STUDIES IN SPORT PHYSICAL EDUCATION AND HEALTH 101

Sanna Sihvonen

POSTURAL BALANCE AND AGING

Cross-sectional Comparative Studies and a Balance Training Intervention

Esitetään Jyväskylän yliopiston liikunta- ja terveystieteiden tiedekunnan suostumuksella julkisesti tarkastettavaksi yliopiston liikunnan salissa L304 syyskuun 29. päivänä 2004 kello 12.

Academic dissertation to be publicly discussed, by permission of the the Faculty of Sport and Health Sciences of the University of Jyväskylä, in the Auditorium L304, on September 29, 2004 at 12 o'clock noon.

UNIVERSITY OF JYVÄSKYLÄ

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Publishing Unit, University Library of Jyväskylä

Cover picture by Metitor oy

URN:ISBN 951391920X
ISBN 951-39-1920-X (PDF)

ISBN 951-39-1894-7 (nid.)
ISSN 0356-1070

Jyväskylä University Printing House, Jyväskylä 2004

ABSTRACT

Sanna Sihvonen
Postural balance and aging: Cross-sectional comparative studies and a balance training intervention
Jyväskylä: University of Jyväskylä, 2004, 65 p.
(Studies in Sport, Physical Education and Health
ISSN 0356-1070; 101)
ISBN 951-39-1920-X
Finnish Summary
Diss.

This study was undertaken to gain knowledge about postural balance across different age groups of men and women aged 8-93 years and between middle-aged and older female fallers and non-fallers aged 50-68 years. In addition, the effects of balance training on postural balance and falls were investigated among frail older women living in residential care.

In cross-sectional comparative studies postural balance was measured using standardized force platform balance tests assessing body sway in various standing positions. In the balance training study the exercise group participated in visual feedback-based balance training for four weeks three times a week. Balance measurements were carried out before and after the training period. The dimensions of balance function studied were standing body sway, dynamic weight shifting and functional balance test performance (Berg Balance Scale). After the training period one year fall surveillance was carried out.

The balance measurements in various age groups showed a U-shaped dependency between body sway and age, indicating that children and older adults had higher body sway compared to the middle-aged subjects. Among middle-aged and older subjects men showed higher sway velocities than women. No significant differences were detected in postural balance between middle-aged and older female fallers and non-fallers. In younger fallers aged 50-58 years health-related problems and use of medication were commoner than in non-fallers. Among frail older women improvements in postural balance after balance training were found. Moreover, a significant reduction in the monthly risk of falling was demonstrated in the training group.

A deeper understanding of balance behavior across the life span can be helpful in preventing and treating balance impairments among older adults. The results of the intervention study indicate that balance training may be a useful strategy in balance rehabilitation and fall prevention among older women with health limitations.

Key words: postural balance, aging, balance differences between age groups, body sway, balance training, frail older women, falls

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ACKNOWLEDGEMENTS

I have had the privilege to complete this thesis under supervision of Docents Pertti Era and Sarianna Sipilä who are dedicated and proficient researchers and excellent teachers. I am indebted to you for guiding me during these years. Thank you for your encouragement and wise advice that have carried my work forward. I highly esteem your expertise that you shared during our constructive and enjoyable discussions.

I would like to express my warmest gratitude to the official examiners of this thesis Assistant Professor Karim Khan and Assistant Professor Stephen Lord for their speedy examination and valuable comments on the manuscript.

I wish to direct my sincere thanks to all participants of the studies included, particularly residents and staff of Viitaniemi and Sammonkatu care facilities who generously took part in the study and helped with the practical arrangements of the intervention.

Mr. Timo Törmäkangas, Mr. Markku Kauppinen and Mr. Jukka Jokela have kindly answered my questions concerning statistical methods. Thank you for your help. I am grateful to Mr. Michael Freeman for revising the English language of this thesis. Ms. Anna Rantanen has helped me with the final lay out of this thesis and has offered advice in many practical matters, I very much appreciate that. Mr. Mika Kyllönen from Metitur Oy is thanked for offering technical help with the measurement device whenever needed.

My very special thanks are due to my colleagues and fellow doctoral students at the Department of Health Sciences for the cooperation and creating a friendly working atmosphere. Writing an academic thesis is demanding but you have made it also fun. Many good memories will follow me. I sincerely thank PhD Raija Leinonen for the warm friendship and pushing me forward during the course of this work. Your helping hand has always been very close.

This book is dedicated to my parents Kaisa and Pentti Sihvonen. I cannot thank enough for your love and care. I remember with warm thoughts my father who would have been delighted that I completed this challenge. I am also grateful to my sister and her family for their support.

I thank very warmly my husband Hannu for your love and support. It is a pleasure to have a family where everybody is willing to do their share. My children Roope and Saara are thanked for tolerating well the sometimes busy schedules. You remind me what is really important in life.

This work has been supported by personal grants from Ministry of Education in Finland, Juho Vainio Foundation, Graduate School for Aging, Technology and Well-being, and University of Jyväskylä.

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on following papers, which will be referred to by their Roman numerals.

I Sanna Sihvonen, Sarianna Sipilä, Pertti Era. Postural balance in female and male subjects aged 8 to 93 years: A cross-sectional comparison. Submitted for publication.

II Sanna Sihvonen, Pertti Era, Markku Helenius. 2004. Postural balance and health-related factors in middle-aged and older women with injurious falls and non-fallers. Aging. Clinical and Experimental Research 16, 139-146.

III Sanna Sihvonen, Sarianna Sipilä, Pertti Era. 2004. Changes in postural balance in frail elderly women during a 4-week visual feedback training: A randomized controlled trial. Gerontology 50, 87-95.

IV Sanna Sihvonen, Sarianna Sipilä, Sara Taskinen, Pertti Era. 2004. Fall incidence in frail older women after individualized visual feedback based balance training. Gerontology 50, 411-416 (in press).

1 INTRODUCTION

The ability to control postural balance is an important determinant of mobility across the whole range, from the performance of basic daily tasks to competitive sports. Problems in balance are commonly reported by older people, and impairments in balance with advanced age have been described using both clinical and laboratory balance measures. Among older adults good balance has been associated with independence in daily activities, whereas poor balance has been found to be strongly associated with an increased risk of falls. Deterioration in balance may contribute to fear of falling and a decrease in physical activities which in turn may lead to a vicious cycle of inactivity-related disability. Awareness of the important role of postural balance in maintaining a physically mobile and independent life style among older people has lead to an increased interest in the development of methods to assess and treat poor balance.

The maintenance of balance is a complex physiological process involving the interaction of many body subsystems and taking into account the requirements of the task and the environment. Neuromuscular and musculoskeletal components are important for the control of the body's position and motor output. Sensory systems consisting of visual, vestibular and somatosensory components coordinate the information regarding the body's position relative to gravity and the environment and positions of body parts in relation to each other. Central nervous system processes (cognitive and non-cognitive) are also needed for adaptive and anticipatory aspects of balance control.

The ability to control postural balance may decline with increasing age because of the deterioration in sensory systems, motor control and muscle strength and power. Older adults with balance impairments may not be able to meet the challenges they are faced with during daily life in situations requiring adaptability to tasks and environments. In addition, higher morbidity and increased use of medication with advancing age have been shown to influence the maintenance of balance.

Current research seeks to explore the impact of age-related changes, diseases and medications and investigate the effects of training methods to improve postural balance. Many measures ranging from simple functional tests to high tech equipment have been used to assess balance among older people. However, no general agreement has been reached about the method or parameters to be used to describe balance abilities. Because of the lack of standardized measurements inconsistent results have been reported in relation to the occurrence of age-related changes in balance. In addition, there continues to be inconsistency regarding possible gender differences in postural balance.

Usually balance assessments serve several purposes, such as giving quantitative description of ability, monitoring subject's progress over time and evaluating the effectiveness of interventions in clinical practice or research (Alexander 1994, Woollacott & Shumway-Cook 1996). Technical devices such as computerized force platforms measuring the body sway have been used to obtain quantitative and objective data about a subject's performance. It has been suggested that the identification of specific impairments contributing to balance problems in older persons may also facilitate the implementation of effective training strategies aimed at improving balance control (Lord et al. 1996).

Falling and injuries related to falls are a serious problem for older people; constituting a major threat to their mobility and independence, and at worst a cause of death. The rising number of older persons sustaining falls and injuries imposes a high economic burden on society through the provision of additional services. Because poor balance is a known risk factor for falls, investigating methods to improve balance and prevent falling among older people is a high priority issue.

Recent studies (Campbell et al. 1997, Campbell et al. 1999, Rose & Clark 2000, Robertson et al. 2001, Day et al. 2002) have reported positive effects from specifically designed balance training programs on postural balance and fall incidence among community-dwelling older adults. However, it is not well known whether balance training is effective among frailer, institutionalized older people. Among them the decrements in balance and falls are even more common than in community-dwelling older adults. Only few studies using multifactorial prevention programs have demonstrated positive results in fall prevention among older people living in residential care or nursing homes (Ray et al. 1997, Jensen et al. 2002). Furthermore, it remains unclear what kind of training would be the most effective in improving balance and whether training improving balance reduces fall incidence among frail older people who suffer from multiple health limitations. Fall-prevention strategies adapted for this population should be designed and their effectiveness tested using randomized controlled trials.

2 REVIEW OF THE LITERATURE

2.1 Postural balance across the life span

The ability to maintain balance develops during childhood and may decline later during one's life span for several reasons (Woollacott & Shumway-Cook 1990). Age-related changes may occur in sensory systems, in the use of sensory strategies, in peripheral and central nervous system function, in musculoskeletal structure or in the production of postural corrections. These age-related changes in subsystems involved in balance control contribute to the poorer balance performance of older adults compared with younger people (Teasdale et al. 1991, Alexander 1994, Gu et al. 1996, Woollacott & Shumway-Cook 1996, Camicioli et al. 1997).

Because of the complexity of the postural control system, several methods for measuring postural balance among individuals at different ages have been developed. Clinical tests consisting of series of standing positions with increasing difficulty and functional tests including tasks related to daily living have been commonly used (Tinetti 1986, Berg et al. 1989). During the past 20 years the development of technological solutions such as computerized force platforms, video analysis, and electromyography (EMG) has made it possible to measure balance quantitatively and to identify possible factors contributing to balance impairments (Woollacott 2000). The rising awareness of the importance of maintaining good balance control with advancing age has led to increased emphasis on the development of methods to assess balance and on the collection of data throughout the life span to better understand balance behaviour and treat problems related to it.

2.1.1 Cross-sectional comparisons of postural balance

The association of postural balance and age has often been investigated by cross-sectional studies. The cross-sectional design is an economical way of studying differences across a wide age spectrum and is the most useful in practice. However, the results of such designs may be affected by several factors such as lifestyle and occupation. The influence of heritability may also differ depending on the age group. Several cross-sectional studies have found differences in body sway between age groups, indicating that older adults show increased sway compared to young adults (Sheldon 1963, Era & Heikkinen 1985, Stelmach et al. 1989, Hytönen et al. 1993, Prieto et al. 1996). On the other hand, some studies have shown only subtle differences with increasing age in easy test conditions such as normal standing with eyes open and with eyes closed (Ekdahl et al. 1989, Teasdale et al. 1991, Wolfson et al. 1994, Hurley et al. 1998) or no significant differences at all (Panzer et al. 1995). Clearer differences between age groups have been demonstrated in more difficult test conditions by diminishing the base of support, altering sensory input or using perturbations (Shepard et al. 1993, Whipple et al. 1993, Lord & Ward 1994, Gu et al. 1996, Perrin et al. 1997, Thelen et al. 1997, Hurley et al. 1998, Choy et al. 2003). Most cross-sectional studies have compared balance performance between younger and older adults but only a few previous studies have attempted to describe differences between age groups across the life span (Sheldon 1963, Hytönen et al. 1993). Often subjects belonging to the extreme ends of the life span have been excluded.

Studies with fairly large numbers of subjects representing a wide age spectrum have shown differences between age groups. Sheldon (1963) reported that subjects in the age groups 6-14 years and 50-80 years had greater difficulty in minimizing sway compared to those in the midrange of the age spectrum. Body sway was measured using a pencil attached to a subject by a metal frame. In a study by Hytönen et al. (1993) 212 subjects from 6 to 90 years of age were divided into six age groups containing both males and females. This study, using the force platform method, suggested a U-shaped dependency between sway velocity and age indicating, that children and the oldest adults swayed most, whereas those aged 46-60 showed the greatest stability. Only minor changes were observed between ages 30-60. Recently, Choy et al. (2003) reported a cross-sectional study measuring postural stability by the force platform method in 453 women aged 20 to 80 years. This study showed that women in their 60s and 70s were more unstable than younger women when standing eyes closed on a firm surface. When standing on foam with eyes closed women in their 50s had increased sway compared to the younger ages and significantly higher sway was seen in women in their 60s and 70s compared to the younger age groups. These results support earlier findings where increased sway with increasing age has been associated with somatosensory changes (Lord et al. 1991, Lord & Ward 1994, Hurley et al. 1998).

2.1.2 Longitudinal changes in postural balance

In order to ascertain the effects of age on balance ability longitudinal study designs would be needed. Until now, only a few studies describing changes in postural balance over time among older adults have been published. Longitudinal designs demand high resources and in practice are more difficult to carry out compared to cross-sectional studies. Thus only few studies have been published and the follow-up times have been relatively short, ranging from 3 to 5 years. Onder et al. (2002) reported a 26.6% decline over 3 years in a timed standing balance test in disabled women (mean age 78.9 years) living in the community. Two studies have shown significantly increased sway, measured by force platform systems, over follow-ups of 3 (Baloh et al. 1998) and 5 years (Era et al. 2002) in subjects initially 75-79 years old. Further, Era et al. (2002) demonstrated that the longitudinal decline in balance from the age of 75 to 80 years was greater than the cross-sectional difference between subjects 75 and 80 years of age. In addition, this study showed that at high ages poor performance in balance tests may indicate below-average survival.

2.1.3 Postural balance in females and males

The presence of gender differences in postural balance remains unclear. Some studies have suggested that men sway significantly more than women (Juntunen et al. 1987, Era et al. 1997), but contrasting results have also been found (Overstall et al. 1977). Some others have not found significant differences between the sexes (Brocklehurst et al. 1982, Suomi & Kojeca 1994, Kinney LaPier et al. 1997). It is assumed that differences in study populations, measurement settings, and outcome parameters partly explain the variation in results between studies in relation to age and sex differences.

It has been suggested that a failure to account for anthropometric differences between men and women may also contribute to the inconsistent findings across studies (Kinney LaPier et al. 1997, Chiari et al. 2002). In the inverted pendulum model, a longer lever arm, e.g. taller body height, would cause greater amplitude of movement than a shorter body height (Era et al. 1996). Several studies have normalized sway results by expressing results relative to the body height or foot length, which have shown a tendency to reduce gender differences (Maki et al. 1990, Era et al. 1996, Chiari et al. 2002). In addition, other body properties such as body mass and the location of the body's centre of gravity are assumed to have an effect. Era et al. (1996) observed slower sway velocity in older women with higher body mass. It has been suggested that body characteristics may influence the boundaries of individual postural stability, and this variability may affect the selection of motor strategies to maintain postural balance (Woollacott & Shumway-Cook 1990). Differences in such physiological properties as peripheral sensation, muscle strength and hormonal factors are also assumed to contribute to the conflicting results between the sexes (Era et al. 1986, Lindle et al. 1997, Naessen et al. 1997).

2.1.4 Postural balance in fallers and non-fallers

The identification of groups at risk for falling is important in targeting preventive strategies for those in the high risk categories (Gardner et al. 2000). Numerous studies have shown significant differences in balance performance between older fallers and non-fallers indicating that poor balance abilities are found in fallers (Tinetti et al. 1988, Campbell et al. 1989, Topper et al. 1993, Lord & Clark

1996, Stel et al. 2003). The ability of different balance tests, both clinical and laboratory, to show differences between fallers and non-fallers varies depending on the study designs and populations studied (Maki et al. 1994, Lord et al. 1999, Brauer et al. 2000, Boulgarides et al. 2003). Both retrospective and prospective designs have been used in the effort to find balance tests and parameters of assistance in identifying persons with a high risk for falling. In addition, differing risk factors among persons with different levels of mobility have been found (Thapa et al. 1996, Lord et al. 2003b). It has been suggested that fall-prevention interventions should be targeted at older adults in residential care who can stand unaided but have multiple risk factors for falls (Lord et al. 2003b).

Some studies have demonstrated that low scores in clinical balance tests such as the Berg Balance Scale and the Tinetti Balance subscale can predict older fallers (Tinetti et al. 1988, Bogle-Thorbahn & Newton 1996). However, others have not found clinical tests to be successful in predicting fallers among community-dwelling older adults (Brauer et al. 2000, Boulgarides et al. 2003). Topper et al. (1993) found the measurement of postural sway during quiet standing to be predictive of falls among older adults in assisted living facilities. Among community-dwelling older adults, in particular, aspects of lateral stability in sway measurements have shown to be predictive of falls (Maki et al. 1994, Williams et al. 1997, Lord et al. 1999). To enhance the early detection of fallers the ability of balance tests to discriminate between younger fallers and non-fallers should also be studied.

2.2 Age-related changes in postural control systems

Postural balance can be viewed as a motor skill that the neuromuscular system learns to accomplish using many systems: passive biomechanical elements, several sensory modalities, muscles and joints, and the central nervous system (Woollacott & Shumway-Cook 1990, Shumway-Cook & Woollacott 1995, Pollock et al. 2000). The continuous process of postural control is demonstrated in Figure 1. Sensing the position of body relative to gravity involves combinations of visual, vestibular, and somatosensory inputs. The body movements used to maintain postural balance can vary from simple contractions to complex series of movements depending on the demands of the task and the environment. Central adaptive processes are needed to modify the sensory and motor components so that stability can be maintained under changing conditions. Research on the systems involved in postural control has shown that age-related changes may occur within or between the subsystems involved in postural control and these decrements contribute to the deterioration in balance abilities seen among older adults (Alexander 1994).

Many visual functions deteriorate with increasing age and it has been shown that visual impairment could initiate the pathway to physical disability (Salive et al. 1994). The changes in visual function induced by aging include degeneration of the retina, crystalline lens opasification, progressive optical aberrations and loss of pupillary reactivity that alter the way in which the visual signal is propagated to the retina (Bonnel et al. 2003). Such reductions in visual acuity and contrast sensitivity cause problems in contour and depth perception, which are critical for postural control. Furthermore, neuronal cell loss and alterations in the kinetics of rod function have been shown to result in delayed dark adaptation among older adults (Owsley et al. 2000). Despite of the deterioration of many visual functions with aging, increased dependence on visual inputs for controlling balance in older people has been reported (Horak et al. 1989, Whipple et al. 1993, Perrin et al. 1997, Speers et al. 2002). If a balancing task becomes more demanding, as during surface–referencing in sensory organization testing, visual information is increasingly relied upon (Brandt et al. 1986).

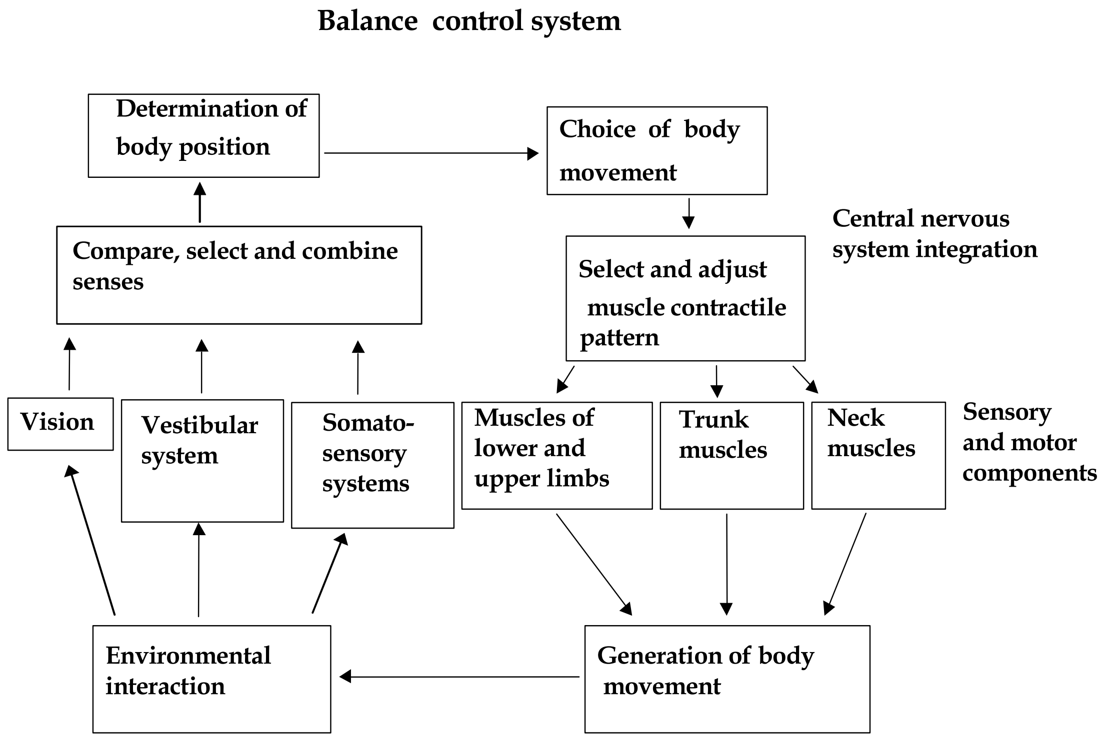

FIGURE 1 The process model of postural control (modified from Allison 1995).

Sundermier et al. (1996) reported over-reliance on visual cues for postural control in a group of older adults with balance deficits compared to a group of healthy young people. It has been proposed that visual input cannot fully compensate for impairment in proprioception (Bergin et al. 1995).

Structural, age-related decreases in vestibular organs, such as reduction in the number of hair cells in both the canals and the otolith organs, and in the number of nerve fibers, cause alterations in vestibular function (Rosenhall 1973, Rosenhall & Rubin 1975). A major role of the vestibular system is the stabilization of the head (Pozzo et al. 1990), and it is assumed to provide an orientation reference against which other systems may be compared and calibrated (Keshner & Cohen 1989). A loss of vestibular function with increasing age may cause this reference to be more unreliable. This may lead to problems dealing with conflicting information coming from the other sensory systems (Manchester et al. 1989, Teasdale et al. 1991). It has been shown that in response to postural disturbances older adults may not be able to stabilize their head as well as young adults (Alexander et al. 1992). It may also explain why older adults with vestibular deficits experience dizziness and unsteadiness when they are confronted with conflicting visual and somatosensory information (Woollacott 2000).

Regulation of postural balance is also dependent on information from the proprioceptive and mechano-receptive organs. Several aspects of proprioception such as position sense and movement detection threshold have been found to deteriorate due to aging (Skinner et al. 1984, Horak et al. 1989, Robbins et al. 1995). This impaired proprioception has been linked with balance problems which in turn have been associated with the higher risk of falls in older adults (Woollacott et al. 1986, Horak et al. 1989, Manchester et al. 1989, Teasdale et al. 1991, Lord & Ward 1994, Lord & Clark 1996). The deterioration in function of proprioceptive receptors located in muscles, tendons and joints affect postural control through diminished information about the position of the limbs and body to each other and the distension of muscles (Quaniam et al. 1995). These losses increase the threshold for movement detection and decrease precision in reproducing joint angles, leading to poorer balance control (Hay et al. 1996, Thelen et al. 1998, McChesney & Woollacott 2000). Receptors in cutaneous and subcutaneous tissue, particularly pressoreceptors in the sole of the foot derive exteroceptive information, and hence less accurate input with aging may cause difficulties in maintaining balance (Pyykkö et al. 1988, Latash 1998). It has been suggested that one in five older persons would show evidence of peripheral neuropathy (Richardson et al. 1996).

The inputs from sensory systems trigger a response in central nervous system which selects, coordinates and compares the information and initiates the appropriate corrective postural responses (Dietz 1992). The sensory systems provide redundant information so that normally an individual is able to compensate for a partial loss of one of these systems by relying more heavily on the remaining ones (Woollacott et al. 1982). Along with deterioration in sensory input the ability to weigh conflicting information from sensory sources and select optimal responses may alter with increasing age (Horak & Nashner 1986).

Thus, older adults often exhibit problems with adapting their use of sensory inputs to varying task and environmental situations such as walking in dimly lit areas or on unusual support surfaces like ramps, thick carpets or grass (Woollacott & Tang 1997).

The motor responses needed to control balance may involve monosynaptic reflexes, the fastest possible corrections to changes in balance, long latency synergistic motor responses and voluntary postural movements (Allum & Keshner 1986). With ageing the performance of tasks requiring central nervous system processing are slowed, with particular slowing in information integration and in response preparation processes (Salthouse & Somberg 1982). This slowing of motor skills may be critical in maintaining balance, particularly in challenging situations (Horak & Nashner 1986). Differences between young and older adults in producing motor responses for maintaining balance have been found. Research on movement strategies has indicated that three different kinds of reactive postural responses exist: an ankle strategy, a hip strategy and a stepping strategy (Horak & Nashner 1986). It has been suggested that the ankle strategy is used to compensate for small amounts of sway whereas the strategy involving higher amounts of movement at the hip joint is used to compensate for larger shifts of the body's center of gravity (Horak & Nashner 1986, Woollacott & Shumway-Cook 1996). When perturbation displaces the center of gravity beyond the limits of stability, the stepping strategy is used in order to avoid a fall. It has been shown that older adults tend to use the hip strategy in conditions where young adults rely on the ankle strategy, indicating that decreased muscle strength or reduction in the range of movement or in sensation around ankle joint will lead to a different response (Manchester et al. 1989, Shumway-Cook & Woollacott 1995). Age-related changes in the ability to activate muscle response strategies in an anticipatory manner have been noted. Longer onset latencies in postural muscles, as well as altered activation patterns and contraction amplitudes have been found in older compared to young adults (Inglin & Woollacott 1988, Stelmach et al. 1989).

During recent years more attention has been paid to aspects of consciousness such as attention, cognition and memory that are important for optimal balance function. According to the findings of Shumway-Cook et al. (1997b) in subjects with balance deficits even very simple cognitive tasks can have further impact on balance skills. It has been suggested that with ageing these processes may not integrate as well and/or quickly, with the result that in order to maintain balance and avoid falling older people may have to give a greater proportion of their attention to maintaining their balance during activities (Woollacott & Shumway-Cook 2000). The "stops walking when talking" phenomenon reflects this difficulty (Lundin-Olsson et al. 1997).

The decrease in muscle strength with increasing age, particularly in the lower extremities, has been well established (Larsson et al. 1979, Porter et al. 1995, Rantanen et al. 1997, Hughes et al. 2001). In the isometric and concentric strength tests persons in their 70s or 80s show on average a 20 to 40% lower strength levels compared to young adults, and in the group of very old people even greater reduction is seen. Reductions in power and muscle explosive force capacity with age might influence postural abilities in older persons, particularly responses to sudden, severe perturbations (Larsson et al. 1979, Porter et al. 1995, Skelton et al. 2002). Whipple et al. (1987) found that in fallers the strength of the dorsiflexors of the ankle was 7.5 times less than in the group of non-fallers. It has been assumed that the muscle weakness partly explains the poorer functioning of the postural control system in the elderly (Era & Heikkinen 1985, Era 1988, Era et al. 1996).

2.3 Balance training and its role in fall prevention among older adults

2.3.1 Postural balance in physically active and inactive older adults

Several studies with either cross-sectional or longitudinal designs have shown a decrease in physical activity with increasing age. A longitudinal follow-up study among community-living older people initially 75 and 80 years of age have shown that physical activity, including daily chores such as domestic work and walking to the shops, declines with increasing age (Sihvonen et al. 1998, Äijö et al. 2002). A cross-sectional study found that more physically active postmenopausal women (mean age 65.3 years) had significantly better postural stability assessed by a swaymeter than less active women (Brooke–Wavell et al. 2001). In this study duration of activity was monitored and women were grouped into a low or high activity group using a cut-off point of 15 min daily activity. Similarly, in a cross national comparison 75-year old subjects who reported a higher level of physical activity, including activities of daily living, performed significantly better in force platform balance tests compared to their less active counterparts (Era et al. 1997). Other studies have emphasized the importance of current activity level on balance performance (Perrin et al. 1999, Bulbulian & Hargan 2000). Recent periods of activity seemed to have greater beneficial effects on postural balance than activities performed only at younger ages. However, comparisons between physically active and inactive persons may be confounded by primary selection. It may be that persons with better balance and other motor skills choose more often to lead physically active life-style compared to those whose basic mobility skills are at lower level. In order to examine in more detail the effects of physical activities on postural balance intervention studies, including physical training among older persons, have been carried out.

2.3.2 Balance training interventions among older adults

Various exercise interventions among older adults aiming at improving balance have been reported. Exercise programs have included training including such aspects as endurance, muscle strength, mobility, flexibility and sensory training separately or in combination or have concentrated on only one component of the postural control system (for example vestibular system training). Appendix 1 presents a summary of studies aimed at improving balance performance in older adults. Studies describing the content of balance exercises and measures are included.

Studies using specifically targeted balance training programmes have reported improvements in postural balance among older adults (Woollacott et al. 1993, Hu & Woollacott 1994a, 1994b, Wolfson et al. 1996, Shumway-Cook et al. 1997a, Rose & Clark 2000, Wolf et al. 2001). Improvements in body sway and muscle response characteristics have been noted after 10-15 day training protocols focused on improving the use of different sensory inputs and the sensory integration among older adults (Woollacott et al. 1993, Hu & Woollacott 1994a, 1994b). An 8-week visual feedback training study among older adults with a history of falls showed improvements in both functional balance tests and force platform measures (Rose & Clark 2000). Also, positive effects in five clinical tests of balance have been shown after an 8-week training program consisting of mostly functional balance exercises (Shumway-Cook et al. 1997a). Wolfson et al. (1996) reported that 3-month balance training including visual feedback improved balance measures such as sensory organization test score, single stance time and voluntary limits of stability. Another study reported that an individualized balance training program developed by a physical therapist after a careful clinical examination among older subjects significantly improved their performance on the Berg Balance Scale and Dynamic Gait Index compared to the controls (Wolf et al. 2001). However, these studies have lacked follow-up data on falls and have also been carried out among relatively healthy elderly subjects.

Many forms of general exercise have appeared not to be particularly effective in improving postural balance among older adults. A few studies have reported some improvements in balance after strength training periods (Lichtenstein et al. 1989, Topp et al. 1993). Some others have found that general muscle training has lead to gains in muscle strength, whereas there have been only minor (Era 1988, Judge et al. 1993, Skelton et al. 1995, Schlicht et al. 2001) or no improvements in balance (Grilly et al. 1989). This may indicate that improvements in muscle strength do not always transfer directly to improved balance or daily functioning in different subgroups of older people (Skelton et al. 1995, Keysor & Jette 2001). It has also been shown that seated forms of strength exercise may not be effective in balance training and fall prevention, regardless of their value in addressing certain other risk factors (Buchner et al. 1997, McMurdo et al. 2000, Gillespie et al. 2001). It is assumed that the reason for the minor improvements in balance may have been the lack of focus on training related to balance control, causing training effects on the balance subsystems to be insignificant.

Many exercise interventions among frail older adults have included combinations of balance and muscle strength training (McMurdo et al. 2000, Rubenstein et al. 2000, Hauer et al. 2001, Nowalk et al. 2001, Hauer et al. 2002). The results have not been completely consistent, although significant improvements in physical performance measures have often been found. Moreover, significant reductions in fall incidence have not systematically been found. Most trials have been carried out among older persons around 80 years of age who had suffered a fall/falls or been diagnosed as fall-prone or who were suffering from different medical conditions and functional impairments. According to some authors a high drop-out rate and low adherence to the exercise program along with a need of individualized training programs may be the reasons for not finding statistically significant decrease in fall rates (McMurdo et al. 2000, Nowalk et al. 2001). It remains unclear whether specific balance training alone has beneficial effects among frail, institutionalized older adults. It is likely that the association between balance improvements and fall prevention may not be similar in different populations of older people.

2.3.3 Balance training as part of multifactorial fall prevention programs

Multifactorial fall prevention programs have utilized exercise as one component of interventions focusing on various intrinsic and extrinsic fall-risk factors. In a large series of randomized controlled trials, the FICSIT (Frailty and Injuries: Cooperative Studies of Intervention Techniques), the effects of different types of interventions were studied among community-living older adults by using exercise and modifications of other fall risk factors (i.e. medication, environment) either alone or in combination (Province et al. 1995). A fall risk reduction of 30% was reported by combining multiple interventions (Tinetti et al. 1994). When all the exercise interventions were pooled, a risk reduction of 10% was seen; however, a higher reduction of 25% in falls was found when the effect of balance training was taken into account (Province et al. 1995). One study site using tai chi as a training method reported that the onset of first or multiple falls were significantly delayed by the tai chi group (Wolf et al. 1996). Another randomized controlled trial described improvements in balance results after an individually tailored home exercise program containing both strength and balance exercises in community-dwelling older women over 80 years of age (Campbell et al. 1997, Robertson et al. 2001). There was also a significant reduction in the number of falls in the exercise group after one year and 2 years of follow-up (Campbell et al. 1997, Campbell et al. 1999). A falls prevention trial for older adults over 70 years living at home using group-based exercise, home hazard management and vision improvement showed that exercise was the most effective single intervention tested (Day et al. 2002). The authors concluded that an exercise program focusing on balance could help prevent falls among older adults living at home and in good health.

A few studies among frail older adults where balance training has been included in a multifactorial program have shown positive effects in reducing falls (Ray et al. 1997, Jensen et al. 2002). Ray et al. (1997) demonstrated significantly lowered rates of recurrent falls after a comprehensive safety program. Another multifactorial intervention study in which resident-specific exercises in residential care facilities were included showed reduced falls and femoral fractures after 34-week follow-up period (Jensen et al. 2002).

According to Shumway-Cook et al. (1997a) the goals of balance retraining for older adults should be to remedy or prevent underlying impairments, to develop effective task-specific sensory and motor strategies and to adapt task-specific strategies so that functional tasks can be performed in changing environmental contexts. Several reviews have suggested that balance training should be included in exercise programs recommended to older adults (Feder et al. 2000, American Geriatrics Association et al. 2001, Carter et al. 2001, Gillespie et al. 2001, Judge 2003, Skelton & Beyer 2003). In conclusion, further research is needed to determine the relative efficacy of different approaches to the treatment of balance disorders and to investigate the extent to which subjects are able to learn effective strategies for controlling balance despite the presence of underlying impairments (Horak et al. 1997).

3 PURPOSE OF THE STUDY

This study was undertaken to gain knowledge about postural balance across different age groups and between middle-aged and older female fallers and non-fallers. In addition, the effects of balance training on postural balance and falls were investigated among frail older women. More specifically, the aims of this study were:

1. to examine possible age and gender differences in postural balance measured by different force platform balance tests
2. to explore possible differences in postural balance between 55-68 year-old female fallers and non-fallers measured by different force platform balance tests
3. to investigate the effects of a four-week visual feedback based training program among frail older women living in residential care facilities on
   i) different aspects of postural balance, including standing balance, dynamic weight shifting and functional balance test performance
   ii) fall incidence, fear of falling and physical activity over a one-year follow-up period.

4 MATERIAL AND METHODS

4.1 Study designs and subjects

4.1.1 Comparison of different age groups of males and females (I)

This cross-sectional data consist of balance measurements carried out in various age groups. Postural balance was assessed in a population with a wide age spectrum using force platform balance tests. Balance measures of 404 females and 189 males in the age range 8 to 93 years were collected. The only exclusion criterion was that a person was unable to stand independently on a force platform. The objective was to collect a sample representing the general population, although participation was voluntary. The groups tested were school children, students, administrative office workers, construction workers, cleaning personnel, rehabilitation centre staff members, unemployed persons, third-age university students, patients from a local out-patient hospital and elderly people living at home and in residential care. Recruitment was done by contacting different schools, colleges, work places, and institutions and disseminating information about the study to possible participants. Women and men were separately allocated to different age groups because of the different numbers of female and male subjects. Women in age categories 66-75 years, 76-80 years and over 81 years were assigned to separate groups, whereas older men were treated as a single group aged 66 and over, since the number of male participants over 75 years of age was low.

4.1.2 Comparison of female fallers and non-fallers (II)

This study was carried out alongside a bigger fall accident study conducted in the City of Jyväskylä during winter 1999-2000. Women (n=257) who had experienced an injurious fall outside and needed medical attention took part in the larger study set up to examine different factors related to these falls. While still under acute medical care 58 female subjects aged 50-68 years agreed to participate in the further investigation and were invited to an interview and balance tests. After a mailed invitation 40 women from this group came to the health care center and participated in the balance measurements, thus forming the group of fallers (n=40). For these women an age-matched group of non-fallers (n=97) was recruited. They were drawn from women who participated in the data collection for the previous study of different age groups who had not fallen during the previous year before the balance measurements. Fallers and non-fallers were divided into two age categories: the younger age group consisted of women aged 50-58 years and the older age group of women aged 59-68 years.

Fallers took part in the balance measurements in a health care center approximately within 3.5 months after injury. These subjects had sustained the following injuries: upper limb fractures (17 subjects), lower limb fractures (3 subjects), head trauma (4 subjects) and soft tissue trauma (16 subjects comprising of 5 shoulder trauma, 3 other upper limb trauma, 6 lower limb trauma, 2 upper body bruises). No significant differences between participants and non-participants were found in the variables concerning the severity of the falling accident, the type and place of trauma, number of days of sick leave and costs of medical care. The injuries sustained did not differ between younger and older fallers. The most common trauma in both groups were wrist fractures (33% in the younger fallers, 32% in the older fallers), followed by soft tissue traumas of shoulder and upper limb (22% in the younger fallers, 32% in the older fallers).

4.1.3 Balance training intervention (III, IV)

A randomized controlled trial to study the effects of visual feedback-based balance training among frail older women was conducted in two residential care homes situated in the City of Jyväskylä. This trial incorporated a four-week balance training intervention and a post-training 12-month fall surveillance period. The baseline measurements including the anthropometric measurements, structured interview on health, and balance measurements were carried out 1 week before the intervention. Balance measurements for both groups were also completed immediately before and after the intervention. Force platform measurements were performed to the exercise group after two weeks training to monitor closely the possible training effects. Follow-up measurements for both groups were carried out 4 weeks after training period.

All female residents (n=72) of the residential care homes received an invitation to participate in informational meetings where the protocol of the study was explained to them. Fourty-four women presented of whom 32 volunteered to participate in the study. Four volunteers were excluded because of health problems during the initial stage (1 hip surgery, 1 acute illness, 2 dementia). The inclusion criteria were: age 70 years or over, ability to stand without a walking aid, ability to see visual feedback from a computer screen and ability to follow instructions for testing and training. Subjects (n=28) were randomly assigned to an exercise group (EG, n=20) and a control group (CG, n=8). One person from the control group was hospitalised during the trial because of an acute illness and had to be excluded from the study. Since the study was carried out in two separate places, the randomization was done in blocks. Eligible women were randomized unequally into exercise and control groups to protect the numbers in the exercise group in anticipation of greater drop out in the exercise group. The randomization was done by drawing lots.

Background characteristics of all subjects

The distribution of subjects into different study groups and their anthropometric characteristics, number of chronic diseases and use of medication are reported in Tables 1 and 2. As expected, the data on anthropometric characteristics, chronic diseases and use of medication showed differences between age groups. Chronic diseases and use of medication were more common in the older age groups than in younger or middle-aged subjects. No significant differences between older fallers and non-fallers or between the balance training group and controls were found in number of chronic diseases or use of medication, except that in the younger fallers the presence of chronic diseases and use of medication was significantly more common than in the non-fallers. The most common chronic diseases reported by both sexes in the younger age groups (<36 years) were allergies and asthma, in the middle-aged and older age groups (36-65 years) hypertension and musculoskeletal problems and in the oldest age groups (≥66 years) hypertension and other cardiovascular diseases. This was also seen in the two age-groups of fallers and non-fallers and in the groups in the intervention study.

TABLE 1 Anthropometry (mean, SD), chronic diseases and use of medication (n, %) in the female groups studied.

Females	n	Height cm	Weight kg	Chronic diseases yes (%)	Medication yes (%)
Comparison of different age groups					
8-10 years	18	135.4 (7.7)	29.4 (5.1)	2 (11)	2 (11)
11-14 years	18	164.3 (5.7)	53.4 (8.8)	0 (0)	0 (0)
15-20 years	19	165.8 (5.4)	60.2 (7.7)	1 (5)	2 (10)
21-35 years	40	165.7 (5.5)	63.4 (8.6)	6 (15)	10 (25)
36-45 years	72	162.9 (6.3)	65.5 (12.4)	12 (17)	12 (17)
46-55 years	73	163.1 (5.2)	70.5 (14.3)	29 (40)	34 (47)
56-65 years	53	160.8 (5.0)	69.3 (11.5)	30 (57)	36 (68)
66-75 years	48	160.1 (5.4)	70.2 (11.7)	33 (69)	33 (69)
76-80 years	18	158.4 (4.2)	63.9 (8.5)	16 (89)	15 (83)
81+ years	42	155.0 (4.7)	63.7 (12.0)	39 (87)	39 (87)
Comparison of female fallers and non-fallers					
Younger non-fallers, 50-58 years	61	162.3 (5.1)	71.8 (14.4)	29(48)	39 (64)
Younger fallers, 50-58 years	18	162.1 (5.9)	73.1 (12.0)	15(83)	15 (83)
Older non-fallers, 59-68 years	34	160.2 (5.6)	68.7 (11.5)	18 (53)	21 (62)
Older fallers, 59-68 years	22	158.1 (5.3)	70.9 (12.1)	11(50)	16 (73)
Balance training intervention					
Exercise group	20	158.3 (6.1)	69.8 (13.8)	18 (90)	19 (95)
Control group	7	162.1 (5.4)	71.6 (14.1)	6 (86)	6 (86)

TABLE 2 Anthropometry (mean, SD), chronic diseases and use of medication (n, %) in the male groups studied.

Males	n	Height cm	Weight Kg	Chronic diseases yes (%)	Medication yes (%)
8-10 years	18	132.4 (7.4)	29.4 (7.4)	2 (11)	1 (6)
11-14 years	9	172.9 (5.6)	61.4 (13.6)	0 (0)	0 (0)
15-20 years	14	179.6 (4.4)	73.9 (8.2)	1 (7)	1 (7)
21-35 years	89	179.9 (5.9)	77.9 (9.8)	18 (20)	12 (13)
36-45 years	15	178.3 (5.5)	79.5 (7.8)	2 (13)	3 (20)
46-55 years	15	177.4 (8.1)	81.1 (9.8)	2 (13)	2 (13)
56-65 years	16	175.4 (5.3)	81.9 (9.8)	8 (50)	6 (37)
66+ years	13	170.5 (6.4)	73.5 (11.2)	10 (77)	10 (77)

4.2 Data collection

The measurements of balance and the variables reported in the original papers are listed in Table 3.

Body height and weight were measured with conventional methods. A short questionnaire on health and use of medication (Schroll et al. 1997) was completed by all subjects.

Balance measurements were carried out using the Good Balance measurement system (Metitur Oy, Palokka, Finland). The force platform was surrounded by a larger rectangular platform thereby presenting a wide even area intended to enhance the test subject's sense of security. The strain gauge force transducers were situated in the corners of the equilateral triangular platform of which the length of each side was 800 mm. Only vertical forces were registered. The amplified analogue signals were digitized with a sampling frequency of f_s=50 Hz and transmitted to the computer through a serial port. All filtering and data processing was conducted in digital form by the software.

TABLE 3 The measures used in the data collection

Variables	Studies	Reference/Method
Anthropometry		
Body height	I-IV	A scale on the wall
Body mass	I-IV	Calibrated mechanic scale
Blood pressure	I-IV	Digital meter (Omron)
Interview/Questionnaire		
Number of chronic conditions	I-IV	Schroll et al. 1997
Number of medications	I-IV	Schroll et al. 1997
Self-rated problems in hearing	II	Era 1991
Self-rated problems in vision	II	Era 1991
Dizziness	II	
Physical activity	I-IV	Grimby 1986
Fear of falling	IV	
Fall surveillance	IV	
Balance measurements		
Standing balance tests		Good Balance, Metitur Oy
1 *Normal standing eyes open (EO)*	I-IV	
2 *Normal standing eyes closed (EC)*	I-IV	
3 Feet together standing EO	III	
4 Feet together standing EC	III	
5 Semi-tandem standing EO	III	
6 Semi-tandem standing EC	III	
7 Tandem standing EO	I-II	
8 Tandem standing EC	I-II	
Dynamic balance tests		Good Balance, Metitur Oy
1 Leaning forward	III	
2 Zig-zag	III	
3 Circle	III	
Berg Balance Scale	III-IV	Berg et al. 1989

The goal of the data processing was to compute the time series of center of pressure (COP) positions from the digitized signals of the force transducers. Data filtering was performed for each channel separately. Two different filters were used: first a median filter with a window length of seven data points, after that a low-pass infinite impulse response filter with a cut-off frequency of f_c=20 Hz (Good Balance user's manual 2000). The use of a median filter has the advantage that it effectively removes or strongly reduces impulse noise. High frequency noise from the measurement system and the A/D-conversion was reduced by the low-pass filtering.

In the standing balance tests the subject was required to stand as motionless as possible on the platform in a predefined position for a given time. Depending on the study a selection of the following measurements was carried out while the subject was standing on the force platform: 1) normal standing for 30 or 40 s with eyes open, hands placed on hips, feet comfortably apart and gaze fixed on a mark (a cross on the opposite wall at a distance of 2 m) at eye level, 2) normal standing as before for 30 or 40 s but with eyes closed, 3) standing feet together for 30 s with eyes open, hands placed on hips and gaze fixed on a mark at eye level, 4) standing as before for 30 s but with eyes closed, 5) semi-tandem (the first metatarsal joint of one foot besides the calcaneus of the other foot) standing for 20 s with eyes open, 6) semi-tandem standing 20 s with eyes closed, 7) tandem standing (feet positioned heel-to-toe along the midline of the platform) for 20 s with eyes open, and 8) tandem standing for 20 s with eyes closed. The tests were performed in the same order for every subject, starting with the easiest test and advancing to the more difficult tests. If the subject was not able to hold a position for the required time she/he was allowed two additional trials for that position. After a short break the tests were repeated in the same order. These eight tests are referred to as standing balance tests throughout this study.

Three different balance outcome variables were calculated from the movement of the centre of pressure for each of the standing balance tests: anteroposterior sway velocity, mediolateral sway velocity and the velocity moment. Velocity moment refers to first moment of velocity calculated as the mean area covered by the movement of the centre of pressure during each second of the test, taking into account both the distance from the geometrical midpoint of the test and the speed of the movement during the same period (Era et al. 1996). The effect of body height was compensated for by adjusting the absolute sway measures according to subject's height ([sway variable/subject height in cm] x 180) (Era et al. 1996).

The dynamic balance tests included tests in which the subjects were asked to move their centre of pressure along a track shown on a computer screen. These tests included 1) leaning in three forward directions, 2) following a zigzag figure, and 3) following a circle shown on a computer screen. The target arrangements of the tests are shown in the original paper. The time used to complete the test (performance time) and the extent of the path travelled by the centre of pressure during the test (performance distance) were measured and were used as results. The test with the shortest performance time out of five repetitions was taken for the analysis.

Berg Balance Scale (BBS) (Berg et al. 1989) was used as a functional balance measure. This performance-based test rates balance during fourteen different tasks, including sitting, standing, reaching, leaning, turning and stepping.

A good test-retest reproducibility of the standing balance tests in normal standing with eyes open and eyes closed has been shown previously (Hofmann 1998, Sihvonen & Era 1999). The intra class correlation coefficients for the dynamic tests used in the training intervention at one-week intervals are reported in the original paper. The reliability and validity of the BBS has been tested among elderly persons (Berg et al. 1995) and it is one of the most widely used functional balance tests.

In the balance training study, fall surveillance for 12 months was carried out by monthly returned diaries. Falls were defined as unintentional changes in position coming to the rest on the floor or ground. The subjects were instructed to complete diaries daily and return them by mail at the end of each month. Participants were contacted by phone if no diary was returned, if it was incompletely filled in or if a subject reported a fall/falls. Injurious falls were those resulting in medical treatment (hospitalization, emergency department visits, physician visits).

Balance training program

In the intervention study the exercise group attended 20-30 minute individualized dynamic balance exercise sessions on a force platform balance measurement and training system (Good Balance, Metitur Oy, Palokka, Finland) three times a week for four weeks. Training was carried out by providing visual feedback of the movement of the subject's COP. The exercise time was gradually increased from 20 minutes to 30 minutes during the first two weeks of training. The goals of the training were to teach participants to control the movement of their COP during dynamic weight-shifting, leaning and stepping tasks and to manage these tasks in different stance positions (with diminishing the base of support) and with higher spatial and temporal demands (larger distances, more directions, higher movement speed). They were also challenged to adapt their postural control according to the demands of the situation such as standing on different support surfaces (foam plastic 5 cm or 12 cm thick) and performing additional tasks such as head movements and verbal tasks. The idea was to vary the task components according to each participant's level of performance. The aim was to use the same structure of balance exercises but accommodate them to each subject's physical performance level in order to maximally challenge her balance abilities. All women, both in the EG and CG, were requested to continue their normal daily routines and not to change their level of physical activity.

4.3 Statistical analyses

Standard procedures were used to calculate means and standard deviations. Differences between groups were tested using Student's t-tests for independent samples. For the discrete variables cross tabulations together with χ^2-tests were performed. The normality of the distributions was tested with the help of Kolmogorov-Smirnov tests. In order to achieve normal distributions some extreme test results were excluded from the analyses.

From the data obtained for the various age groups the results of 7 women (one from the age group 46-55, two from the 56-65, three from the 66-75 and one from the 81+ groups) and 7 men (one from the age group 8-10, one from the 11-14, three from the 21-35, one from the 36-45 and one from 66+ groups) in one or more tests had to be removed from the analyses because their results were identified as extreme. In the comparative study of fallers and non-fallers two extreme cases had to be excluded from the analysis. An extreme value was defined as a value outside three times the interquartile range.

The main effects of age and gender and interactions of age by gender in three different balance tests and in three different sway parameters were investigated by two-way analysis of variance. If significant effects were found, simple contrasts were used to localize the differences between men and women.

The effects of the intervention were analysed by ANOVA for repeated measures. Friedman's tests were used to detect changes within groups in the categorical variables. In order to study the monthly risk of falling, a dynamic poisson-regression model was constructed. For each subject, the 12-month follow-up time was divided into 1-month periods and for each period, the number of falls as well as the values of covariates were recorded separately. The main covariate of interest was the balance training. Since the risk of falling was assumed to be dependent on previous falls, two covariates describing the falling history of the subject were included in the model. These were the occurrence of previous falls during the follow-up time and the occurrence of falls over the previous year. The logarithms of the average number of falls during each 1-month period were dynamically modelled by a linear predictor describing the subject's observed history up to the period under consideration. The parameters in the model could then be expressed as baseline risk and risk ratios describing the effects of the respective dichotomous covariates. A probability level of $p< 0.05$ was used as an indicator of statistically significant results in all analyses.

5 RESULTS

5.1 Postural balance in relation to age and gender (I)

Figures 2-4 show the mean (± SD) anteroposterior and mediolateral sway velocity and velocity moments in the different age groups of female and male subjects in three standing balance tests, namely normal standing eyes open and closed and tandem standing eyes open. All sway parameters showed an expected U-shaped dependency between body sway and age across the different tests. The effect of age was significant in all the parameters of sway in all three tests ($p=0.000-0.034$). In both sexes the youngest subjects aged 8-10 years and the oldest subjects 66+ years had significantly higher anteroposterior and mediolateral sway velocities and velocity moments compared with subjects in the midrange of the age spectrum. The results showed that differences between age groups were similar in both genders and no significant interactions of age by gender were found, except in anteroposterior sway velocity in normal standing EC ($p=0.049$). In this test the effect of age was more pronounced in the men compared to the women. In addition, significantly higher sway in women 56-65 years of age compared to those aged 21-55 years was found in anteroposterior sway velocity in all tests. A corresponding result was seen in men in normal standing EO.

The effect of gender was significant in anteroposterior sway velocity in normal standing EO ($p<0.001$) and in mediolateral sway velocity in all tests ($p=0.004-0.015$). In normal standing EO men had higher anteroposterior and mediolateral sway velocities compared to women in the age groups 21-55 and 66+ years. A similar difference between genders was seen in tandem standing EO in the oldest age group of 66+ years. In velocity moment no significant gender effect was found in any of three balance tests.

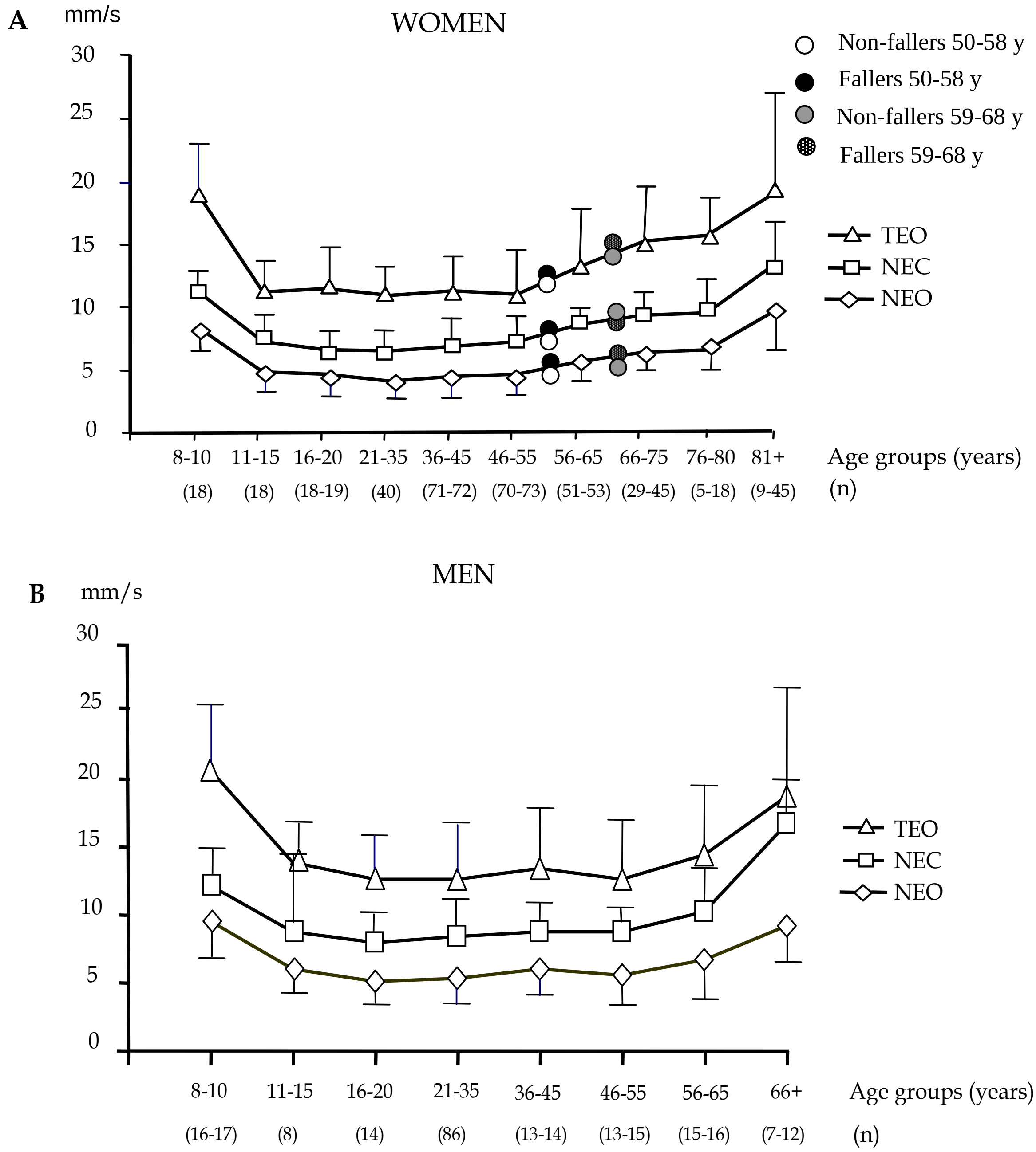

FIGURE 2 Anteroposterior sway velocity in normal standing eyes open (NEO), eyes closed (NEC) and tandem standing eyes open (TEO) in women (A) and in men (B). The age groups 8-10 and 66+ years differed from the other age groups (women p=0.000-0.003, men p=0.000-0.019). Women aged 56-65 differed from those aged 21-55 in all tests (p=0.000) and a similar difference was observed in men in NEO (p=0.031). There was a significant gender difference in NEO in the age groups 21-55 (p=0.001) and 66+ (p=0.009) years. For the statistical analysis men and women were identically distributed into age groups; 8-10, 11-20, 21-55, 56-65, and 66 + years, since no significant differences were found between the subjects from 21 to 55 years of age. Different subject numbers for age categories indicate the variation of subjects able to perform the balance tests.

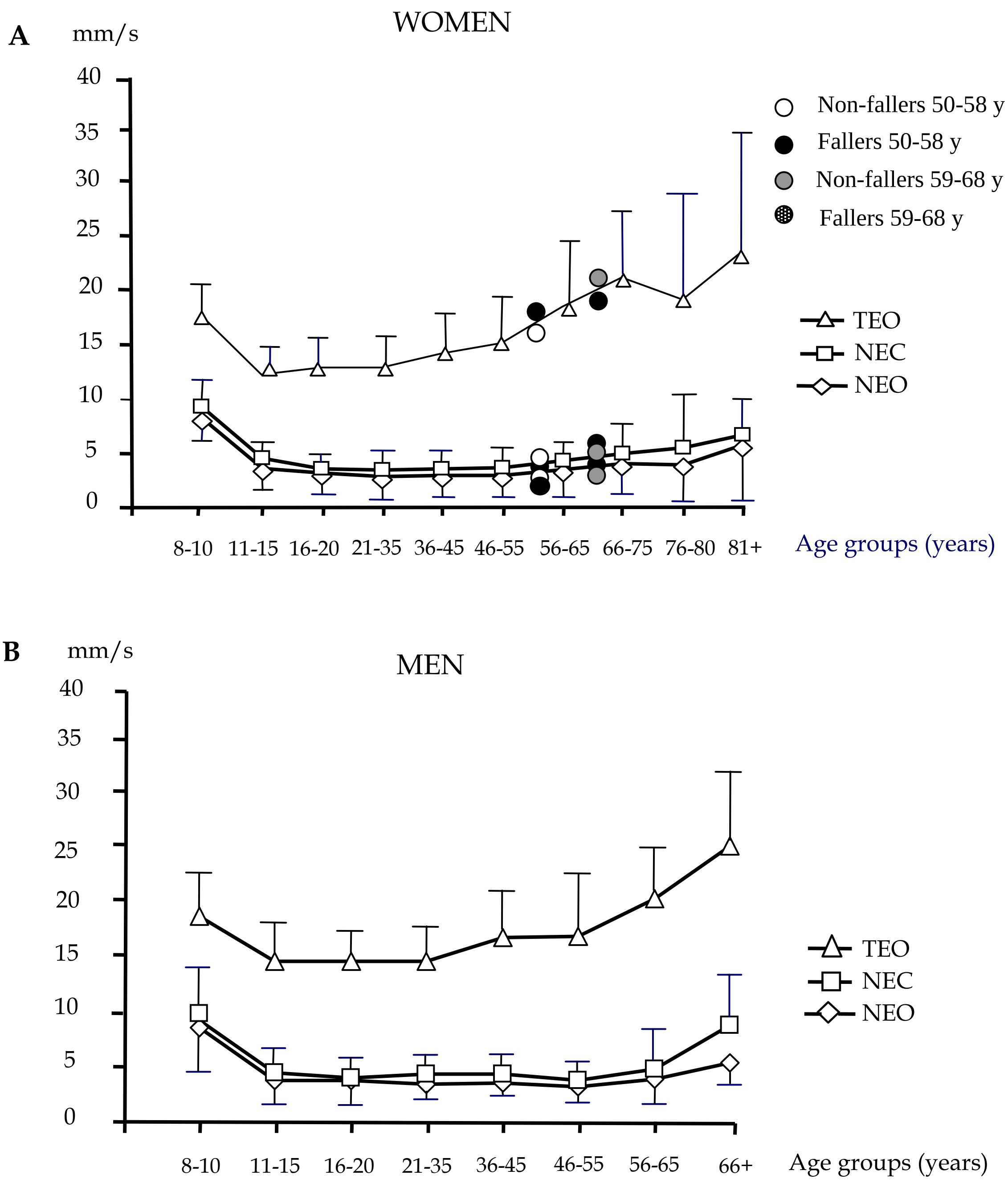

FIGURE 3 Mediolateral sway velocity in normal standing eyes open (NEO), eyes closed (NEC) and tandem standing eyes open (TEO) in women (A) and in men (B). The age groups 8-10 and 66+ years differed from the other age groups (women p=0.000-0.030, men p=0.000-0.023), except in TEO between the two oldest age groups. There was a significant gender difference in NEO in the age group 21-55 (p=0.001) and 66+ (p=0.038) years and in NEC (p=0.002) and in TEO (p=0.047) in 66+ years.

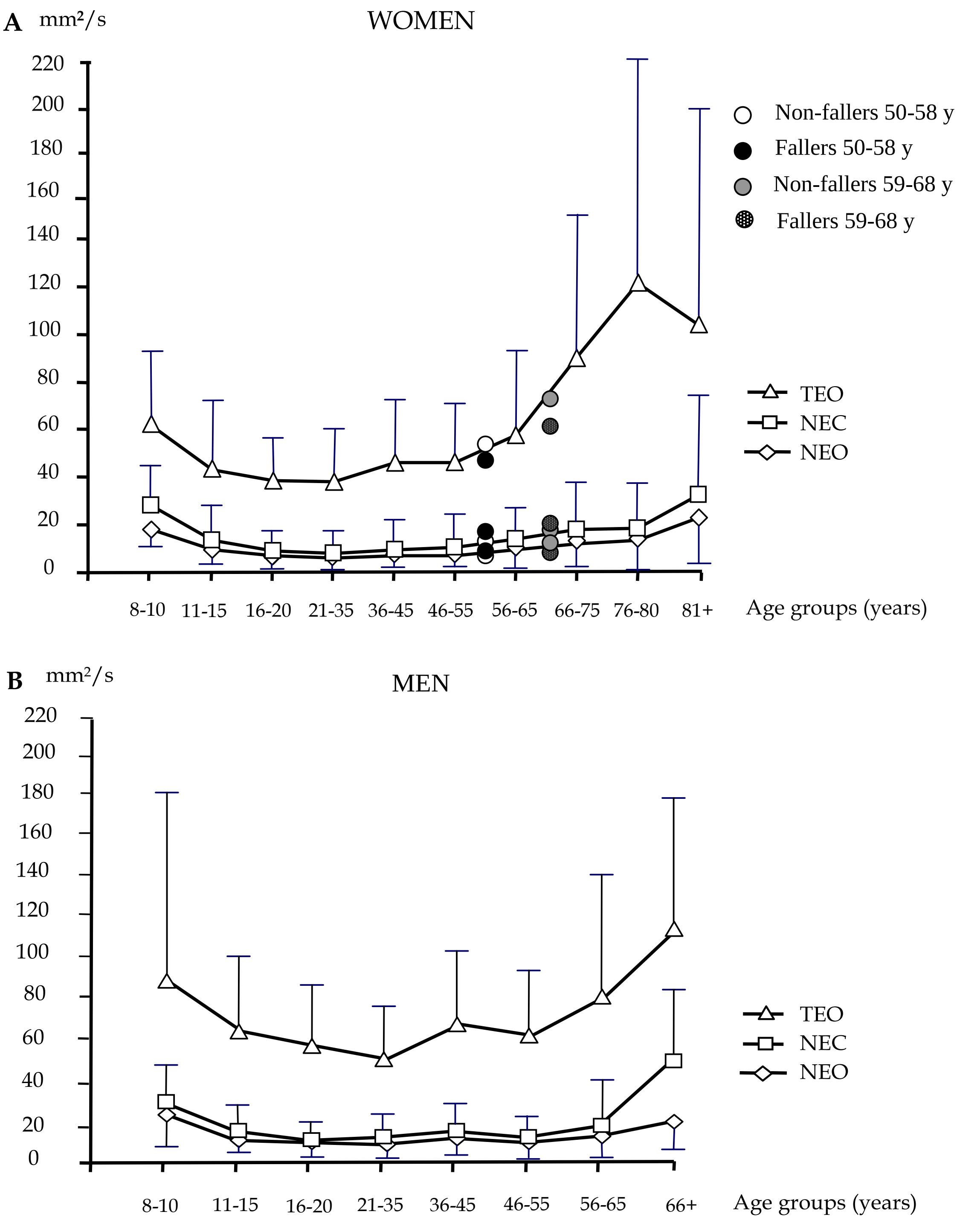

FIGURE 4 Velocity moment in normal standing eyes open (NEO), eyes closed (NEC) and tandem standing eyes open (TEO) in women (A) and in men (B). The age groups 8-10 years and 66 + years differed from the other age groups in NEO (women p=0.002-0.009, men p=0.000-0.032), except the difference between women 8-10 and 56-65 years. In NEC, women aged 66+ differed from those aged 11-20 and 21-55 years (p=0.005-0.032) and men aged 66+ from those aged 21-55 years (p=0.046). In TEO 66+ women differed from the 11-20 and 21-55 year olds (p=0.001-0.008).

5.2 Postural balance in female fallers and non-fallers (II)

Significant differences in postural balance between fallers and non-fallers in the two age categories were not found, as is shown in Figures 2-4. All the subjects were able to complete the normal standing positions, but a few subjects in both age groups were unable to perform the tandem standing eyes open test successfully. The tandem standing eyes closed test was excluded from the analysis, since many subjects (19 in the younger and 27 in the older age group) were unable to perform it.

Having a chronic disease was a differentiating factor between fallers and non-fallers in the younger age category. In the group of non-fallers 48% had a long-term disease, whereas among the fallers 83% reported at least one or more chronic diseases. The most common diagnoses among the fallers were hypertension and bronchial asthma. In addition, the use of prescribed medication was significantly more common in younger fallers and the percentage of multiple medication users was higher compared with non-fallers (50 vs. 25%). In the older age category no significant differences in long-term illnesses or in use of medication between fallers and non-fallers were found. A significantly higher proportion of the younger fallers (83%) also reported feelings of losing stability and of dizziness compared with non-fallers (29%). Furthermore, self-reported difficulties with vision and hearing were significantly more common in younger fallers compared with non-fallers, but since the numbers of subjects with problems were small, these results should be regarded with caution.

5.3 The effects of balance training intervention (III, IV)

No significant inter-group differences were found in the baseline balance measurements. After training, three standing balance tests showed improved velocity moment in the EG compared to the change observed in CG. A significant interaction of group by time (IA) was found in standing feet together with eyes open ($p=0.026$) and eyes closed ($p=0.042$) and in semi-tandem eyes open ($p=0.023$). Accordingly, anteroposterior sway velocity in semi-tandem eyes closed (IA, $p=0.026$) and in semi-tandem eyes open (IA, $p=0.056$) improved in EG compared to CG. In the less demanding standing positions (in normal standing eyes open and eyes closed) no significant effects of balance training were found.

The results of the dynamic balance tests in both groups are shown in Table 4. Women in EG improved the performance time and distance in all dynamic force platform balance tests. The EG showed a mean reduction of 36% in performance time in the dynamic tests compared to a mean increase of 0.6% in CG. Performance distance in these tests decreased on average by 28% in EG compared with the mean 10% decrease seen in CG. Significant interactions of group by time in performance time were found in the Forward leaning and Circle tests and in performance distance in the Zig-zag test, as is shown in Table 4. A few subjects in both groups were unable to perform the Zig-zag and Circle tests. The final score of Berg Balance Scale showed a 7% improvement in EG compared with a 0.7% change in CG (Table 4).

Follow-up measurements were obtained for 24 subjects available for the measurements (17 in EG, 6 in CG). The data showed no significant interactions of group by time in any of the balance tests including standing tests, dynamic tests and Berg Balance Scale, indicating that the changes during follow-up time were not significant. However, a trend towards increased performance time and distance in EG in dynamic tests emerged showing that EG lost some of the improvement gained during training. At the follow-up only small changes in the Berg Balance Scale scores were found, as indicated by no significant effect of time.

TABLE 4 Changes in performance times and distances in three dynamic balance tests and results of Berg Balance Scale at baseline to all subjects, after 2 weeks of exercise for EG and after four weeks to all subjects (means ± SD). The ANOVA for repeated measures is calculated using the baseline and 4-week results.

	Exercise group n=20			Control group n=7		ANOVA (p)		
Test	Baseline	2 weeks	4 weeks	Baseline	4 weeks	Group	Time	Interaction
Forward leaning test								
Time (s)	21.4 ± 8.4	14.2 ± 5.1	13.4 ± 3.6	28.4 ± 8.2	28.6 ± 14.0	0.001	0.031	0.025
Distance (mm)	1614.9 ± 632.6	1662.3 ± 561.2	1252.1 ± 291.1	2125.7 ± 1251.6	1792.0 ± 975.1	0.076	0.006	0.901
Zig-zag test								
Time (s)	29.5 ± 16.2	22.2 ± 7.5	19.8 ± 6.5	39.3 ± 15.5	38.9 ± 11.7	0.006	0.162	0.193
Distance (mm)	3181.5 ± 1520.3	2356.7 ± 651.9	2093.2 ± 551.9	2963.5 ± 951.5	2943.5 ± 1075.0	0.480	0.062	0.071
Circle test								
Time (s)	32.0 ± 11.9	24.6 ± 8.0	19.9 ± 4.8	31.4 ± 7.4	32.1 ± 13.2	0.151	0.053	0.032
Distance (mm)	2767.9 ± 1078.9	2602.8 ± 1040.0	1994.8 ± 770.6	2459.8 ± 529.6	2137.1 ± 792.3	0.829	0.037	0.369
BBS score	48.6 ± 5.4		52.0 ± 4.3	44.6 ± 9.4	44.9 ± 10.0	0.055	0.001	0.003

During the 12-month follow-up period 55% (11/20) of the subjects in EG and 71% (5/7) in CG had fallen. Only one subject in EG had sustained two falls, whereas three subjects in CG had suffered recurrent falls. The total number of falls was 12 in EG and 11 in CG. The cumulative monthly incidence of falls in both groups describing the proportion of falls per number of subjects within a group, are shown in Figure 5. The value 100 means that there were 7 falls in CG. Recurrent falls were significantly more common (Fisher's Exact Test, p=0.027) in CG (6/11) than in EG (1/12). In addition, the proportion of injurious falls was higher in CG (4/11) than in EG (3/12), although no significant difference was found. The risk of falling during the 12-month follow-up was lower in EG than in CG, indicating that the balance training had a significant preventive effect (RR=0.398, 95% CI 0.174-0.911, p=0.029).

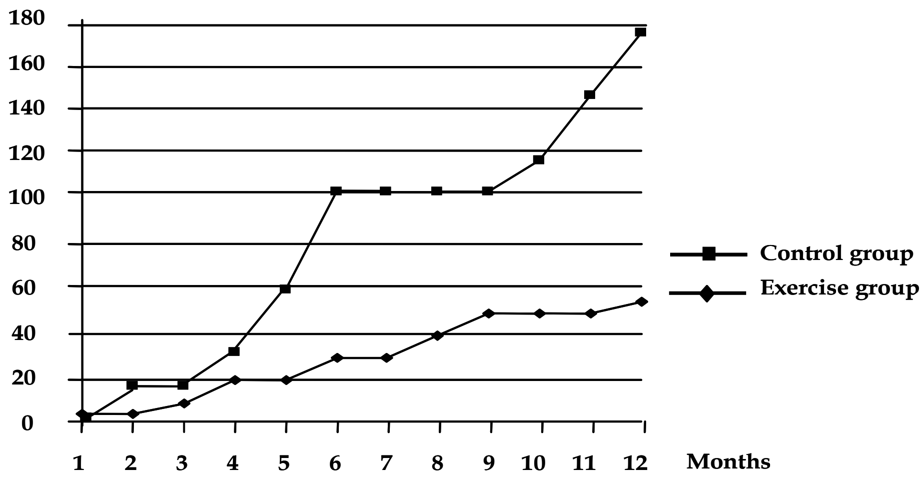

FIGURE 5 Cumulative monthly fall incidence in exercise and control groups (all falls).

At the post-training measurements EG reported an increased level of physical activity compared to the baseline (Friedman's test p=0.004). Post-training measurements also showed a decrease in the fear of falling in EG compared to the baseline (Friedman's test p=0.020). However, during the 12- month follow-up these changes declined. In CG no significant changes compared to the baseline values for physical activity and for fear of falling were found.

6 DISCUSSION

6.1 Postural balance in relation to age and gender

The comparative study of different age groups showed a U-shaped dependency between body sway and age. Children and older adults swayed most, whereas only minor differences were observed between subjects aged 21-55 in both sexes. Postural abilities would appear to reach their peak values in young adulthood and remain almost constant until around the age of 55 years.

Only a few other studies have reported the results of force platform balance measurements in subjects across a wide age spectrum. In the study by Hytönen et al. (1993) men and women were not treated separately, and in the study by Choy et al. (2003) only women aged 20 to 80 years were included. Our data was gender-differentiated and included subjects from both ends of the age spectrum.

We found the lowest sway among young and middle-aged adults. This result further confirms earlier findings by force platform method (Era & Heikkinen 1985, Hytönen et al. 1993, Choy et al. 2003) and by other sway measurements (Sheldon 1963, Lord & Ward 1994). In line with Hytönen et al. (1993) we found that in children the balance abilities are in the process of development. However, our data showed peak values in young adulthood, whereas Hytönen et al. (1993) found the lowest sway velocity among 46-60 year olds. A recent study showed that healthy women in their 60s and 70s were more unstable compared to younger women when standing on a firm surface with eyes closed (Choy et al. 2003), but unlike our findings no significant differences were seen in normal standing with eyes open. Another study did not find significant differences between age groups in easy standing positions, although significantly greater sway with advancing age was reported in more challenging standing positions (Hurley et al. 1998). The higher sway velocities we found with advanced age are supported by longitudinal studies showing a significant increase in sway over follow-ups of three to five years among older subjects (Baloh et al. 1998, Era et al. 2002). It seems that differences in age groups and in subject selection partly account for the inconsistencies between studies. Another source of difficulty in comparing results between studies is the great variability in testing protocols. Differences in the technological solutions, in the formulation of sway parameters and in defining the location of the feet and upper body in standing may mask the underlying phenomena and lead to incompatible results.

The results indicated that among middle-aged and older adults, men showed higher sway velocities than women. In particular, differences were found in normal standing with eyes open in anteroposterior and mediolateral sway velocity, the middle-aged and oldest men showing higher sway velocities than their female age-peers. Similar results in sway velocities in older adults have been earlier found by Era et al. (1996, 1997). Several studies have reported that peripheral sensation is a major contributor to the maintenance of balance (Brocklehurst et al. 1982, Hytönen et al. 1993, Lord & Ward 1994, Era et al. 1996). It is possible that poorer peripheral sensation in men could partly explain their higher sway velocities. According to Era et al. (1996) vibrotactile threshold was the most important factor explaining balance performance among 75-year-old men, but not among women. Reasons for the difference may lie in anthropometrics, health or hormonal factors, such as taller people suffering more from deficits in peripheral sensation (Era et al. 1986) or men having more chronic conditions that affect sensation. In our study significant gender differences were not seen in velocity moment. It is possible that the greater variation in results of velocity moment together with the possibly even greater contribution of height, compared to the sway velocities, despite normalization, may have affected the results. On the other hand, a few studies have shown that when results are normalized by height or foot length gender differences tend to decrease or disappear (Maki et al. 1990, Era et al. 1996, Chiari et al. 2002). It has been suggested that other anthropometric factors, such as variations in body composition and location of centre of gravity can also have an effect (Maki et al. 1990, Kinney LaPier et al. 1997, Chiari et al. 2002).

Our aim was to gather a sample across a wide age spectrum that would represent the general population as closely as possible thereby enabling us to describe a true level of balance abilities in this population, irrespective of the effects of diseases or disorders (diagnosed or not). Thus subjects were not excluded because of diseases or chronic conditions. The only exclusion criterion was the inability to stand independently on a force platform. However, since the sample was based on voluntary participation its representativeness cannot be unproblematically assumed. In many studies strict health criteria have been applied to ensure that only persons free from pathological conditions participate. Both perspectives can be justified, but they may yield differing results (Lord & Ward 1994).The difficulty in studying the effects of aging on postural control lies in separating aging from the diseases and life-style changes that accompany aging (Lord & Ward 1994).

The collection of data on subjects across a wide age spectrum using force platform balance measurements provides a quantitative evaluation of postural balance across the life span. Within the limits of voluntary participation we sought to recruit individuals varying in relation to such factors as occupation, living arrangements and physical activity levels. The sway parameters used in this study demonstrated differences in the balance performance between various age groups and further confirmed the U-shaped dependency between body sway and age. The comprehensive analysis of sway characteristics may serve as a tool to assess the level of functioning of the postural control system.

6.2 Differences in postural balance between fallers and non-fallers

The comparative study on female fallers and non-fallers suggested that in active and community-dwelling women aged 50-68 years differences in postural balance between fallers and non-fallers were not found. In the younger age group of women, i.e. those aged 50-58 years, self-reported chronic diseases, use of medication and dizziness were more common in women with injurious falls compared with non-fallers.

According to our results differences in postural balance between middle-aged and older female fallers and non-fallers are not present. Results are consistent with those of earlier studies that have not found significant differences in postural balance between fallers and non-fallers among subjects whose mean age has been under 75 years (Brauer et al. 2000, Boulgarides et al. 2003). In contrast, studies among older and frailer fallers and non-fallers have demonstrated significant differences between groups in postural balance, suggesting that measurement of postural sway would be a valid test for screening persons with a high risk of falling (Topper et al. 1993, Maki et al. 1994, Lord & Clark 1996, Lord et al. 1999). It is possible that the sensitivity of body sway in differentiating between younger and fitter subjects may not be very high. If the test poses no challenge to a person's balance control, subtle changes may not be noticed. Our subjects were active and working and/or taking part in various social activities indicating that subjects suffering from severe balance deficits were absent from the sample. Furthermore, the participants may represent a selected group of fallers since the refusal rate was rather high. Although non-participant fallers did not differ from participants in fall-related matters, there may have been selection bias, non-participant fallers being less healthy than participating fallers.

Differences in study designs may partly account for the inconsistent results between studies. Prospective designs have often been used, but retrospective studies have also been carried out. In our study the fallers were interviewed and measured after an injurious fall, which may have some influence on the results. Subjects may be more likely to report health-related problems after a fall and fallers may become more aware of the risk of falling. Few studies have found impaired balance in relatively young subjects with fractures, although it is not known if these patients had poor balance before the fall or if the functional impairment had occurred after the fracture (Jarnlo & Thorngren 1993, Ringsberg et al. 1993).

Younger fallers reported significantly more health problems and commoner use of medication than non-fallers. This is in line with several earlier reports (Tinetti et al. 1988, Campbell et al. 1989, Vellas et al. 1998), although our subjects were younger than their counterparts in other studies. It was surprising that the use of medication was more indicative of falling in the younger age category. We had assumed that as health problems become more common with advancing age, the proportion of persons using medication would also increase. Thus, if most older people were experiencing some health problems, this could explain the diminishing difference between fallers and non-fallers with advancing age. However, in our study a higher proportion of the younger fallers had chronic diseases (83 vs. 50%) and were taking medication (83 vs. 73%) compared to the older fallers.

Younger fallers also reported dizziness and problems with vision and hearing more frequently than non-fallers, but such differences were not present between older fallers and non-fallers. Since only self-reported data for these health-related factors were used, these results should be viewed as preliminary. In line with our findings Boulgarides et al. (2003) found that problems with dizziness were predictive of injurious falls. Kristindottir et al. (2001) have suggested that vestibular asymmetry is an important contributory factor to falls and wrist fractures in patients aged over 50 years. Some other studies have associated altered somatosensory input with increased body sway or higher rates of falls while standing with eyes closed on a foam or sway-referenced platform (Stelmach & Worringham 1985, Manchester et al. 1989, Lord & Ward 1994). If a person in her 50s experiences somatosensory changes, the latter may be factors contributing to an increased risk of falling (Kristinsdottir et al. 2001, Choy et al. 2003). These changes may be subtle, but in a challenging situation (slippery surface because of ice and snow) their influence can be critical. Experiencing these difficulties may also lead to fear of falling, which in turn may have many other psychological and physical consequences (King & Tinetti 1995).

The most popular physical activity among women was walking, and most falls happened outside during winter weather conditions. Accordingly, Nordell et al. (2000) found that in persons 64-74 years old most of the falls resulting in a distal forearm fractures occurred outdoors, suggesting that these subjects were active and mobile. In addition, Baloh et al. (1998) reported that the most severe and frequent falls were seen in the most mobile and active people. In the larger fall accident study it was found that the prevailing weather conditions strongly affected the number of falls (Vuoriainen et al. 2000). The peak periods for falls were related to the most unfavourable weather conditions with temperatures close to zero, rapid changes in temperature, and heavy falls of snow. Thus it is assumed that environmental factors may partly explain the accidental falls in this study.

The comparative study among fallers and non-fallers aged 50-68 years showed that in this age group differences between fallers and non-fallers were not found. Our findings suggest that in this group of relatively young and active fallers postural balance may not be among the most important risk factors for falls. However, the further development of test procedures to register subtle changes in balance abilities and somatosensory functions may help in the early detection of younger subjects who may be at high risk for falling.

6.3 The effects of balance training on postural balance and fall incidence

Positive effects of visual feedback-based balance training in frail older women living in residential care homes were found in this study. Our study is among the first such studies to show that individually tailored balance training can significantly reduce the risk of falling in frail elderly women living in residential care. In particular, our results indicated that training decreased the proportion of recurrent falls. A trend towards a smaller proportion of injurious falls was also seen, although non-significant. Frail older women improved their ability to perform standing balance tests and dynamic weight shifting as assessed by the computerized force platform. Further, this study demonstrated that balance training with visual-feedback also improved their performance in the functional balance test. Frail older women benefited from a sufficiently intensive short-term visual feedback based exercise program that focused on voluntary balance control. We showed that this training method could easily be adapted to the health limitations of this group.

In the standing balance tests the velocity moment improved during training in the more demanding standing positions. This sway parameter combines sway velocity and amplitude of sway. Our results indicated that the training method we used affected area of sway more than the velocity of sway. Similarly, Mynark and Koceja (2002) demonstrated a significant decrease in sway area in healthy elderly subjects after two days' balance training. Another study has explained that the increases in sway area with aging could be related to a decrease in the ability of the central nervous system to respond efficiently to corrections sent by the peripheral nervous system (Angulo-Kinzler et al. 1998).

Our data showed that no dependency on vision seemed to develop during the training since the subjects also improved their performance in feet together standing with eyes closed. In accordance with this, Rose and Clark (2000) reported that the most improved performance was observed in standing balance tests where visual inputs were absent. In less demanding standing positions no effects of training were found. These results are in line with earlier findings where measures of body sway have not shown clear changes after training interventions (Era 1988, Lichtenstein et al. 1989, Judge et al. 1993). This may indicate that tests posing no challenge to postural control may not be sensitive enough to detect change. The smaller positive effect of training seen in the standing balance tests compared to dynamic tests may reflect the specificity of the training effect, as balance training in which dynamic exercises were included showed the greatest improvement in dynamic balance control.

The decrease in performance time and distance in the dynamic tests demonstrated more confident postural control when approaching the limits of stability. Motor learning theory has emphasised the role of feedback in the learning of motor skills, and earlier studies have shown the importance of vision in learning to produce effective postural responses (Hu & Woollacott 1994a, 1994b, Nichols 1997, Rose & Clark 2000). Our study supports the notion that through the enhanced use of visual feedback the learning of balance skills can be facilitated. Visual information on how the centre of pressure is situated and how it moves during different tasks serves as a tool to improve volitional postural control. Possibly, this way the subject's ability to use information from other sensory modalities and select more effective postural strategies can be enhanced. According to Dietz (1992) the specific training methods utilized cause changes in movement performance characteristics, which can be related either to changes in skeletal muscles or to alterations in neuromuscular behavior or both.

An earlier balance training study described how selection of motor strategies and enhanced sensory integration as mechanisms of balance improved after a 15-day training period (Hu & Woollacott 1994a, 1994b). In this study healthy older adults practiced maintaining standing balance under altered surface and visual conditions. Another study using more dynamic force platform balance exercises among independently living relatively healthy older adults showed improvements in outcome measures across a spectrum of balance function after a 3-month training period (Wolfson et al. 1996). Also, an 8-week visual feedback training study among older adults with a history of falls showed balance improvements (Rose & Clark 2000) that are in accordance with our results. However, all of these studies did not include subjects living in care facilities and suffering from multiple health problems. Our study demonstrated that this training method is applicable among frail older adults, also supporting the idea of also targeting balance training for those who already have health limitations and are at high risk for falls. The computerized balance training made it easy to make individual adjustments to exercises, allowing progress to be maintained.

The performance of functional activities assessed by BBS showed improvement post-training. It has been suggested that the inclusion of computerized weight-shifting activities that challenge the limits of stability and require accuracy and speed also promote functional improvement in stroke patients (Nichols 1997). Accordingly, Rose and Clark (2000) found that this kind of balance training improved the BBS score in independently living older adults with a history of falling. A similar improvement was seen in our subjects, suggesting that this specific training method improves functional performance and can be effectively adjusted for different groups of older people. Individually tailored practices and close monitoring of performances to maintain progress may be key factors of a successful training program. It is often voluntary postural movements that in normal daily activities place people in unstable situations and at greater risk of falling (Lord et al. 1996). The ability to perform these every day actions safely is very valuable for older adult's independence.

Our finding that balance training decreased the risk of falling among residents of residential care homes is encouraging. Only a few other studies have reported partially positive results of fall prevention using training interventions among frail older people. Rubenstein et al. (2000) showed that in fall-prone men a combination of strength and balance training reduced activity-adjusted fall rates, but unadjusted fall rates were not significantly reduced. A three-month program combining resistance, balance and functional training among geriatric patients with history of injurious falls reported that fall incidence was reduced in the intervention group compared to the control group, although statistical significance was not reached (Hauer et al. 2001). In these studies the follow-up period for falls was three months, which may make it difficult to demonstrate positive results. In our study the protective effect was shown over 12-months. However, it is not clear what causes these differences. Studies not successful in reducing falls in frail elderly people have suggested that high drop-out rates, low adherence to exercise programs and need for more intense individually tailored training programs could be reasons for failing to show positive effects (McMurdo et al. 2000, Nowalk et al. 2001).

In our study the reduction of falls was due to a decrease in multiple falls, not the number of subjects who fell. This concurs with earlier findings by Campbell et al. (1999), who reported similar results among community-dwelling older people after a home-based strength and balance program. According to Robertson et al. (2001) this study of individually tailored exercise showed that exercise as a single intervention may not be effective in preventing falls in older people 75-79 years of age whereas it was effective in frailer older people over 80 years of age. It has been suggested that exercise interventions among frailer persons with a tendency to frequent falls may have greater effect compared to interventions among more healthy subjects (Bayer 2001). Among community-living older people over 71 years of age falls were a strong predictor of admission to a skilled-nursing facility, particularly multiple and injurious falls reflecting an increased risk (Tinetti & Williams 1997). Thus targeting fall prevention also at frail older adults already suffering from health limitations is a high priority issue.

Training induced a reduction in the fear of falling and led to an increase in the level of physical activity compared to the baseline. These changes declined during the post-training 12-month follow-up. This demonstrates a typical relationship between fear of falling and physical activity. A person afraid of falling may restrict her activities thereby making her frailer which in turn increases the fear of falling. Franzoni et al. (1994) found that in mobile nursing home patients the fear of falling was an important predictor of functional decline. Individualized balance training may help persons to identify their own capabilities and limitations and thus help them to overcome fear. Reduced fear of falling after balance training has in fact been shown in a few other studies (Shumway-Cook et al. 1997a, Hauer et al. 2001). Apparently, a decrease in fear of falling means that a person's confidence in her mobility has first to be restored.

Our data consisted of women in two residential care homes and the sample size was small, which may limit the generalisability of the results. Also, the unequal allocation of subjects to the EG and CG was not desirable, but the protection of the number of subjects in the EG was assumed necessary. The study group represented 39% of the eligible women in the two residential care facilities. Four women were excluded at the initial stages of the study because of health problems. It is possible that selectively the women who were not willing to participate had poorer health compared with the participants, thus introducing an element of selection into the data.

No complications occurred among the subjects of the study during the training period and they were highly motivated to participate. It is encouraging that an intervention of this kind can be successfully carried out among frail older women in residential care. There were no withdrawals from the study in either group during the training period and all the subjects presented for the final measurements. The participation rate in the training program was high (97.5%); only 6 individual training sessions altogether had to be cancelled, mostly because of other appointments (visits to physicians and dentists). No injuries were sustained during the training sessions.

Positive comments by exercisers after training included statements such as "I feel my gait is safer and I'm less afraid to go out to do my shopping" as well as "I realized how much I can do myself to keep up my balance skills". The balance training took place in both residential care homes and it is likely that the easy access to the training site facilitated participation. Although individually tailored balance training may seem to demand high resources, positive effects can be achieved in a short time period.

The high frequency of falls and injuries among older adults living in residential care facilities necessitate awareness-rising about fall prevention. Exercise interventions showing positive effects on fall incidence among frail elderly have been scarce. The guidelines issued by the panel drawn from the American and British Geriatrics Societies and American Academy of Orthopedic Surgeons (2001) have recommended exercise and balance training for recurrent fallers. However, the panel was not able to decide on the preferred type, duration or intensity of training. Our study is among the few that have shown individually tailored balance training to be a promising method of improving balance skills and lowering the risk of falling among frail older women. Nevertheless, larger randomized controlled trials are needed to confirm these findings. Further challenges remain in extending the limited knowledge gathered so far on the possibilities of using balance training as a strategy to prevent falls among frail older adults and increasing the availability of balance training among older adults.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present study can be summarized as follows:

1) Standardized force platform tests in subjects representing a wide age spectrum confirmed the U-shaped dependency previously found between body sway and age. The results indicated that peak values in postural balance are reached in young adulthood, whereas the deterioration in postural balance seems to begin around age 55 years. In addition, our results suggested that among the middle-aged and older subjects men showed higher sway velocities than women. Further investigations are still needed to assure potential differences and to find out if balance measurement methods may influence them.
2) In women aged 50-68 years force platform balance tests did not demonstrate differences in postural balance between women with injurious falls and non-fallers. Younger fallers aged 50-58 years reported more health-related problems than other groups. Results may indicate that among women aged 50-68 years other factors than postural balance may be more important in relation to falling. Outdoor falls may be partly prevented by improving environmental maintenance.
3) Visual feedback-based balance training among frail older women improved postural balance as assessed by force platform tests and a functional balance test. The specifically designed progressive balance training program could be adapted for older adults suffering from health limitations. It is encouraging that balance skills can be improved among frail older adults.
4) Balance training decreased the monthly risk of falling in frail older women living in residential care during the one-year follow-up period. In particular, fewer recurrent falls occurred in the exercise group compared to the controls. Balance training is a promising method for fall prevention among older adults with health limitations.

The results suggest that force platform balance tests are sensitive to show the effect of age on postural balance. In active women aged 50-68 years differences in postural balance between fallers and non-fallers were not found. The intervention study reported here is among the first to point out the benefits of balance training in enhancing the maintenance of postural balance and preventing falls among the growing number of residents in long-term care.

YHTEENVETO

Ikääntyminen ja tasapaino: Eri ikäisten tasapaino ja tasapainoharjoittelun vaikuttavuus ikääntyneillä palvelukodissa asuvilla naisilla

Tasapainon hallinta on yksi liikkumiskyvyn perusedellytyksistä, joka vaikuttaa olennaisesti ikääntyneen henkilön kykyyn suoriutua itsenäisesti jokapäiväisistä toiminnoista. Tasapainoon liittyvät ongelmat ovat ikääntyneiden keskuudessa yleisiä ja niiden on todettu olevan eräs kaatumistapaturmien keskeinen taustatekijä. Tutkimukset ovat osoittaneet, että ikääntymisen myötä tasapainonhallintaan osallistuvissa elinjärjestelmissä tapahtuu muutoksia, jotka heikentävät tasapainon ylläpitämistä. Toisaalta on myös todettu, että tasapainon hallintaa voidaan harjoittelun avulla edistää. Viime aikoina on entistä laajemmin otettu käyttöön erilaisia tasapainon mittaamiseen tarkoitettuja menetelmiä, joiden avulla pyritään mahdollisimman tarkasti selvittämään mm. iän myötä tasapainossa tapahtuvia muutoksia ja kehittämään uusia menetelmiä tasapainon harjoittamiseksi. Vain harvoissa tasapainokykyä selvittävissä tutkimuksissa tutkittavat ovat edustaneet laajaa ikäjakaumaa. Edelleen on myös epävarmuutta siitä millainen harjoittelu olisi tehokkainta tasapainon parantamiseksi ja erityisen vähän on tutkittu mahdollisuuksia harjoittaa hyvin ikääntyneiden ja heikkokuntoisten henkilöiden tasapainoa. Kuitenkin on osoitettu, että juuri laitoksessa asuvien ikääntyneiden henkilöiden keskuudessa tasapainovaikeudet ovat yleisimpiä ja heidän kaatumisriskinsä on erityisen suuri.

Tämän tutkimuksen tarkoituksena oli selvittää eri ikäryhmien ja miesten ja naisten välisiä eroja voimalevyllä tehdyissä kehon huojuntaa mittaavissa tasapainotesteissä. Tutkimukseen osallistui 593 8-93-vuotiasta henkilöä. Tavoitteena oli kerätä normaaliväestöä kuvaava otos, jossa henkilöitä ei suljettu etukäteen sairauksien vuoksi pois. Mahdollisia tasapainoon liittyviä eroja selvitettiin myös tapaturmaisesti kaatuneiden 50-68-vuotiaiden naisten (n=40) ja samanikäisten ei-kaatuneiden naisten (n=97) välillä. Lisäksi toteutettiin tasapainoharjoittelututkimus, jossa selvitettiin näköpalautteeseen perustuvan tasapainoharjoittelun vaikutuksia tasapainoon ja kaatumisten ilmaantuvuutta palvelukodissa asuvilla ikääntyneillä 70-90-vuotiailla naisilla (n=27).

Poikkileikkaustutkimuksissa kehon huojuntaa mitattiin tietokoneistetun voimalevyn avulla. Mittausten aikana tutkittavat seisoivat mahdollisimman vakaassa asennossa. Testejä vaikeutettiin sulkemalla silmät ja pienentämällä jalkojen tukipintaa. Kehon huojuntaa arvioitiin huojunnan eteen-taakse suuntaisena ja sivusuuntaisena nopeutena sekä vauhtimomenttina, joka huojunnan nopeuden lisäksi kuvaa huojunnan pinta-alan suuruutta.

Tasapainoharjoittelututkimukseen osallistunut ryhmä kävi yksilöllisesti suunnitelluissa harjoituksissa kolme kertaa viikossa neljän viikon ajan. Tasapainoharjoittelu toteutettiin voimalevypohjaisen tietokoneistetun laitteen avulla, jossa harjoittelija saa näköpalautetta omasta suorituksestaan. Harjoittelun progressio toteutettiin käyttämällä vaikeampia alkuasentoja ja lisäämällä liikelaajuutta ja – nopeutta kunkin tutkittavan suoritustason mukaisesti. Tasapainomittaukset suoritettiin ennen ja jälkeen harjoittelujakson ja ne sisälsivät tasapainon eri ulottuvuuksia mittaavia testejä. Voimalevyllä mitattiin kehon huojuntaa ja suoritettiin dynaamiset painonsiirtotestit. Toiminnallista tasapainoa arvioitiin Berg Balance Scalen avulla. Harjoittelun jälkeen seurattiin kaatumisten ilmaantumista sekä harjoitus- että kontrolliryhmissä yhden vuoden ajan.

Tasapainomittaukset eri ikäryhmissä osoittivat, että iän ja kehon huojunnan välillä näytti vallitsevan U-muotoinen riippuvuussuhde siten, että lapsilla ja ikääntyneillä kehon huojunta oli suurempaa kuin keski-ikäisillä henkilöillä, kun taas erot keski-ikäisten henkilöiden välillä olivat pieniä. Mittauksissa todettiin myös, että keski-ikäisillä ja vanhemmilla miehillä kehon huojunta oli samanikäisiin naisiin verrattuna suurempaa. Tasapainon suhteen ei havaittu tilastollisesti merkitseviä eroja kaatuneiden ja ei-kaatuneiden naisten välillä. Nuoremmassa 50-58-vuotiaiden ryhmässä havaittiin, että kaatuneilla naisilla oli enemmän terveyteen liittyviä ongelmia ja lääkkeiden käyttö oli yleisempää kuin samanikäisillä ei-kaatuneilla naisilla.

Tasapainoharjoittelun seurauksena iäkkäät naiset paransivat suoriutumistaan dynaamisissa painonsiirtotesteissä ja toiminnallisessa tasapainotestissä. Tasapainoharjoittelulla todettiin myös merkitsevä kaatumisia ehkäisevä vaikutus, kun tarkasteltiin kaatumisten kuukausittaista ilmaantumista seurantavuoden aikana.

Tämän tutkimuksen tulokset viittaavat siihen, että kehon huojuntamittausten avulla voidaan arvioida tasapainokykyä elämänkulun eri vaiheissa. Tulokset osoittivat eroja tasapainonhallintakyvyssä eri ikäryhmissä, jotka tulisi ottaa huomioon valittaessa eri-ikäisille sopivia tasapainotestejä. Näköpalautteeseen perustuva tasapainoharjoittelu osoittautui lupaavaksi tasapainokuntoutuksen muodoksi iäkkäillä naisilla. Tämän tutkimuksen perusteella laitoksessa asuvien ikääntyneiden henkilöiden tasapainoa voidaan harjoittelulla parantaa ja kaatumisten ehkäisy on mahdollista.

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APPENDIX 1 Summary of studies on balance training in older adults.

Reference	Age (years)	n	Sex	Group/Training	Frequency of training	Balance measures	Duration of training	Training effect on balance	Training effect on falls	Comments
Era (1988)	74-78	42	M	- strength training - gymnastics - controls	2x 1 h a week	body sway	8 weeks	+ postural sway in both training groups	NA	
Grilly et al. (1989)	72-92	47	F	- gymnastics - controls	3x 15-35 min a week	body sway	12 weeks	- postural sway	NA	
Lichtenstein et al. (1989)	over 65	50	F	- mobility and BT - controls	4x a week, 1 h 2x a day	sway area, sway velocity	16 weeks	+ sway area, - sway velocity	NA	
Johansson, Jarnlo (1991)	70	34	F	- gymnastics - controls	2x 1 h a week	functional measures	5 weeks	+ functional measures	NA	
Sauvage et al. (1992)	over 60	14	F, M	- strength and aerobic training - controls	3x 45-75 min a week	body sway, functional measures	12 weeks	- body sway + functional measures	NA	subjects in residential care
Judge et al. (1993)	62-75	21	F	- combined (strength and mobility) training - flexibility training	Combined 3x 1 h a week, flexibility group 1x 30 min a week	body sway	6 months	- body sway	NA	
Topp et al. (1993)	over 65	55		- dynamic strength training - controls	3x 1h a week	body sway, dynamic measures	12 weeks	+ body sway eo, dynamic measures - body sway ec	NA	subjects in residential care
Woollacott et al. (1993)	65-92	12	F, M	- sensory BT	3x 1 h a week	sensory organization tests (SOT)	8 weeks	+ SOT	NA	no control group
Hu, Woollacott (1994a)	65-90	24	F, M	- sensory BT - controls	10x 1 h	body sway	15 days	+ body sway	NA	
Skelton et al. (1995)	75-90	52	F	- strength training - controls	1x 1h a week supervised 2x a week home sessions	selected functions	12 weeks	+ normal pace kneel rise + step up height	NA	functional benefit limited

continued overleaf

Appendix 1 continued

Reference	Age (years)	n	Sex	Group/Training	Frequency of training	Balance measures	Duration of training	Training effect on balance	Training effect on falls	Comments
Wolf et al. (1996)	over 70	72	F, M	- computerized BT - tai chi - education group	2-3x a week	balance on force platform	15 weeks, 4 month follow-up	+ computerized training on a force platform tests + tai chi in fear of falling	+ falls in tai chi group	different training schedules (contact time even)
Wolfson et al. (1996)	mean age 80	110	F, M	- BT - strength - balance + strength - controls	3x a week, 45 min balance and strength, 90 min balance +strength	SOT, single leg stance time, limits of stability	3 months	+ BT groups in all balance measures	NA	tai chi maintenance for training groups for 6 months 1h a week, some balance gains persisted
Shumway-Cook et al. (1997a)	over 65	105	F, M	- 1. fully adherent BT - 2. partially adherent BT - controls	1. group 2x + 5-7x home exercises a week, 2. group less than 75% of the required sessions	functional balance, risk of falls	8-12 weeks	+ functional balance depending on the degree of adherence	+ fall risk, in particular full adherence group	subjects not randomized, subjects with history of falls during past 6 months
Buchner et al. (1997)	68-75	105	F, M	- strength training - endurance - strength+endurance - controls	3x 1h a week	functional balance, gait, falls	24-26 weeks	- gait, functional balance	+ falls, visits to ER	subjects with some problems in strength and balance
Campbell et al. (1997)	over 80	233	F	- home–based strength and BT - controls	2x a week	strength, functional balance, falls	6 months	+ balance	+ falls	
McMurdo et al. (2000)	mean age 84	133	F, M	- combined fall risk assesment and seated BT - reminiscence therapy	2x 30 min a week	functional reach, TUG	6 months	- balance performance	- fall incidence	subjects in residential care, high drop-out rate
Rose, Clark (2000)	mean age 78.5	45	F, M	- computerized BT - controls	2x 45 min a week	SOT, limits of stability, BBS, TUG	8 weeks	+ SOT, limits of stability, BBS,TUG	NA	subjects had history of two or more falls during year prior the study
Rubenstein et al. (2000)	mean age 74	59	M	- exercise including strength, endurance, mobility, BT - controls	3x 90 min a week	sit-to-stand, 6-min walk, indoor obstacle course, POMI test, 1-leg stand time	12 weeks	- balance performance + gait measures	- fall incidence + fall rates adjusted for activity level	subjects fall-prone men with chronic impairments

continued overleaf

Appendix 1 continued

Reference	Age (years)	n	Sex	Group/Training	Frequency of training	Balance measures	Duration of training	Training effect on balance	Training effect on falls	Comments
Hauer et al. (2001)	mean age 82	57	F	- combined strength and BT - controls	strength 3x 1,5 h a week, balance 3x45 min a week	standing balance, functional reach, TUG, POMA, max gait speed, selected functions	3 months	+ balance performance in various tests	+ fall incidence reduced not significantly	subjects were frail, high-risk geriatric patients with a history of injurious falls
Nowalk et al. (2001)	mean age 84	110	F, M	- strength+endurance +fall prevention - tai chi+fall prevention - fall prevention	3x a week	stand-up time, time to walk 20 feet	2 years	- balance performance	- fall incidence	subjects in long–term care facilities, low adherence to the program
Schlicht et al. (2001)	mean age 72	24	F, M	- strength training - controls	3x a week	1-leg blind balance time, 5 sit-to-stand, max gait speed	8 weeks	- 1-leg balance time, 5 sit-to-stand + max walking speed	NA	
Wolf et al. (2001)	over 75	94	F, M	- individualized BT - controls	12x 30 min sessions	BBS, Dynamic Gait Index	4-6 weeks	+ BBS, Dynamic Gait Index	NA	subjects had balance problems, positive effect on BBS disappeared at 1 year follow-up
Day et al. (2002)	70 and over	1090	F, M	- exercise - home hazard management - vision improvement - controls delivered to 8 groups	1x 1h a week+ daily home exercises	postural sway, max balance range, coordinated stability, TUG	15 weeks + home exercise for 12 months	+ max balance range + coordinated stability	+ fall incidence	
Lord et al. (2003a)	62-95	551	F, M	- exercise (balance, strength, functional activities, aerobic exercises) - flexibility and relaxation controls - no exercise controls	2 x 1h a week	choice stepping reaction, 6 min walk, simple reaction time, body sway, max balance range, coordinated stability	12 months	+ choice stepping reaction + 6 min walk + simple reaction time - body sway - leaning balance + flexibility group vs. no exercise group in max balance range	+ fall incidence	subjects living in retirement villages

+ =significant positive effect of training, - =no significant effect, BT=balance training, F=female, M=male, SOT=sensory organization testing, BBS=Berg Balance Scale, TUG=Timed Up and Go-test, POMI=Performance Oriented Mobility Index, eo=eyes open, ec=eyes closed, NA=not applicaple