelling older adults

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Abstract

Background and aims Vision is an important prerequisite for balance control and mobility. The role of objectively measured visual functions has been previously studied but less is known about associations of functional vision, that refers to self-perceived vision-based ability to perform daily activities. The aim of the study was to investigate the relationship between functional vision and balance and mobility performance in a community-based sample of older adults.

Methods This study is part of a Geriatric Multidisciplinary Strategy for the Good Care of the Elderly project (GeMS). Participants (576) aged 76–100 years (mean age 81 years, 70 % women) were interviewed using a seven-item functional vision questionnaire (VF-7). Balance and mobility were measured by the Berg balance scale (BBS), timed up and go (TUG), chair stand test, and maximal walking speed. In addition, self-reported fear of falling, depressive symptoms (15-item Geriatric Depression Scale), cognition (Mini-Mental State Examination) and physical activity (Grimby) were assessed. In the analysis, participants were classified into poor, moderate, or good functional vision groups.

Results The poor functional vision group ($n = 95$) had more comorbidities, depressed mood, cognition decline, fear of falling, and reduced physical activity compared to participants with moderate ($n = 222$) or good functional vision ($n = 259$). Participants with poor functional vision performed worse on all balance and mobility tests. After adjusting for gender, age, chronic conditions, and cognition, the linearity remained statistically significant between functional vision and BBS ($p = 0.013$), TUG ($p = 0.010$), and maximal walking speed ($p = 0.008$), but not between functional vision and chair stand ($p = 0.069$).

Conclusion Poor functional vision is related to weaker balance and mobility performance in community-dwelling older adults. This highlights the importance of widespread assessment of health, including functional vision, to prevent balance impairment and maintain independent mobility among older population.

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Keywords Aging · Vision screening · Postural balance · Mobility limitation · Accidental falls

Introduction

Aging is associated with increasing prevalence of ocular diseases, and decline in different aspects of vision and vision-related functioning [1]. Despite these changes, the importance of vision to maintain postural control seems to increase with age [2]. Vision also plays an important role in mobility performance [3]. Therefore, it is not surprising that impaired vision has been reported as a major risk factor for falls among older adults [4].

Among older adults the assessment of visual acuity alone may underestimate the degree of disability related to vision impairment because considerable changes may occur in visual functions other than acuity [1]. Many of these objectively measurable visual functions have found to associate with balance and mobility performance. In community-settings loss in contrast sensitivity [5–8], stereopsis [5], visual fields [7, 9] as well as visual acuity [8] have been associated with impaired postural control or mobility. However, less is known about interactions between these different types of vision impairment [10].In addition, objective measurements of visual functions do not take into account the role of environmental, task-specific and individual factors affecting performance [11]. For example, daily functioning of older adults may take place under less-than-optimal conditions of lighting and contrast [12]. Furthermore, there may be great differences in abilities to compensate vision impairment with other resources such as muscle strength, balance and reaction time to maintain safe and independent mobility [5, 6]. Therefore, assessment of visual functioning has been approached from different perspectives. A clear distinction has been drawn between objectively measured visual functions, i.e., how the eye functions, and functional vision, i.e., how vision deficits may affect functioning in daily and social activities [13].

Several functional vision questionnaires have been developed to measure vision impairment caused by cataracts [14]. Later assessments of self-rated functional vision were proposed to be useful for vision screening of community-dwelling older adults [15] and for assessing their risk of falling [16]. Thus far, however, the relationship between self-rated functional vision and physical functioning has not been evaluated using well-established physical performance tests [17]. The aim of this cross-sectional study was to investigate whether there is a relationship between self-rated functional vision and objective measures of balance and mobility among older adults living in community.

Methods

Study design and participants

The data of the present cross-sectional study were drawn from the Geriatric Multidisciplinary Strategy for the Good Care of the Elderly project (GeMS). This was a population-based randomized comparative study conducted in the city of Kuopio, Finland from 2004 to 2007. The objective of the GeMS study was to evaluate a model for geriatric assessment, care, and rehabilitation. The study is described more detailed in [18]. A random sample of 1,000 persons (500 each in the intervention and comparison groups) was selected from all the inhabitants of Kuopio aged $\geq$75 years in November 2003 ($n = 5{,}615$). The present study used cross-sectional data from the year 2005, when the seven-item visual function index (VF-7) was used for the first time in the GeMS study. A multidisciplinary intervention, focused on medication, nutrition, and exercise, had started during the preceding year. Of the original sample of 1,000 persons, 717 were examined in 2005. Losses from the study were due to 164 refusals, two participants who moved away, 116 deaths, and one person who could not be reached before the scheduled examination. Residents of long-term care facilities were excluded from the present study ($n = 72$). To ensure the reliability of the assessments, we further excluded 40 people who scored 17 or less on the mini-mental state examination (MMSE). In addition, participants were excluded if they had missing data on the VF-7 ($n = 4$) or on all of the balance and mobility tests ($n = 25$). Thus, the final study population comprised 576 community-dwelling participants. The Research Ethics Committee of Northern Savo Hospital District and Kuopio University Hospital approved this study, and all of the participants gave their written informed consent prior to participation in the study.

Data collection

Three trained nurses, two physiotherapists, and two physicians were responsible for the data collection for the present study. Data collection was supplemented by a caregiver interview if a participant had difficulty in answering the questions. The balance and mobility measurements were done by the physiotherapists. If the participant was unable to visit the outpatient clinic, the measurements and interviews took place in the participant's home.

Balance and mobility

The Berg balance scale (BBS) was used to assess balance by observing the participant performing 14 different functional activities [19]. The overall score range is 0 (severely impaired) to 56 points (excellent). The timed up and go test (TUG) was used to assess balance and basic mobility skills [20]. The patients were instructed to stand up from a chair, walk for a distance of 3 m at maximal speed, turn, walk back, and sit down on the chair. A modified chair stand test [21] was used to assess the ability of participants to perform sit-to-stand and stand-to-sit tasks five times as fast as possible. As a modification of the original test, hands were held to each side and participants were allowed to help with their hands if needed. Maximal walking speed (m/s) was measured for a 10-m distance. Two markers were used to indicate the start and finish of the 10-m path. Participants started walking 2 m before the first mark and were instructed to continue walking past the end mark for a further 2 m, so that they were walking at their maximal pace within the timed 10 m path.

Performance measurements were always done in a same order. Each test was performed once. If the participant did not seem to fully understand the instructions, the tester repeated those once. The flooring was standardized so that all balance and mobility tests were conducted on a rigid floor surface. The participants had shoes on except in BBS. For all of the timed tests time was measured with a stop-watch, and use of a walking aid was allowed ($n = 81$) in the TUG and maximal walking speed tests.

Functional vision

Functional vision was assessed by the VF-7, a modified version of the VF-14 [22]. The VF-7 comprises seven activities dependent on functional vision and is validated for use in patients with cataracts [23]. Patients are asked how much difficulty they have doing each activity, with or without glasses. The activities are reading small print; seeing steps, stairs, or curbs; reading traffic, street, or store signs; doing fine handwork; cooking; watching television and driving in darkness. Each question is scored as follows: 4, 3, 2, or 1, respectively, if the subject has no, little, moderate, or a great deal of difficulty performing the activity, and 0 if the subject is unable to perform the activity due to lack of vision. An item is not included in the scoring if the patient does not do the activity for reasons other than his or her vision. The score is obtained by averaging responses across all activities and multiplying by 25. Scores range from 0 (representing maximum impairment) to 100 (representing no impairment).The response rate varied between 97 and 100 % for all other VF-7 questions, but was lower for the questions about cooking ($n = 519$, 90 %) and driving in darkness ($n = 99$, 17 %). Only 114 participants had a valid driving license, and the gender distribution of the respondents for the question about driving in darkness was uneven (16 women and 83 men). Thus, the question was dropped from the final index.

For analytical purposes, participants were categorized into three groups according to their VF-7 results: (1) poor functional vision, VF-7 score ≤ 75, ($n = 95$); (2) moderate functional vision, scores between 75 and 100 ($n = 222$); and (3) good functional vision, the score of 100 ($n = 259$). The cut-off value between poor and moderate functional vision groups (VF-7 score $= 75$) represented a sum score in a theoretical situation in which participant stated that they had little difficulties (score 3) with all of the activities in question.

Health status

Cognitive function was assessed using the MMSE [24] and depressive symptoms were assessed using the 15-item Geriatric Depression Scale (GDS-15) [25]. Body mass index (BMI, kg/m^2) was calculated from body weight and height measured by the study nurses. The use of medication was self-reported by participants, and was verified against prescription forms, drug containers and medical records. Ocular status was defined by interviewing the participants and verifying the information and diagnoses against medical records. In addition, glaucoma diagnoses were verified from the Special Reimbursement Register (maintained by the Social Insurance Institution of Finland).

Comorbidity was computed using a modified functional comorbidity index (FCI), which is a validated scale that predicts physical function in older adults [26]. The FCI takes into account the number of medical conditions, with higher scores indicating greater comorbidity. In this study, data on the following medical conditions were available: rheumatoid arthritis and other connective tissue diseases, osteoporosis, chronic asthma or chronic obstructive pulmonary disease (COPD), coronary artery disease, heart failure, myocardial infarction, Parkinson's disease or multiple sclerosis, stroke, diabetes, depression, visual impairment, hearing impairment, and obesity (BMI >30). Patient diagnoses obtained from the Special Reimbursement Register were used to screen for the presence of rheumatoid arthritis and other connective tissue diseases, chronic asthma or COPD, Parkinson's disease, and multiple sclerosis. For the purposes of this study, the FCI item of visual impairment (i.e., presence of an eye disease that could potentially impair eyesight) was omitted.

Fear of falling, self-rated mobility and physical activity

Participants' fear of falling was investigated by asking them the question "Does fear of falling restrict your everyday locomotion?" The possible answers were: no; yes, outdoors in slippery conditions; yes, outdoors in winter; yes, outdoors year-round; or yes, indoors). In the analysis, the "yes" responses were combined under the single response "yes." Self-rated mobility was assessed by asking whether respondents could walk 400 m (yes; yes, with difficulty, but without help; not without help; or no). In the analysis, the categories "yes" and "yes, with difficulty, but without help" were combined under the single category "yes independently". The level of physical activity was assessed using a modified version of the scale by Grimby [27]. The participants were categorized on the basis of their self-rated physical activity into a low-activity group (no other exercise, at most light walking 1–2 times/week), a moderate-activity group (light walking or other light exercise several times a week or moderate exercise 1–2 times/week), or a high–activity group (moderate or vigorous exercise several times/week).

Statistics

Variables with normal distribution descriptive values were expressed by means and standard deviations (SD); statistical comparison between the groups was made using analysis of variance (ANOVA). Variables with ordinal descriptive values were expressed by median and interquartile range (IQR); statistical comparison between groups was made using Kruskal–Wallis test. Measures with a discrete distribution are expressed as counts (%) and analyzed by Chi Square. Statistical significance for the hypotheses of linearity (orthogonal polynomial in the level of functional vision group values, linear trends) for physical performance was evaluated by bootstrap-type analysis of covariance (ANCOVA); because of the violation of distribution assumptions. Age, gender, FCI and MMSE scores were used as covariates in the ANCOVA analyses. The normality of the variables was tested using the Shapiro–Wilk W-test. The α-level was set at 0.05. Stata statistical software, release 12.1 (StataCorp, College Station, TX, USA), was used for the analyses.

Results

Of the 576 participants in the present study, 70 % ($n = 402$) were women and the mean age of the participants was 81 years (range 76–100 years). The mean (SD) VF-7 index for the whole study group was 88.2 (18.7); 88.4 (20.9) for men and 88.1 (20.1) for women.

The characteristics of the participants, grouped by level of functional vision, are shown in Table 1. Groups differed significantly with regard to all demographic, health and activity characteristics except for gender and BMI. The participants in the poor functional vision group were older and their years of education were fewer compared to those with moderate or good functional vision. Participants with poor functional vision had higher FCI scores and a higher number of medicines, and they were more likely to have macular degeneration, glaucoma, a lower limb endoprosthesis or history of hip fracture. They also had lower MMSE and higher GDS-15 scores. In addition, participants in the poor functional vision group were less physically active, less often able to walk 400 m independently, and more often had a fear of falling compared to those with moderate or good functional vision.

The mean performance in poor, moderate and good functional vision groups for BBS was 43 (95 %CI 41–45), 48 (47–49), 50 (49–51) points; for chair stand 18.2 (15.9–20.4), 15.2 (14.2–16.2), 14.6 (13.9–15.2) seconds; for TUG 17.3 (14.9–19.7), 12.9 (11.9–13.9), 11.7 (10.9–12.6) seconds and for walking speed 1.08 (0.97–1.19), 1.28 (1.22–1.34), 1.41 (1.35–1.47) m/s, respectively. The linear relationships between self-rated functional vision and BBS ($p < 0.001$), TUG ($p < 0.001$), walking speed ($p < 0.001$) and chair stand ($p = 0.0089$) were statistically significant. After adjusting for gender, age, FCI, and MMSE scores, the linearity remained statistically significant between functional vision and BBS ($p = 0.013$), TUG ($p = 0.010$), and walking speed ($p = 0.008$), but not between functional vision and chair stand ($p = 0.069$) (Fig. 1).

Discussion

This cross-sectional study found a significant relationship between functional vision and objectively measured balance and mobility performance among community-dwelling people aged ≥76 years. The average results of balance and mobility tests were significantly poorer among persons with poor functional vision compared to those with moderate or good functional vision. After adjusting for gender, age, cognition and comorbidity, linear association still remained significant for BBS, TUG and walking speed but not for chair stand results.

The level of balance and mobility performance that older adults with poor functional vision achieved in this study may have harmful consequences. Adequate vision is important for maintaining balance and detecting and avoiding hazards in the environment [28]. In earlier studies, older adults with BBS scores of <46 were more likely to develop ADL difficulty over an 18-month period [29], and they were at increased risk for multiple falls if their BBS score was <45 [30]. For the TUG test was reported that performance time of >14 s [31] predicted higher risks of falling. In addition, a walking speed of at least 1.2 m/s is generally required to cross the road safely during a green light [32]. In our study, the participants with poor functional vision performed below all of these cut-off levels

Table 1 Characteristics of participants by functional vision group ($n = 576$)

Characteristic	Functional vision by VF-7 score			p
	Poor ($n = 95$)	Moderate ($n = 222$)	Good ($n = 259$)	
Demographics				
Female, n (%)	65 (68)	167 (75)	170 (66)	0.070
Age, mean (SD)	84 (5)	81 (4)	80 (4)	<0.001
BMI, mean (SD)	27 (4.6)	27 (4.4)	27 (4.4)	0.730
Education years, med (IQR)	6 (4, 8)	7 (6, 10)	7 (6, 10)	0.004
Clinical data				
FCI, med (IQR)	2 (1, 4)	2 (1, 3)	2 (1, 3)	0.001
Number of medicines, med (IQR)	7 (4, 8)	5 (3, 7)	4 (2, 6)	<0.001
Lower limb endoprosthesis, n (%)	29 (31)	41 (18)	45 (17)	0.018
Hip fracture, n (%)	8 (8)	9 (4)	4 (2)	<0.001
MMSE, mean (SD)	26 (3)	27 (3)	27 (3)	<0.001
GDS-15, mean (SD)	2.5 (2.5)	1.7 (1.9)	1.1 (1.5)	<0.001
Ocular status, n (%)				
Cataracts operated	46 (48)	103 (46)	103 (40)	0.251
Macular degeneration	36 (38)	22 (10)	12 (5)	<0.001
Glaucoma	14 (15)	26 (12)	15 (6)	0.015
Activity, n (%)				
Fear of falling	49 (52)	57 (26)	58 (22)	<0.001
Able to walk 400 m independently	79 (83)	207 (93)	246 (95)	<0.001
Yes	36 (38)	129 (58)	177 (68)	
Yes, with difficulty, but without help	43 (45)	78 (35)	69 (27)	
Physical activity				<0.001
Low	50 (53)	70 (31)	80 (31)	
Moderate	36 (38)	95 (43)	110 (42)	
High	9 (9)	57 (26)	69 (27)	

BMI body mass index, *FCI* functional comorbidity index, *med* median, *MMSE* mini-mental state examination, *GDS-15* geriatric depression scale

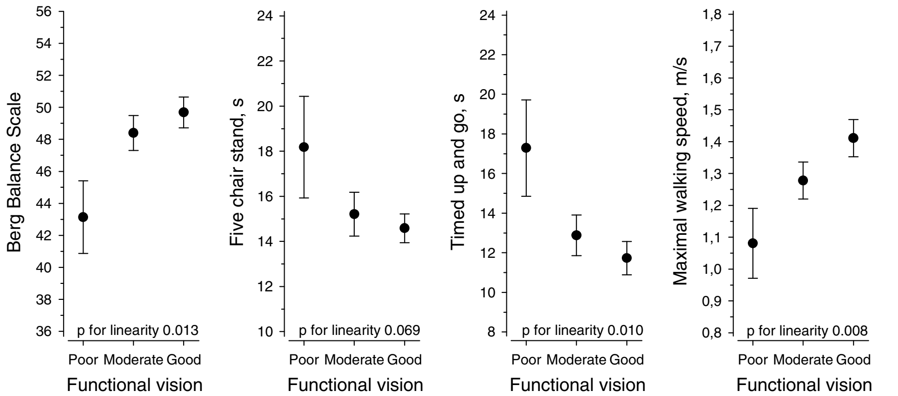

Fig. 1 Mean (95 % CI) of balance and mobility performance according to functional vision group. Higher score on the Berg Balance Scale indicates better performance

indicating that risk factors for disability and future falls seem to accumulate.

It has been previously found that in addition to detecting hazards in the environment, vision plays an important role in maintaining stability when standing or moving [28]. Thus, it appears that good vision provides support for safely and quickly undertaking the chair stand test [33]. In this study, an independent association between functional vision and chair stand test performance was not found. In a previous study, chair stand test performance was weakened only among persons with more severe visual impairments compared to walking speed, stair climbing, and tandem standing tests where problems occurred already with milder visual impairments [34]. Compared with other physical performance tests used in the present study, the chair stand is less demanding in terms of balance control and vision because no navigation in the environment is needed [28]. The sit-to-stand performance is though influenced by visual function, particularly contrast sensitivity, but there are several other factors associated with the test time, the most important being quadriceps strength [33]. Consequently, in the chair stand test older adults may to some extend better compensate their visual limitations than in the other tests used here.

The found cross-sectional association between functional vision and balance and mobility performance may have several explanations. Independent and safe mobility is a complex action where movement emerges from an interaction between the individual, the task, and the environment [11]. On individual level postural control of stance and locomotion requires function of motor, sensory, and cognitive systems, which all are affected by aging [2]. In addition to these physiological changes, declines in health including number of comorbidities, depressiveness and memory problems were common in the poor functional vision group. These results are consistent with the findings of previous studies in which depression [35] and cognitive decline [36] were more prevalent among older adults with poor functional vision. Thus, strategies to compensate for the effects of vision impairment were more limited among persons with poor functional vision [37]. This idea suggests that the role of vision in balance and mobility performance may become even more critical in old age when health problems tend to accumulate.

One possible explanation for weaker balance and mobility performance might be the avoidance of physical activity due to reduced functional vision. Our findings of low physical activity and fear of falling among the participants with poor functional vision was concordant with the findings of Kempen et al. [38]. Poor vision is a well-established risk factor for falling among older adults [4]; a functional vision index, the Activities of Daily Vision Scale, has been reported to be a useful tool to assess falling risk in older adults [16]. A cause-and-effect relations cannot be concluded because of the cross-sectional design of the present study, but previous longitudinal studies support the default hypothesis that poor functional vision is a predisposing factor for development of fear of falling [39], and fear-related avoidance of physical activity predicts declines in balance and mobility performance [40]. Characteristics of participants in this study are parallel to this idea: history of hip fractures, fear of falling, impaired ability to walk 400 m, and low physical activity were more prevalent among participants with poor functional vision.

Vision impairment and vision-related balance and mobility limitations seem to weaken ability and willingness to be physically active. Decreasing physical activity may speed up sarcopenia and muscle strength especially after an age of 75 years [41]. Older adults share numerous overlapping pathways and risk factors for disability such as decreasing physical function, increasing number of chronic medical conditions and impaired vision [42]. Thus, both multifaceted assessment and rehabilitation of balance and mobility performance are important components of disability prevention among visually impaired older adults.

Strengths and limitations

A major strength of this study is that it comprised a large representative population sample of community-dwelling older adults aged 76–100 years. Another strength is the use of objective and valid measures of balance and mobility performance. In addition, the measures were conducted by physiotherapists who were familiar with and well educated to these tests. Furthermore, the sample was probably more representative of the general population of people aged 76–100 years than those in previous studies, because the interviews and measurements were done at participants' homes if they were unable to come to the study clinic. Thus, more frail community-dwelling subjects were included in the study. Cognition had some impact on reliable self-assessment and on understanding and retaining the instructions. We tried to minimize the confounding effect of cognitive impairment on the participants' self-rating of their functional vision by excluding the participants with the lowest MMSE scores ($\leq$17) and adjusting the analysis with MMSE scores.

This study also has some limitations. Due the cross-sectional design, causal inferences cannot be made. In addition, the generalizability of the results may be limited, because we excluded the frailest participants, who were unable to perform balance and mobility tests, and the participants residing in institutional care. Any population-based cut-off scores for VF-7 have not been established and therefore we needed to base the grouping in theoretical cut-off scores. Further, the present data was not collected at the baseline of the intervention study, but 1 year later. The multidisciplinary intervention, focused on medication, nutrition, and exercise, had started gradually during the preceding year. As part of the exercise counseling intervention, 153 participants had started weekly strength and balance training at the gym during the fall of 2004 or the year 2005 before the assessments. However, the assessment of functional vision and the physical performance measurements were made cross sectionally without any time disparity. The VF-7 and the original VF-14 questionnaires were designed to allow clinical practices to assess severely impaired populations. In this population-based sample, 45 % of the participants had no visual impairment (full score on VF-7); thus, a ceiling effect was notable. In population-based studies, questionnaire items that are seldom answered must be considered [15]; in our study, this resulted in the driving at night question being dropped from the final index. The findings of the present study suggest that the relevance of functional vision items to community-dwelling older adults should be carefully considered.

In conclusion, poor functional vision was related to worse performance in balance and mobility tests among community-dwelling older adults. Poor functional vision often coexisted with other health problems but there was also linear association independent of gender, age and comorbidity between the functional vision and performance in balance and mobility tests. This indicates a need for widespread assessment of health, including functional vision, when aiming to prevent balance impairment and mobility limitations, as well as falls and disabilities, in older adults.

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Conflict of interest The authors declare no conflicts of interest.

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II

HEALTH AND PHYSICAL FUNCTION PREDICTING STRENGTH AND BALANCE TRAINING ADOPTION: A COMMUNITY-BASED STUDY AMONG INDIVIDUALS AGED 75 AND OLDER

by

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Health and Physical Function Predicting Strength and Balance Training Adoption: A Community-Based Study Among Individuals Aged 75 and Older

Eeva Aartolahti, Sirpa Hartikainen, Eija Lönnroos, and Arja Häkkinen

This study was conducted to determine the characteristics of health and physical function that are associated with not starting strength and balance training (SBT). The study population consisted of 339 community-dwelling individuals (75–98 years, 72% female). As part of a population-based intervention study they received comprehensive geriatric assessment, physical activity counseling, and had the opportunity to take part in SBT at the gym once a week. Compared with the SBT-adopters, the nonadopters (n = 157, 46%) were older and less physically active, had more comorbidities and lower cognitive abilities, more often had sedative load of drugs or were at the risk of malnutrition, had lower grip strength and more instrumental activities of daily living (IADL) difficulties, and displayed weaker performance in Berg Balance Scale and Timed Up and Go assessments. In multivariate models, higher age, impaired cognition, and lower grip strength were independently associated with nonadoption. In the future, more individually-tailored interventions are needed to overcome the factors that prevent exercise initiation.

Keywords: muscle strength, postural balance, exercise, geriatric assessment, adherence, cognition

Promoting physical activity in older adults is an important public health goal. It has been shown that regular exercise can prevent, and serve as an effective therapy for, many chronic diseases and functional limitations (Nelson et al., 2007). Strength and balance training (SBT) has been demonstrated to improve physical function and prevent disability (Singh, 2002), falls (Panel on Prevention of Falls in Older Persons, American Geriatrics Society, & British Geriatrics Society, 2011), and the development and progression of frailty syndrome (Peterson et al., 2009) in older adults. Despite the recognized health benefits, relatively few older adults participate in supervised SBT. In Finland, less than 10% of the population aged ≥ 75 years participates in strength training (Laitalainen, Helakorpi, & Uutela, 2010) at the level recommended in health-enhancing exercise and physical activity guidelines (Nelson et al., 2007). Similarly, in Australia, 12% of persons aged > 65 years participate in strength training, and 6% participate in balance training (Merom et al., 2012). Typically, less than half of those invited to take part in fall prevention activities agree to participate, and nearly half decline to attend SBT groups (Yardley et al., 2008).

The prevalence of comorbid conditions increases with age and heightens the risk for developing mobility disability (Fried, Ferrucci, Darer, Williamson, & Anderson, 2004). Poor health has also been described as a significantly greater barrier to general physical activity after the age of 80 years than at younger ages (Moschny, Platen, Klaassen-Mielke, Trampisch, & Hinrichs, 2011). The determinants of exercise for older adults were evaluated in a review of randomized controlled trials (RCT): better physical condition, a previous physically active lifestyle, nonsmoking, and higher exercise self-efficacy predicted better adherence (Martin & Sinden, 2001). However, these study populations were very limited compared with general community settings, where multiple morbidities and functional limitations are common. A recent review revealed that the evidence on the determinants of physical activity and exercise was insufficient in healthy adults aged > 55 years (Koeneman, Verheijden, Chinapaw, & Hopman-Rock, 2011). Barriers to physical activity among older adults, especially for adults over 80 years of age with regard to SBT, have been studied even less frequently (Baert, Gorus, Mets, Geerts, & Bautmans, 2011). Thus, studies on the health and physical function affecting the initiation of exercise among community-dwelling older adults with a wide variety of functional limitations and comorbidities are sparse.

Information regarding the barriers to beginning a training program may improve the design and implementation of exercise programs in community settings (Glasgow, Vogt, & Boles, 1999). The purpose of the current study was to detect the factors related to health and physical function that are associated with nonadoption of supervised SBT in a community-based sample of older adults.

Methods

Participants

This study is part of the Geriatric Multidisciplinary Strategy for the Good Care of the Elderly study (GeMS). GeMS is a population-based intervention study (Lihavainen et al., 2012) that comprised a baseline assessment, a two-year intervention with annual assessments, and a one-year follow-up period. It was conducted in the city of Kuopio, Finland from 2004 to 2007. A random sample of 1,000 individuals was selected from all the inhabitants of Kuopio aged 75 years and over in November 2003 (n = 5,615). After excluding the subjects who died, refused to participate, or had moved out of the area, a total of 781 participants were included in the baseline

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assessment. The participants in the current study (n = 339) were the community-dwelling individuals who were included in the intervention group at baseline (Figure 1). An additional inclusion criterion was that the participant had received physical activity counseling from a physiotherapist at the beginning of the study. Written informed consent was obtained from the study participants. The study was approved by the Research Ethics Committee of Northern Savo Hospital District and Kuopio University Hospital.

Comprehensive Geriatric Assessment (CGA)

Three trained nurses, two physiotherapists, and two physicians collected the GeMS data. Sociodemographic factors, health status, medication use, nutritional status, cognitive functioning, physical performance, and ability to perform activities of daily living were assessed. The data collection was supplemented by a caregiver interview if a participant had difficulty answering the questions. The balance and mobility measurements were collected by the physiotherapists. If the participant was unable to visit the outpatient clinic, the measurements and the interviews took place at the participant's home.

Health Status

Comorbidity was defined using a modified version of the 18-item functional comorbidity index (FCI), a validated scale that predicts physical function in older adults (Groll, To, Bombardier, & Wright, 2005). The FCI takes into account the number of medical conditions, with higher scores indicating greater comorbidity. This study collected data on the following 13 conditions (Tikkanen et al., 2012): (1) rheumatoid arthritis and other connective tissue diseases, (2) chronic asthma or chronic obstructive pulmonary disease (COPD), (3) Parkinson's disease or multiple sclerosis, (4) osteoporosis, (5) coronary artery disease, (6) heart failure, (7) myocardial infarction, (8) stroke, (9) diabetes, (10) depression, (11) visual impairment, (12) hearing impairment, and (13) obesity (BMI > 30).

The use of medication was self-reported by the participants, and they were also asked to bring their prescription forms and drug containers to the interviews. In addition, self-reported drug use was verified against medical records. The sedative load model was used to quantify the cumulative effect of taking multiple drugs with sedative properties (Linjakumpu et al., 2003; Taipale et al., 2011). Cognitive function was assessed using the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). The scores range from 0 to 30, with higher scores indicating better performance. Depressive symptoms were assessed using the 15-item Geriatric Depression Scale (GDS-15) (Sheikh et al., 1991), with scores ≥ 5 considered to be indicative of possible depression. The short version of the Mini Nutritional Assessment (MNA-SF) was used to assess the risk of malnutrition (Rubenstein, Harker, Salva, Guigoz, & Vellas, 2001). The maximum score on the MNA-SF is 14; scores of 12–14 indicate normal nutritional status, scores of 8–11 indicate a risk of malnutrition, and scores of 0–7 indicate malnutrition. Self-rated health was assessed with the following question: "How would you rate your health at the moment?" The participants selected one of five response alternatives. In the analysis, alternatives 1 and 2 (good or very good) and 4 and 5 (poor or very poor) were combined.

Physical Functioning

The Berg Balance Scale (BBS) was used to assess balance. The participant was observed performing 14 different functional balance tasks that test the ability of individuals to stand, reach, bend, and transfer (Berg, Wood-Dauphinee, Williams, & Maki, 1992). Each of the 14 items is scored from 0 to 4, and the overall scores range from 0 (severely impaired) to 56 points (excellent). The Timed Up and Go test (TUG) was used to assess balance and basic mobility skills (Podsiadlo & Richardson, 1991). The participants were instructed to stand up from a chair, walk for a distance of 3 m at maximal speed, turn around, walk back, and sit down on the chair. Time was measured with a stopwatch, and the use of a walking aid was allowed in the TUG. The participants performed the BBS barefoot and the TUG test using their regular shoes.

Grip strength was measured in kilograms using a Saehan dynamometer (Saehan Corporation, South Korea). The measurements were taken with the participant seated, elbow flexed at a 90° angle next to but slightly apart from the body. The participants were allowed to make one maximal effort for both hands, and the result from the stronger hand was used in the analyses. The grip strength analyses were conducted separately for men and women. The ability to perform instrumental activities of daily living (IADL) was assessed using the Lawton Instrumental Activities of Daily Living Scale (IADLS) (Lawton & Brody, 1969).

Self-rated mobility was assessed by asking whether the respondents could walk 400 m (yes; yes, with difficulty, but without help; not without help; or no). In the analysis, the categories "yes" and "yes, with difficulty, but without help" were combined under the single category "yes, independently".

The level of physical activity was assessed using a modified version of the Grimby scale (Frändin & Grimby, 1994; Grimby, 1986). The participants were asked "Which of the following options describes best your present physical activity?" Ratings ranged from (0) hardly any physical activity; (1) light physical exercise (e.g., walking 1–2 times a week); (2) light physical exercise (e.g., walking several times a week); (3) moderate physical exercise that causes some shortness of breath and sweating 1–2 times a week; (4) moderate physical exercise that causes some shortness of breath and sweating several times a week; (5) hard or very hard physical exercise that causes quite strong sweating and shortness of breath several times a week; and (6) competitive sports and exercise several times a week. The participants were categorized on the basis of their self-rated physical activity into the low-activity group (0–1), the moderate-activity group (2–3), or the high-activity group (4–6).

Physical Activity Counseling

The individually-tailored annual physical activity counseling with the physiotherapist started with a semistructured interview that charted the participants' current and prior physical activity. During the counseling session, practical and detailed goals for future physical activity were set, and both the participant and the physiotherapist signed the plan. The session took approximately 1.5 hr. In addition to the counseling, the physical activity component of the intervention included an opportunity to participate in group-based SBT once a week. The eligibility for SBT was based on clinical examination by a doctor and training was supervised by a trained physiotherapist. The SBT was conducted at one gym in the city center. The intervention did not include transportation to the gym, but the participants received help in finding community transportation services or arranging transportation with family members or neighbors. Training was free of charge. The inclusion criterion for training was that the participant was able to move independently or with minimal help at the gym.

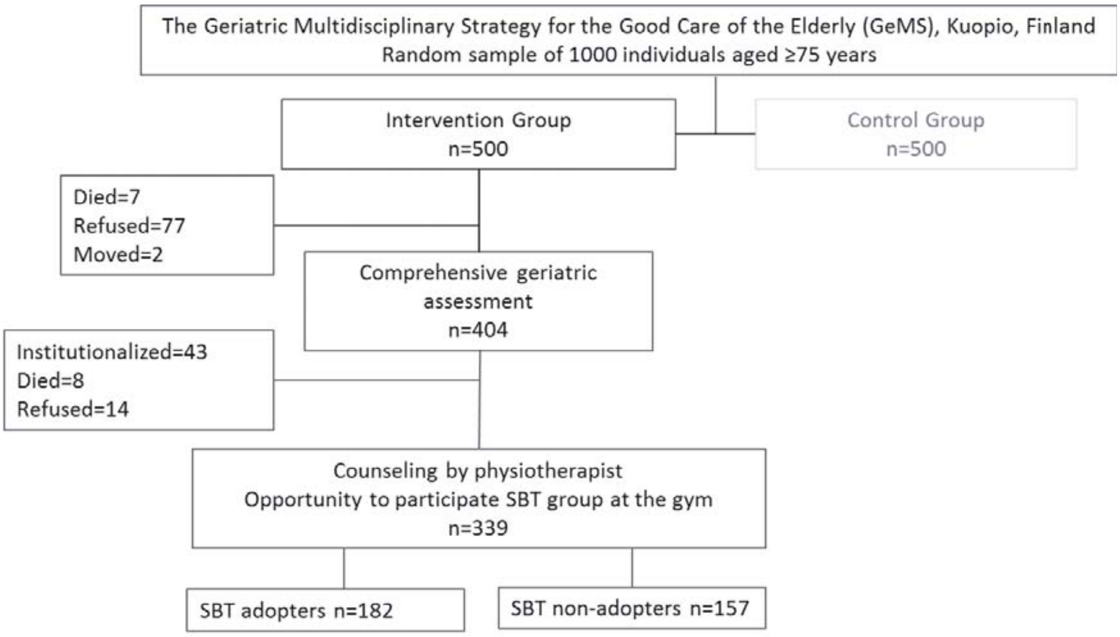

Figure 1 — Flowchart of the study.

Adoption of Training

The participation to SBT was monitored by the study physiotherapists and recorded on the training logs at the gym. The criterion for SBT adoption was taking part at least once in training at the gym during the study period. The term nonadoption is used here as a synonym for not to take up, initiate, or start training.

Statistical Analysis

The data are presented as means with standard deviations (*SD*) or 95% confidence intervals (95% CI) or as counts with percentages. The normality of the variables was tested using the Shapiro-Wilk *W*-test. The statistical significance of the difference between the exercise and nonexercise groups was analyzed with a *t* test for continuous variables and a chi-square test for categorized variables. Logistic regression models were used to study the factors associated with nonadoption (i.e., not initiating training). The bivariate analyses were adjusted for age and sex. In the second phase, the independent variables that were significantly related to nonadoption in the bivariate analysis were used as predictors in the multivariate analysis. To avoid multicollinearity, BBS and TUG scores were omitted from the multivariate model because they were strongly correlated with the IADLS. The participants' education level was not included because data were missing for several participants. If the 95% CI did not include 1, the result was regarded as statistically significant. The α-level was set at .05. SPSS version 19.0 (IBM, USA) was used to conduct the analyses.

Results

Of the 339 participants (75–98 years old, 72% female), 157 (46%) did not adopt SBT during the intervention. The characteristics of the participants are summarized in Table 1. The nonadopters were older ($p < .001$) and had less education ($p < .001$) than the adopters. With regard to health status, the nonadopters had more comorbidities ($p < .011$) and lower cognition ($p < .001$), more often consumed a sedative load of drugs ($p < .001$) or had a risk of malnutrition ($p = .002$), and had poorer self-perceived health ($p < .003$) compared with the SBT adopters.

With regard to self-reported functioning, the group of nonadopters was less physically active ($p < .009$) and had more difficulties with IADL ($p < .001$) and walking 400 m ($p < .001$). In addition, a higher proportion of them used a walking aid ($p < .001$). In terms of measured physical performance, the nonadopters had lower grip strength (women: $p < .001$; men: $p = .025$) and more balance and mobility problems according to the BBS ($p < .001$) and the TUG ($p < .001$) compared with the adopters. (Table 1).

In the bivariate analysis, nonadoption was associated with higher age, lower education, a greater sedative load of drugs, lower levels of cognition, the risk of malnutrition, less ability to perform IADL, lower performance in BBS and TUG, and having grip strength in the two weakest quartiles (Table 2). In the multivariate analysis, higher age, weaker cognition, and lower grip strength were independently associated with nonadoption. For each point the MMSE decreased, the odds of nonadoption increased by 14%.

Table 1 Characteristics of the Participants by SBT Adoption (n = 339)

Variable	SBT adopters (n = 182)	Nonadopters (n = 157)	p
Demographics			
Female, n (%)	130 (71)	114 (73)	.810
Age, years, mean (SD)	79.7 (3.9)	82.3 (4.8)	< .001
Years of education, mean (SD)	7.6 (3.6)	6.5 (2.9)	.001
Living alone, n (%)	93 (51)	90 (58)	.250
Health status			
FCI, mean (SD)	2.1 (1.5)	2.6 (1.8)	.011
Asthma or COPD, n (%)	14 (8)	13 (8)	.840
Coronary artery disease, n (%)	71 (39)	72 (46)	.230
Myocardial infarction, n (%)	32 (18)	32 (20)	.510
Heart failure, n (%)	23 (13)	38 (24)	.006
Parkinson's disease, n (%)	4 (2)	5 (3)	.570
Stroke, n (%)	18 (10)	17 (11)	.800
Diabetes, n (%)	20 (11)	24 (15)	.240
GDS-15 ≥ 5, n (%)	10 (5.6)	10 (6.4)	.740
BMI, mean (SD)	27.3 (4.0)	26.7 (4.7)	.220
Sedative load ≥ 1, n (%)	38 (21)	64 (41)	< .001
MMSE ≤ 24, n (%)	18 (10)	55 (35)	< .001
MNA-SF ≤ 11, n (%)	13 (7)	28 (18)	.002
Self-perceived health, n (%)			.003
Good or very good	79 (43)	72 (46)	
Average	88 (48)	54 (34)	
Poor or very poor	15 (8)	30 (19)	
Physical functioning			
IADLS, mean (SD)	7.2 (1.4)	6.1 (2.1)	< .001
TUG (s), mean (SD)	11.5 (5.7)	16.0 (11.2)	< .001
BBS, mean (SD)	50 (6.9)	46 (10.2)	< .001
Grip strength (kg), mean (SD)			
Women	21 (5.3)	16 (7.4)	< .001
Men	35 (9.9)	31 (6.9)	.025
Unable to walk 400 m independently	4 (2)	21 (13)	< .001
Use of walking aid, n (%)	39 (21)	62 (39)	< .001
Grimby physical activity score, n (%)			.009
Low	51 (28)	67 (43)	
Moderate	93 (51)	69 (44)	
High	38 (21)	20 (13)	

Note. SBT = strength and balance training; FCI = functional comorbidity index; COPD = chronic obstructive pulmonary disease; GDS-15 = 15-item Geriatric Depression Scale; BMI = body mass index; MMSE = Mini-Mental State Examination; MNA-SF = Mini Nutritional Assessment (short form); IADLS = instrumental activities of daily living scale; TUG = Timed Up and Go; BBS = Berg Balance Scale.

Discussion

To our knowledge, this is one of the first studies exploring SBT adoption in a community setting after a multidisciplinary CGA and physical activity counseling. In this study, SBT adoption was assessed based on actual participation in training, not only by self-report or willingness to take part. Almost half (46%) of the community-dwelling older adults did not participate in SBT at the gym. Compared with the results of a previous survey from the UK, in which 41% of population aged ≥ 54 years reported that they would definitely not attend group-based SBT for fall prevention (Yardley et al., 2008), the degree of nonparticipation in our study with a far older population seems moderate. Conversely, fall prevention exercise trials for older people have reported notably higher (70%) participation rates (Nyman & Victor, 2012). The participants in RCTs are recruited differently, and they often have better health and a higher level of functioning than the older adults in our community-based intervention study.

Previous research has reported that physical activity decreases with aging (Cohen-Mansfield, Shmotkin, & Goldberg, 2010; Laitalainen et al., 2010), which aligns with the present finding that higher age was independently associated with SBT nonadoption. In contrast to a previous study (Chevan, 2008), female sex was not associated with participation in training in this study. For older women, group-based training may be even more motivating because of its social component (King, 2001). In addition to more advanced age, the nonadopters had more comorbidities and poorer self-perceived health. They used more drugs with sedative properties and were more often at risk for malnutrition compared with the SBT adopters. This result indicates that the nonadopters had a greater accumulation of health problems. One clinical implication of these results is that many of these barriers, such as the risk of malnutrition and the sedative load of drugs, are treatable. The sedative load of drugs may prevent participation in SBT by increasing tiredness and dizziness and impairing attention. Furthermore, the safety and effectiveness of SBT are questionable if energy or protein intake is lacking. Thus, medication and nutritional assessments and further interventions might be necessary before SBT initiation.

Of the physical functioning measures, low grip strength was a significant independent predictor of nonadoption. Grip strength is a practical measure of sarcopenia (Hairi et al., 2010), and it predicts major mobility disability (Marsh et al., 2011). The functional impairments, chronic diseases, and undernutrition detected among the nonadopters are signs and symptoms of frailty and core elements in the cycle of frailty (Fried et al., 2009). Sarcopenia is a key pathophysiological feature in this cycle because it decreases muscle strength, power, and walking speed and leads to disability and dependency (Fried et al., 2009).

In our study, the nonadopters also demonstrated reduced balance and mobility as assessed by the BBS and the TUG. Our objective measures of balance and mobility support the previous finding that self-rated mobility limitations prevent the initiation of weight training among older community-dwelling adults (Rasinaho et al., 2012). In our study, a higher proportion of nonadopters (39% vs. 21%) used a walking aid. The use of a walking aid or a fall during the past year has shown to limit older adults' participation in strength training or balance-challenging activities (Merom et al., 2012). These factors also make it challenging to go to the gym, especially when combined with the inability to walk 400 m independently, a self-rated functional limitation significantly more common among the SBT nonadopters than the adopters.

One-third of the nonadopters in this study had cognitive impairment (MMSE ≤ 24), and lower cognitive status independently predicted SBT nonadoption. This result is concordant with a previously reported finding that better cognitive function predicts exercise initiation in older adults (Cohen-Mansfield et al., 2010). However, the evidence suggests that SBT may have several benefits for cognitive performance among older adults (Brown, Liu-Ambrose, Tate,

Table 2 Factors Associated with Nonadoption of SBT (*n* = 339)

	Bivariate*	Multivariate
Characteristic	**Odds Ratio (95% Confidence Interval)**	
Female	0.95 (0.58–1.57)	0.93 (0.53–1.61)
Age	1.15 (1.09–1.22)	1.08 (1.02–1.15)
Years of education	0.92 (0.85–0.99)	
Functional comorbidity index	1.15 (1.00–1.32)	
Sedative load ≥ 1	2.16 (1.31–3.57)	1.66 (0.96–2.88)
MMSE	0.82 (0.76–0.89)	0.86 (0.79–0.94)
Self-perceived health		
Good or very good	1	
Average	0.71 (0.44–3.98)	
Poor or very poor	1.94 (0.94–3.98)	
MNA-SF ≤ 11	2.84 (1.42–5.71)	2.09 (0.97–2.88)
IADLS	0.74 (0.64–0.85)	0.90 (0.76–1.07)
Use of a walking aid	1.67 (0.99–2.81)	
BBS	0.96 (0.93–0.99)	
TUG	1.06 (1.02–1.10)	
Grimby physical activity score		
High (4–6)	1	
Moderate (2–3)	1.10 (0.58–2.11)	
Low (0–1)	1.79 (0.90–3.55)	
Grip strength quartile		
4	1	1
3	1.90 (0.98–3.66)	1.59 (0.76–3.32)
2	2.79 (1.42–5.46)	2.48 (1.05–4.50)
1	4.63 (2.30–9.34)	3.28 (1.16–5.74)

Note. SBT = strength and balance training; MMSE = Mini-Mental State Examination; MNA-SF = Mini Nutritional Assessment (short form); IADLS = instrumental activities of daily living scale; BBS = Berg Balance Scale; TUG = Timed Up and Go. On the MMSE, IADLS, and BBS, a higher score represents better performance. *Age- and sex-adjusted bivariate odds ratios.

& Lord, 2009; Liu-Ambrose et al., 2010). In addition, patients diagnosed with dementia may be able to enhance their mobility and physical functioning (Pitkälä, Savikko, Pöysti, Strandberg, & Laakkonen, 2013) and relieve the cognitive and noncognitive symptoms of dementia (Olazaran et al., 2010) by engaging in physical exercise. Cognitive decline leads to the inability to perform instrumental activities of daily living (Marshall et al., 2011). In our study, the inability to perform IADL was associated with SBT nonadoption. Problems performing IADL, such as difficulties with transportation, are most likely considerable barriers for older adults to take part in training outside the home.

Strengths and Limitations

The major strength of this study was the community-based setting. There were as few exclusion criteria as possible, and this study included the oldest participants with several comorbidities to reflect real-life situations. In the GeMS study, the participants underwent a CGA, and their health conditions and medical history were carefully assessed and documented by health care professionals. Objective measures of functional status as well as valid and reliable measures of health determinants were used.

We acknowledge that this study has certain limitations. We found that the weakest participants most in need of the training did not initiate it. Therefore, forms of training other than SBT, including home-based exercises (Ashworth, Chad, Harrison, Reeder, & Marshall, 2005; Liu & Fielding, 2011) and accessible aerobic activities such as walking (Liu & Fielding, 2011), might be needed for the most frail or homebound adults. According to earlier studies, multiple interacting factors determine exercise participation, and these factors have previously been categorized as personal characteristics, program-related factors, and environmental factors (King et al., 1992). The present study focused on health-related factors and aspects of physical functioning that affect SBT adoption; behavioral and psychological barriers or motivators were not addressed in this study.

Conclusions

This study has clarified the role of health-related barriers to SBT adoption in community settings. Several health-related factors and aspects of physical functioning may affect SBT adoption. Age, cognitive status, and grip strength were independent predictors of participation. In the future, more individually-tailored interventions and alternative methods of training will be necessary to overcome these barriers.

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III

HEALTH CONDITION AND PHYSICAL FUNCTION AS PREDICTORS OF ADHERENCE IN LONG-TERM STRENGTH AND BALANCE TRAINING AMONG COMMUNITY-DWELLING OLDER ADULTS

by

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Health condition and physical function as predictors of adherence in long-term strength and balance training among community-dwelling older adults

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ABSTRACT

Aim: Strength and balance training (SBT) has remarkable health benefits, but little is known regarding exercise adherence in older adults. We examined the adherence to strength and balance training and determinants of adherence among ≥75 year old adults.
Methods: 182 community-dwelling individuals (aged 75–98 years, 71% female) began group-based SBT as part of a population-based Geriatric Multidisciplinary Strategy for the Good Care of the Elderly study. Training was offered once a week for 2.3 years. Adherence was defined as the proportion of attended sessions relative to offered sessions. Participants were classified based on their adherence level into low (≤33.3%), moderate (33.4–66.5%) and high (≥66.6%) adherers.
Results: The mean length of training was 19 ± 9 months, and 68% continued participation for at least two years. The mean training adherence was 55 ± 29% for all participants and 18%, 53% and 82% for low, moderate and high adherers, respectively. High adherence was predicted by female sex; younger age; better cognition; independence in Instrumental Activities of Daily Living; higher knee extension strength; faster walking speed; and better performance on the Berg Balance Scale and Timed Up and Go tests. Poorer self-perceived health and the use of a walking aid were related to low adherence.
Conclusions: Long-term continuation of training is possible for older community-dwelling adults, although poorer health and functional limitations affect training adherence. Our findings have implications for tailoring interventions and support for older adults to optimize their exercise adherence.

1. Introduction

Physical activity and exercise promote healthy aging and prevent mobility limitations and disability (Ip et al., 2013). Strength and balance training (SBT) is an important part of the health-enhancing exercise and physical activity guidelines for older adults (American College of Sports Medicine et al., 2009), and also recommended for prevention of falls (Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society, 2011). However, strength and balance training is still relatively uncommon among rapidly increasing older population. In Finland, less than 17% of the adults aged 75–79 years engage in muscle-strengthening activities weekly, and participation even decreases with age (Laitalainen, Helakorpi, & Uutela, 2010).

Low adherence to exercise may threaten the achievable health benefits, but yet little is known about adherence to SBT among older adults. An important issue when implementing exercise interventions is whether the recruited participants can continue the training for a relatively long time and with reasonable frequency. Previous studies have reported high adherence rates in randomized controlled trials (RCTs) where participants have completed more than 70% of their prescribed exercise sessions (Martin & Sinden, 2001; Nyman & Victor, 2012). Most RCTs have

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been conducted with a highly selected sample of older adults, though regular exercise might be most required and effective for those older adults with functional limitations and comorbidities (American College of Sports Medicine et al., 2009; Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society, 2011). Information regarding to older adults adherence to exercise interventions may improve the design and implementation of exercise programs in community-settings (Glasgow, Vogt, & Boles, 1999).

To the best of our knowledge, no study has reported the determinants of adherence to supervised long-term SBT in ≥75 year old adults. Previous studies have reported adherence to shorter-term (Fielding et al., 2007; Sjösten et al., 2007) or home-based exercise interventions (Jette et al., 1998) and assessed self-report measures such as self-efficacy (Koeneman, Verheijden, Chinapaw, & Hopman-Rock, 2011), attitudes (Hawley-Hague et al., 2014) or socioeconomic characteristics (Chevan, 2008) as potential determinants of training adherence. However, the role of health and physical function related factors in predicting SBT adherence has not been reported previously. The aim of this study was to investigate adherence to SBT during a 2.3-year intervention period in a community-based sample of adults aged ≥75 years. We also studied whether health status or performance-based measures of physical function predicted adherence to the SBT intervention.

2. Materials and methods

2.1. Participants

This study is part of a larger project, Geriatric Multidisciplinary Strategy for the Good Care of the Elderly (GeMS), which is a population-based intervention study that evaluated the effects of annual geriatric assessment and optimization of care (Lihavainen et al., 2011). A population-based sample of 1000 people aged ≥75 years who lived in Kuopio, Finland was invited and randomized into an intervention (n = 500) and control group (n = 500). A total of 781 individuals (81 living in residential care facilities) participated in the study. The community-dwelling individuals of the intervention group (n = 339) received physical activity counseling and the opportunity to start SBT. The participants of this study (n = 182) are a subgroup of the intervention group, i.e., those individuals who started the offered SBT intervention. The eligibility for SBT was based on clinical examination by a physician. Exclusion criteria were minimal. Only individuals at high risk of adverse events were excluded. If a participant had acute health condition at the baseline examination, it was possible to start SBT later when the condition was sufficiently controlled. Inclusion criterion was the ability to move independently or with minimal help at the gym. Those participants of the intervention group who did not start the offered SBT (n = 157) were older and had lower health, MMSE score and physical functioning compared to the SBT-initiators analyzed in this study (Aartolahti, Hartikainen, Lönnroos, & Häkkinen, 2014). Only few SBT-initiators (n = 8, 4%) had previously participated in SBT at gym regularly, at least once in a month. The GeMS study was approved by the Research Ethics Committee of Northern Savo Hospital District and Kuopio University Hospital. Written informed consent was obtained from study participants.

2.2. Strength and balance training (SBT)

The individually tailored annual physical activity counseling with the physiotherapist preceded the strength and balance training. Counseling started with a semi-structured interview that charted the participants' current and prior physical activity. Practical and detailed goals for future physical activity were set. Opportunity to participate in group-based SBT was offered once a week between September 2004 and December 2006 and supervised by a physiotherapist. Training was organized in small groups in the city center and was free of charge. Each training session started with combined 15 min warm-up and balance exercises. Progressive strength training included knee extension and flexion, leg press, hip adduction, abduction and extension, and abdominal crunch with gym equipments (Technogym, Italy). The intensity of training was determined by repetition maximum (RM): 60–85% of 1 RM, 2–3 sets and 8–12 repetitions. After a couple of introductory training sessions the prediction of one repetition maximum was done using multiple repetition maximum testing with 3–6 repetitions to failure (Knutzen, Brilla, & Caine, 1999). Progression was accomplished by increasing the load while maintaining the same number of repetitions.

2.3. Adherence

The SBT participation was recorded by the physiotherapist on the training logs at the gym. The total length of training was 2.3 years but the gym was closed on midweek holidays and summer holidays. Thus the number of offered training sessions per participant varied from 94 to 104. Training adherence was measured by the number of training sessions attended relative to the number of training sessions offered, and expressed as adherence percentage. For the statistical analysis, the participants were categorized according to their adherence level: (1) ≤33.3%, low adherers, (2) between 33.3 and 66.6%, moderate adherers, and (3) ≥66.6%, high adherers.

2.4. Comprehensive geriatric assessment

Three trained nurses, two physiotherapists, and two physicians collected the GeMS data. Sociodemographic factors, health status, cognitive and physical functioning, and ability to perform activities of daily living were assessed. The balance, mobility and muscle strength measurements were carried out by the physiotherapists.

2.4.1. Health status

Comorbidity was defined using a modified version of the 18-item Functional Comorbidity Index (FCI) (Groll, To, Bombardier, & Wright, 2005). The FCI takes into account the number of medical conditions, with higher scores indicating greater comorbidity. This study collected data on the following conditions: (1) rheumatoid arthritis and other connective tissue diseases, (2) chronic asthma or chronic obstructive pulmonary disease, (3) Parkinson's disease or multiple sclerosis, (4) osteoporosis, (5) coronary artery disease, (6) heart failure, (7) myocardial infarction, (8) stroke, (9) diabetes, (10) depression, (11) visual impairment, (12) hearing impairment, and (13) obesity.

Cognitive function was assessed using the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975), and depressive symptoms were assessed using the 15-item Geriatric Depression Scale (Sheikh et al., 1991) with scores ≥5 indicating possible depression. Self-rated health was assessed with the following question: "How would you rate your health at the moment?" The participants selected one of five responses. In the analysis, alternatives 1 and 2 (good or very good) and 4 and 5 (poor or very poor) were combined. Hospital admissions were identified from the Finnish National Hospital Discharge Register maintained by the National Institute for Welfare and Health (Sund, 2012).

2.4.2. Physical function

The Berg Balance Scale (BBS) (Berg, Wood-Dauphinee, Williams, & Maki, 1992) and the Timed Up and Go test (TUG) (Podsiadlo & Richardson, 1991) were used to assess balance and basic mobility skills. Maximal walking speed (m/s) was measured for a 10-m distance (Aniansson, Rundgren, & Sperling, 1980). Time was measured with a stopwatch, and the use of a walking aid was allowed in the TUG and walking speed test. One trial in each of these tests was performed. The participants performed the BBS barefoot and other tests using their regular shoes.

Grip strength was measured in kilograms using a Saehan dynamometer (Saehan Corporation, South Korea). The participant was seated, elbow flexed at a 90° angle slightly apart from the body. Two maximal efforts for both hands were allowed, and the best result of the stronger hand was used in the analyses. Maximal isometric knee extension strength with a knee angle 60° was measured in a sitting position using an adjustable dynamometer chair (Good Strength; Metitur Oy, Finland). Participants were allowed three maximal efforts, and the performance with the highest value was accepted as the result.

The ability to perform Instrumental Activities of Daily Living (IADL) was assessed using the Lawton Instrumental Activities of Daily Living Scale (Lawton & Brody, 1969). The level of physical activity was assessed using a modified version of the Grimby scale (Grimby, 1986). The participants were categorized on the basis of their self-rated physical activity into the low-activity group (no other exercise beyond light walking 1–2 times/week), the moderate-activity group (light walking or other light exercise several times/week or moderate exercise 1–2 times/week), or the high-activity group (moderate or vigorous exercise several times/week). Walking aid used for indoor or outdoor mobility was also recorded.

2.5. Statistical analysis

The characteristics of the participants were analyzed using descriptive statistics and were expressed as means and standard deviations (SD), medians with interquartile range [IQR] or as counts with percentages. The statistical comparisons between the three adherence groups were made using analysis of variance (ANOVA) for continuous variables and Kruskal–Wallis test for ordinal descriptive values. Chi-square test was used for variables with discrete distribution. The α-level was set at 0.05.

With the low SBT adherence group as a reference, multinomial logistic regression analyses were conducted to estimate the odds ratios (OR) for determinants of moderate and high adherence levels. The analyses were run for each variable with age and/or sex as covariates. SPSS version 19.0 (IBM, USA) was used to conduct the analyses.

3. Results

The mean age of 182 participants (71% women) was 79.7 (range 75–98) years and the average adherence to SBT was 55 ± 29% (range 1–99%). The adherence level was low in 56 (31%) participants, moderate in 46 (25%) and high in 80 (44%) participants (Table 1). The mean adherence within these three groups was 18 ± 10, 53 ± 9 and 82 ± 7% for low, moderate and high adherers, respectively. Seven low adherers died and 6 participants (4 low, 2 moderate adherers) moved to institutional care facilities during the intervention.

Table 1
Characteristics of participants (n = 182) by strength and balance training adherence level.

		Low (n = 56)	Moderate (n = 46)	High (n = 80)	p-value
Demographics					
Female, N (%)		35 (63)	32 (70)	63 (79)	0.11
Age, years, mean ± SD		81 ± 4.7	80 ± 4.1	79 ± 2.7	0.001
Education years[a], med [IQR]		6 [6, 7]	7 [7, 9]	7 [7, 11]	0.02
Health status					
Functional Comorbidity Index, mean ± SD		2.1 ± 1.6	2.9 ± 1.7	1.7 ± 1.1	<0.001
Coronary artery disease, N (%)		23 (42)	26 (58)	22 (28)	0.004
Heart failure, N (%)		9 (16)	9 (20)	5 (6)	0.06
Diabetes, N (%)		5 (9)	22 (10)	5 (6)	0.02
GDS-15 ≥5, N (%)		5 (9)	3 (7)	2 (3)	0.23
BMI >30, N (%)		10 (18)	10 (22)	24 (30)	0.24
MMSE, mean ± SD		27 ± 3.2	27 ± 2.1	28 ± 2.0	0.02
Self-rated health, N (%)	Poor/very poor	10 (18)	3 (7)	2 (3)	0.03
	Moderate	24 (43)	24 (52)	40 (50)	
	Good/very good	22 (39)	19 (41)	38 (48)	
Physical function					
Physical activity, N (%)	Low	18 (32)	15 (33)	18 (23)	0.66
	Moderate	27 (48)	23 (50)	43 (54)	
	High	11 (20)	8 (17)	19 (24)	
IADL, mean ± SD		6.6 ± 1.7	7.2 ± 1.1	7.6 ± 0.9	<0.001
Grip strength (kg), mean ± SD	Men	33 ± 11	33 ± 7	41 ± 9	0.02
	Women	21 ± 6	20 ± 5	22 ± 5	0.13
Knee extension strength (N)[a], mean ± SD	Men	359 ± 102	410 ± 73	457 ± 120	0.02
	Women	248 ± 88	253 ± 91	276 ± 65	0.19
Walking speed(m/s), mean ± SD		1.2 ± 0.4	1.3 ± 0.4	1.4 ± 0.3	0.002
Berg Balance Scale (p), mean ± SD		48 ± 8.4	49 ± 8.0	53 ± 3.0	<0.001
Timed Up and Go (s), mean ± SD		14.0 ± 7.8	11.9 ± 5.3	9.7 ± 3.0	<0.001
Chair rise (s), mean ± SD		16.8 ± 5.9	15.9 ± 5.8	15.0 ± 4.5	0.18
Walking aid users, N (%)		18 (32)	14 (30)	7 (9)	0.001
Hospital admission during offered training					
Persons, N (%)		39 (70)	38 (83)	34 (43)	<0.001
Number of admissions, med [IQR]		3 [2, 6]	2 [1, 4]	2 [1, 3]	0.02
Number of inpatient days, med [IQR]		21 [6, 62]	13 [2, 40]	5 [2, 9]	<0.001

BMI: Body Mass Index, GDS-15: Geriatric Depression Scale, MMSE: Mini-Mental Scale Examination, IADL: Instrumental Activities of Daily Living.
[a] Missing value n = 2.

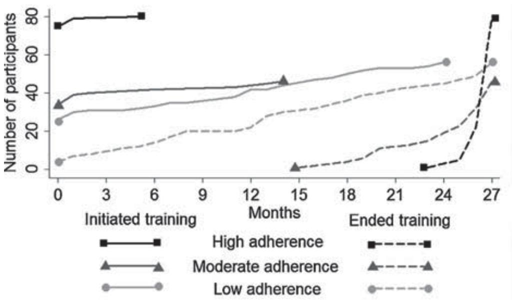

Fig. 1. Initiation and cessation of training by high ($n = 80$), moderate ($n = 46$), and low ($n = 56$) training adherence levels. The *x*-axis describes the time since the beginning of the intervention program in months.

The average length of the individual training periods was 19 ± 9 months (range 1–120 weeks). Part of low adherers initiated training even during the second year of intervention (Fig. 1), and their average length of participation in SBT was 7 ± 6 months. High and moderate adherers continued training for 26 ± 1 and 22 ± 5 months, respectively. By month 24 of the training intervention, 123 participants (68%) were still attending in SBT.

Compared to low and moderate adherers, the high adherers were younger, had longer education, fewer comorbidities, better self-rated health and higher MMSE scores (Table 1). The proportion of participants with cognitive impairment (MMSE ≤24) was 16% in the low, 11% in the moderate and 5% in the high adherence group ($p = 0.10$). Comorbidity was highest among moderate adherers, and 83% of them were hospitalized during the SBT intervention, whereas the number of hospital admissions and inpatient days were the highest among low adherers. The high adherers performed better in IADLs and all balance and mobility tests, except for chair rise test. Men in the high adherence group had the highest grip and knee extension strength levels but in women, there was no difference in any strength levels according to adherence groups.

In the age and sex adjusted analysis with low adherence as a reference (Table 2), higher FCI and IADL score predicted moderate adherence to SBT. High adherence was predicted by female sex, younger age, higher MMSE score and knee extension strength, and better IADL, walking speed, BBS and TUG test performance. Poor or very poor self-rated health and the use of a walking aid lowered the probability of high adherence.

4. Discussion

This study was one of the first community-based studies reporting on adherence to long-term SBT intervention in older adults aged ≥75 years, and assessing the role of health and physical function related factors in predicting SBT adherence. We found that long-term SBT was possible for older adults, and approximately two thirds of the SBT-initiators continued the training for over two years. High adherers comprised almost a half of the SBT-initiators, and they attended on average to three of four SBT sessions monthly. The moderate adherers attended to a half and low adherers to a fifth of the offered SBT sessions. The results reflected both the possibilities and challenges in implementing long-term exercise programs for older adults with great disparities in health and physical functioning.

The mean adherence (55%) in this community-based study is lower compared to the majority of supervised fall prevention (73–89%) (Nyman & Victor, 2012) or strength and flexibility exercise programs (87%) (Martin & Sinden, 2001) investigated in RCTs. Longer-duration RCTs (12 months) have shown lower adherence rates compared to shorter trials (2–4 months) (Nyman & Victor, 2012). However, the mean adherence in the moderate adherers (53%) in our study is comparable to the adherence (50%) among sedentary 70–89 year old adults who participated in a weekly center-based physical activity intervention (Fielding et al., 2007). Although comorbidities and functional limitations among the present participants were common due to population-based sampling, the dropout rate due to death or institutionalization was low. Given that the participants were community-dwelling ≥75 year old adults, the fact that 68% of them continued training for over two years may be considered fairly promising. Our finding that advanced age was related to lower adherence is consistent, while the positive association between female sex and higher adherence was in contrast to earlier findings (Chevan, 2008; Sjösten et al., 2007). This may be due to the difference in the intervention or sample characteristics.

In our study, slow walking speed, decreased performance in balance tasks and the use of a walking aid decreased the probability of high adherence. Simple measures of physical functioning, such as walking speed, BBS and TUG may thus be used to detect those older adults who need more individualized guidance and support to maintain SBT. Return to a physical activity program after acute illness or hospitalization may be difficult

Table 2
Age and sex adjusted associations with moderate and high adherence to strength and balance training (reference category: low adherence).

		Moderate adherence ($n = 46$)			High adherence ($n = 80$)		
		OR	95% CI	*p*-value	OR	95% CI	*p*-value
Female sex		1.55	(0.66–3.65)	0.31	2.83	(1.30–6.58)	0.01
Age		0.93	(0.84–1.03)	0.14	0.81	(0.73–0.90)	0.001
Functional Comorbinity Index		1.38	(1.05–1.81)	0.02	0.79	(0.60–1.03)	0.08
MMSE		1.04	(0.89–1.20)	0.65	1.21	(1.03–1.42)	0.02
Self-rated health	Good/very good	1			1		
	Moderate	1.09	(0.47–2.54)	0.84	0.87	(0.40–1.89)	0.72
	Poor/very poor	0.34	(0.81–1.45)	0.15	0.13	(0.03–0.68)	0.02
Hand grip strength		0.98	(0.92–1.04)	0.48	1.05	(0.99–1.11)	0.10
Knee extension strength[a]		1.00	(1.00–1.01)	0.36	1.01	(1.00–1.01)	0.02
IADL		1.31	(0.96–1.78)	0.09	1.67	(1.17–2.37)	0.01
Time to walk 10 m		0.95	(0.86–1.05)	0.33	0.77	(0.65–0.90)	0.001
Berg Balance Scale		1.03	(0.97–1.08)	0.35	1.22	(1.10–1.35)	<0.001
Timed Up and Go		0.96	(0.89–1.02)	0.19	0.82	(0.73–0.92)	0.001
Walking aid user		1.00	(0.40–2.49)	1.00	0.24	(0.09–0.67)	0.01

MMSE: Mini-Mental Scale Examination, IADL: Instrumental Activities of Daily Living.
[a] Missing value $n = 2$.

especially for those sedentary older adults with mobility limitations (Phillips et al., 2010). The majority of participants had one or more hospital admissions during the intervention period and in particular, the low adherers had long hospital stays. In addition, higher independence in IADLs predicted high adherence. This longitudinal study with objective measures confirms the recently reported cross-sectional relationship that those with functional limitations are less likely to meet the recommendations for strength training (Kraschnewski et al., 2014).

To some extent, in our study, disease management and health promotion may have served as motivators for exercise similarly to the results reported by Rasinaho, Hirvensalo, Leinonen, Lintunen, and Rantanen (2007). The baseline multidisciplinary comprehensive geriatric assessment by health professionals as well as the annual follow-ups and supervised training may have encouraged the older adults with comorbid conditions to adopt a new regular physical activity habit. This support may partly explain that those with a moderate adherence level had a higher average number of comorbidities than those with low adherence level. Thus, clinicians should not let the mere number of medical conditions determine who would be able to participate in SBT. Instead, self-rated health has reported to play more important role in SBT adherence than the number of comorbidities (Dogra, 2011). Also in our study, the poor self-rated health decreased the probability of high SBT adherence by 87%.

Previous studies have reported that older adults with cognitive impairment had lower maintenance of participation in exercise programs with only 25% continuing exercise longer than one year (Tak, van Uffelen, Paw, van Mechelen, & Hopman-Rock, 2012). In our study, better cognition predicted high SBT adherence. Although cognitive impairment might result to some challenges in SBT participation, promotion of such activities for older adults would deserve special attention because of the potential benefits. According to systematic reviews exercise interventions enhance mobility (Pitkälä, Savikko, Pöysti, Strandberg, & Laakkonen, 2013) and may improve the ability to perform activities of daily living (Forbes, Forbes, Blake, Thiessen, & Forbes, 2015) among people with dementia. In recently published RCT high intensity supervised progressive resistance training improved cognition among participants with mild cognitive impairment (Fiatarone Singh et al., 2014).

The main strength of the current study was the community-based setting. This study included older adults with a wide range of health and functioning reflecting real-life situations. Moreover, objective measures of functional status as well as valid and reliable measures of health determinants were used as part of the comprehensive geriatric assessment carried out by health care professionals. The long intervention period enabled the assessment of long-term adherence. In the analyses we used adherence as a categorical outcome variable. Contrary to linear analysis, this made it possible to use three categories that described the high variability in adherence precisely. High adherence category represented a probably efficient level of adherence, i.e., regular exercisers without long-term interruptions who attended at least two thirds of the offered training sessions.

In conclusion, this study demonstrated that community-dwelling older adults, 75 years and older, were able to continue regular SBT for more than two years, despite hospital admissions, comorbidities and functional impairments. Although long-term continuation of training is possible for older adults, health and functional status plays an important role in training adherence. Therefore, additional support and alternative training options are needed to serve the older adults with limiting conditions, such as cognitive or mobility impairments.

Conflict of interest

No potential conflicts of interest were disclosed.

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IV

EFFECTS OF LONG-TERM TRAINING ON MUSCLE STRENGTH AND MOBILITY IN ADULTS AGED 75 AND OLDER

by

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