STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH
116

Satu Pajala

Postural Balance and Susceptibility to Falls in Older Women

Genetic and Environmental Influences in Single and Dual Task Situations

JYVÄSKYLÄN YLIOPISTO

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Esitetään Jyväskylän yliopiston liikunta- ja terveystieteiden tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston vanhassa juhlasalissa (S212)
syyskuun 13. päivänä 2006 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Sport and Health Sciences of the University of Jyväskylä,
in Auditorium S212, on September 13, 2006 at 12 o'clock noon.

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2006

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Publishing Unit, University Library of Jyväskylä

Cover picture is taken from the Pajala family album

URN:ISBN:9513925722
ISBN 951-39-2572-2 (PDF)

ISBN 951-39-2516-1 (nid.)
ISSN 0356-1070

Jyväskylä University Printing House, Jyväskylä 2006

ABSTRACT

Satu Pajala
Postural balance and susceptibility to falls in older women. Genetic and environmental influences in single and dual task situations
Jyväskylä: University of Jyväskylä, 2006, 78 p.
(Studies in Sport, Physical Education and Health
ISSN 0356-1070; 116)
ISBN 951-39-2572-2
Finnish Summary
Diss.

This study was conducted to assess the contribution of genetic and non-genetic influences to postural balance while standing and walking under single and dual task conditions. Furthermore, the role of familial and non-familial influences in susceptibility to falls was examined. In addition, the validity of force platform balance tests as predictors of falls was elucidated.

The present study was part of the Finnish Twin Study on Aging (FITSA). A population based sample of this study consisted of 206 monozygotic and 228 dizygotic female twins aged 63-76 years. Postural balance was assessed with force platform stance tests and walking tests. The balance tests were carried out as single tasks and while simultaneously performing motor, verbal or arithmetic tasks. After the balance testing, 12-month fall surveillance was carried out. A quantitative genetic method was used to obtain estimates of genetic and non-genetic sources of variability.

Genetic influences accounted for 14 to 35% of the individual differences in postural balance while standing and while walking with higher proportions accounting for variation in dual task tests than in single task tests. Familial factors, consisting of genetic and shared environmental influences explained 35% of the variability in the susceptibility to experience at least one fall during the follow-up year and 45% of the variability in the risk for recurrent falls. Susceptibility to injurious falls was entirely due to non-familial factors. Poor performance in the force platform balance tests predicted risk for indoor falls in older community-dwelling people who had no evident balance impairment. This finding supports the validity of the force platform method and highlights the necessity to assess postural balance with methods that accurately detect small balance deficits. The dual task tests did not add to the prediction of falls among the older participants of the present study.

This is the first attempt to provide estimates of the relative role of genetic and non-genetic influences in explaining individual differences in balance and falls, using accurate and valid methods among a population-based sample of older people. Relatively low genetic contribution to balance and falls was observed and thus, phenotypic identification of people with balance deficits or apparent risk factors for falls remains the best way to target and plan efficient prevention. However, tendency of falls to occur among members of a family should be added to fall risk screening of older people. The results of this study enhances understanding the etiology, interrelationship and relative importance of the systems involved in balance control and risk factors for falls.

Key words: aging, twin study, heritability, postural control, postural sway, force platform method, walking, dual tasking, fall prediction

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ACKNOWLEDGEMENTS

I have been privileged to have three versatile and accomplished supervisors, Professors Taina Rantanen and Markku Koskenvuo, and Docent Pertti Era. I owe my greatest debt to Taina Rantanen for having faith in me when she invited me to join the FITSA research group. In addition to her advice, encouragement and support, which have been invaluable for the completion of this thesis, it was she who introduced me to the scientific world and opened up new prospects for the future. I am grateful to Markku Koskenvuo for his scientific expertise when I was grappling with the secrets of the twin methodology; it has been a pleasure to work with a person who always has a twinkle in his eye. I am especially grateful to Pertti Era for the dedication he has shown in supervising this work; his valuable advice and ideas have challenged my way of thinking and greatly enhanced the outcome.

I have had the honour and great pleasure to work in close liaison with Professor Jaakko Kaprio, a great scientist and warm personality.

The official reviewers of this thesis were Professor Fay Horak from the Sciences Institute, Oregon Health and Science University, USA, and Professor Gerald McClearn from the Center for Developmental and Health Genetics at Penn State University, USA. I highly admire their expertise and warmly thank them for their prompt work and constructive comments. I take especial pride and joy in having Professor Kaare Christensen as my opponent in the public defence of this thesis.

My first steps in the field of gerontology were taken under the guidance of Emeritus Professor of Gerontology Eino Heikkinen. He made an indelible impact on me with his enthusiasm and wisdom. Mr. Asko Tolvanen, Mr. Timo Törmäkangas and Mr. Markku Kauppinen are acknowledged for their time and patience in counselling on statistical methods and analyses in connection with this study, and Mr. Michael Freeman for revising the English language of this work.

My warmest thanks go to my closest colleague Ms. Kristina Tiainen for her admirable patience in working side by side with me for so many years. Our discussions have been important and travels together enjoyable. I cherish our friendship. I am indebted to Ms. Anne Viljanen for her dedication to the data collection of the FITSA study, not to mention her amazing ability to keep everything under control. I take delight in her indefinitely positive attitude and humour. Ms. Virpi Onnela is thanked for her diligence in doing phone interviews during fall surveillance and fall data handling. Ms Marja Petman, Ms Tuovi Nykänen and Mr Erkki Helkala and other staff members of the Laboratory of Sports and Health Sciences are thanked for their contribution to the completion of the laboratory measurements of the FITSA study.

Doing research is most of the time an extremely lonely pursuit and therefore having colleagues around is crucial. I thank all of you for relaxing coffee breaks and sharing thoughts in corridor conversations. My special gratitude goes to my fellow doctoral students Ms. Tuulikki Sjögren, Ms. Marjo Wallin and Ms. Tiina-Mari Lyyra for their empathy and sharing my frustrations during the final stage of this work. I am much obliged to Ms. Anna Rantanen for being indispensable, always ready with a helping hand in any practical matter whenever you need it.

I thank my parents Salme and Kosti Arvonen for their love and endorsement of the choices of my life, my sister Sirpa for being the best sister I could imagine and my niece Sanni and nephew Sampsa for bringing joy to my life.

My heartfelt thanks go to my dear friends Tuuli, Jaana and Heli for sharing the days of joy and for offering a shoulder to cry on. I dedicate this work to my beloved, late grandma, my archetype of successful aging, and to my goddaughter, little Aino.

This study was carried out at the Finnish Center for Interdisciplinary Gerontology in the department of Health Sciences at the University of Jyväskylä. The FITSA study was done in cooperation with the Department of Public Health at the University of Helsinki as the participants of this study were recruited from the Finnish Twin Cohort. Mrs. Eila Voipio and Mr. Kauko Heikkilä are thanked for their invaluable efforts during the twin recruitment process and staff of the laboratory of the National Public Health Institute for determination of the zygosity of the FITSA participants.

I had the opportunity to encounter in person most of the FITSA participants during the data collection. Their enthusiasm in taking part of the study was a joy to see and they deserve to be acknowledged especially for devoting themselves to the fall surveillance, which involved the whole year.

I wish to thank the Finnish Ministry of Education, Juho Vainio Foundation, Finnish Cultural Foundation, Finnish Union for University Researchers and Teachers, University of Jyväskylä (rector´s grant for completion of the thesis) for honouring me with the personal grants which have enabled me to work full time with this thesis. The main funding for the FITSA project has been received from Academy of Finland and Ministry of Education, Finland.

LIST OF ORIGINAL PUBLICATIONS

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

I Pajala S., Era P., Koskenvuo M., Kaprio J., Tolvanen A., Heikkinen E., Tiainen K., Rantanen T. 2004. Contribution of genetic and environmental effects to postural balance in older female twins. Journal of Applied Physiology 96, 308-315.

II Pajala S., Era P., Koskenvuo M., Kaprio J., Tolvanen A., Rantanen T. 2006. Genetic and environmental contribution to postural balance in single- and dual-task situations. Neurobiology of Aging (in press).

III Pajala S., Era P., Koskenvuo M., Kaprio J., Alén M., Tolvanen A., Tiainen K., Rantanen T. 2005. Contribution of genetic and environmental factors to individual differences in maximal walking speed with and without second task in older women. Journal of Gerontology, Medical Sciences 60A, M1299-M1303.

IV Pajala S., Era P., Koskenvuo M., Kaprio J., Viljanen A., Rantanen T. 2006. Genetic factors and susceptibility to fall in older women. Journal of the American Geriatrics Society 54, 613-618.

V Pajala S., Era P., Koskenvuo M., Kaprio J., Törmäkangas T., Rantanen T. Force platform balance measures as predictors of risk for falling indoors and outdoors in community-dwelling 63- to 76-year-old women. Submitted for publication.

ABBREVIATIONS

ADHD	Attention deficit hyperactivity disorder
ADL	Activities of daily living
AGS	American Geriatrics Society
AP	Antero-posterior
BMI	Body mass index
CI	Confidence interval
CNS	Central nervous system
COP	Center of pressure
DZ	Dizygotic
DT	Dual task
DTC	Dual task cost
EC	Eyes closed
EO	Eyes open
FITSA	Finnish Twin Study on Aging
ICC	Intraclass correlation coefficient
IRR	Incidence rate ratio
ML	Medio-lateral
MMSE	Mini-Mental State Examination
MWS	Maximal walking speed
MZ	Monozygotic
NICE	National Institute for Clinical Excellence
SD	Standard deviation
SEM	Structural equation modelling
VEL	Velocity moment
WML	White matter lesion
XZ	Uncertain zygosity

CONTENTS

1 INTRODUCTION

A quantitative genetic study using a twin design is an effective method for assessing the relative contribution of genetic and environmental influences to individual differences in complex traits such as behavioural traits and phenotypes related to physical performance. The basic idea of this method is to compare twins according to their shared genetic material. Monozygotic (MZ) twins share all their genes, and thus any differences between the co-twins can be attributed to environmental influences. Dizygotic (DZ) twins share on average half of their segregating (separating) genes and consequently differences between the dizygotic co-twins may also be attributed to their genes (Plomin et al. 2001, Hall 2003). Genetic influences can be expected to be present when MZ twins show more resemblance in a given trait than do DZ twins. Estimation of the proportions to which genetic and environmental influences contribute to the trait under study can be done by genetic modelling techniques.

Falls among older persons often occur due to deterioration in the ability to control postural balance when standing and walking. This deterioration in balance control does not necessarily occur with age. Nevertheless, as control of posture is dependent on several systems, all of which are vulnerable to age or disease-related changes, most older persons confront a certain degree of balance impairment (Woollacott 2000). In recent years, increasing research interest has been shown in determining the role of genetic influences on phenotypic variability in relation to physiological functions and physical abilities in older populations. These studies have provided evidence of moderate to substantial genetic contribution to individual variability in such traits as muscle strength and cognitive functions (Harris et al. 1992, Arden & Spector 1997, McClearn et al. 1997, Tiainen et al. 2004, Tiainen et al. 2005). The relative contribution of genetic and environmental factors to postural balance in older people, however, has been neglected. Addressing the genetic factors contributing to postural balance opens up the possibility to better understand the complex system of postural control and the etiology of age-induced changes in it, thereby providing useful information for the design of preventive interventions.

Control of balance relies on harmonious functioning of the peripheral sensory systems; however, this sensory information needs to be integrated at higher neural levels. The critical roles of central information processing and cognitive abilities on balance control, especially among older people, have been established in studies applying dual- or multi-tasking while balancing or walking (Teasdale et al. 1993, Maylor & Wing 1996, Maylor et al. 2001). Dual tasking is a common occurrence in daily life. Customarily, while standing or walking we talk to someone or carry groceries. For older people with even a minor impairment in central processing, performing two simultaneous activities may exceed their central processing capacity and lead to failure in balance control (Shumway-Cook et al. 1997). Recent studies of dual tasking while balancing or walking have suggested that older people with difficulties in dual tasking have a higher susceptibility to falls (Lundin-Olsson et al. 1997, Shumway-Cook et al. 1997, Condron & Hill 2002, Hauer et al. 2003, Bergland & Wyller 2004). However, the evidence accumulated thus far is neither voluminous nor uniform (Bloem et al. 2000, Bootsma-van der Wiel et al. 2003, Hyndman & Ashburn 2004).

Falling occurs from time to time in people at all ages, but the likelihood that a fall will cause injury and have an adverse effect on health and independent functioning is much greater in older than younger people. Susceptibility to falls increases with age and frailty. After 65 years of age, the prevalence of at least one fall annually ranges from 30% to 40%. Likelihood of falling within a year rises to 50% among people aged 80 years and older (Campbell et al. 1981, Prudham & Evans 1981, Blake et al. 1988, Tinetti & Speechley 1989, Campbell et al. 1990, Feder et al. 2000, Tinetti 2003, Bergland & Wyller 2004, Gillespie et al. 2004, Kannus et al. 2005a). However, great many 'younger' and relatively healthy independently living older adults also experience a fall each year. From the societal point of view, fall-induced injuries and other adverse consequences of falls will impose an increasing burden on health care as the number of older people in the population increases. Approximately, 20% of falls causes an injury that requires medical attention and 5-10% of the falls leads to fracture or other severe injury. However, even minor injuries may trigger the vicious circle of fear and limited mobility, which, in turn have adverse effects on overall health and increase the risk for additional falls and disability (Rubenstein et al. 2001, Kannus et al. 2005a, Stevens & Sogolow 2005). For these reasons, the factors predisposing older people to falls as well as assessment of the efficiency of preventive interventions have been intensively studied during recent years.

On the basis of the evidence from the research on risk factors for falls and fall prevention obtained over the past three decades, various guidelines for fall risk assessment and interventions to reduce risk for falls among older people have been published (Feder et al. 2000, American Geriatrics Society (AGS) guideline 2001, Gillespie et al. 2003, Moreland et al. 2003, Skelton & Beyer 2003, Gillespie et al. 2004, Skelton & Todd 2004, The National Institute for Clinical Excellence (NICE) 2004, Close et al. 2005). Despite these efforts, the recommended actions and interventions have not been as effective as expected. Knowledge of the relative roles of genetic and environmental influences in accounting for older people's susceptibility to falls should provide a deeper understanding of the factors underlying falls and the interrelations between these factors. This information may help to promote the efficiency of fall prevention. However, no research hitherto on the role of genetic factors on falls among older people has been conducted.

A fall generally takes place when the adverse effects of intrinsic factors combine with extrinsic factors, i.e. challenges presented by the prevailing environment. Intrinsic risk factors for falls refer to personal characteristics, such as age, gender or sensory and physiological capacity, and extrinsic risk factors for falls refer to issues such as uneven surfaces or poor lighting (King & Tinetti 1995, Feder et al. 2000, AGS guideline 2001, Skelton & Todd 2004, Kannus et al. 2005a, Rao 2005). In terms of fall prevention, there is a need to identify the people at risk. Many fall studies have either utilized a case-control design or have obtained the fall data retrospectively. However, in order to obtain valid information on the factors that predict falls, a prospective design is essential. In addition, especially among healthy older people, the risk for falls may be increased due to slight deficiencies in physical functions or to preclinical disease, neither of which can be captured with robust measures. To date, only a very small number of studies adopting a prospective design and utilizing measures, such as force platform-based balance tests, which have the ability to quantify even small deviations in the ability to control posture, have attempted to identify people at increased risk for falls (Piirtola & Era 2006).

The present study was conducted to add to the existing body of knowledge on postural balance and risk for falls among older people. Determination of the role of genetic and environmental influences on these traits can further increase understanding of the etiology of age-related deterioration in postural control and of the relative importance of various risk factors for impaired balance control and risk for falls. Investigating the utility and validity of dual tasking and the force platform method to assess balance in older people and to identify people at increased risk for falls was done to augment the assessment of balance assessment as a single task to enable more advanced prevention of falls.

2 REVIEW OF THE LITERATURE

2.1 Postural balance while standing, walking and dual tasking among older people

The structure of the human body, the greater part of the mass of which is located two-thirds of the body height above ground, makes it difficult to equilibrate even when stationary. In a quiet stance, the primary task of systems involved in postural control is to maintain the center of gravity within the area of support. During walking, the whole body moves into a particular direction by shifting the center of gravity first beyond the limits of stability and then back again. Thus, during standing and walking integrated cooperation of sensory systems, skeletal muscles and various levels of central nervous system is required. Balance is a pertinent component of daily life activities and balance control is closely linked with the environment in which it is performed. When in older people, decline in the capacity of the postural control system proceeds to the point that the requirements of the activity or the environment in question cannot be met, the probability of a fall increases (Alexander 1994, Winter 1995, Latash 1998, Matsumura & Ambrose 2006).

When assessing postural balance in older persons, the main aim is to evaluate the functioning and possible deterioration of the systems that control posture with respect to the context and task in which the ability to maintain balance is required. Therefore, in balance assessment, various positions and conditions from stable stance to walking, including dual tasking have been applied. In clinical practice, balance assessment is most often done utilizing various functional performance measures. Functional or performance-based balance measures provide rather cursory information about the existence of the balance problem. Test batteries of this type often do not require any specific equipment and can thus be performed in any setting, even in the home of the older person. The advances in technology have meant that computerized posturography has become increasingly available in making assessments, for example in rehabilitation settings. The advantage of quantitative posturography over functional tests is that this method provides detailed information on the success of functioning and on the cooperation of the postural control systems. Posturography data are obtained by force-platform-based balance instruments, which measure surface forces associated with various postural tasks (Horak et al. 1997, Jarnlo 2003, Chaudhry et al. 2004).

High priority in balance assessment is prediction of the future status of physical functioning in daily life and falls. The usefulness and predictive ability of different balance assessment methods vary depending on the health status and level of functioning of the older people being tested. Such performance/functional balance tests as the Berg Balance Scale (Berg et al. 1992, Berg et al. 1995), Tinetti Performance-Oriented Mobility Assessment (Tinetti 1986), Timed "Up and Go" Tests (Podsiadlo & Richardson 1991) have been shown to be valid and predictive for nursing home residents and for more frail and older 'old' people (Jarnlo 2003).

Among community dwelling and independent older adults, the tendency to a ceiling effect weakens the predictive ability of functional balance tests to indicate those at risk for fall (Boulgarides et al. 2003). Force platform-based balance tests produce quantitative and more detailed information on the effectiveness of the postural control systems in balance maintenance. Poor test performance has been shown to be associated with difficulties in performance of the activities of daily living (Era et al. 2002). However, the association between force platform test performance and falls remains unclear. In their review, Piirtola & Era (2006) found only five prospective fall studies among older persons which provided evidence of an association between falls and at least some force platform test parameters.

Age related changes in the systems that control postural balance

In most cases, age-related change in postural balance has been studied with cross-sectional data (Sheldon 1963, Overstall et al. 1977, Brocklehurst et al. 1982, Bohannon et al. 1984, Hytönen et al. 1993, Baloh et al. 1994, Colledge et al. 1994, Wolfson et al. 1994, Hageman et al. 1995). Studies using force platform-based data on balancing ability have showed a U-shaped relationship between balance and age, center of pressure (COP) movement being greater in children and among older people than in young adults (Sheldon 1963, Hytönen et al. 1993). Era et al. (2006) found evidence of a rather early onset of balance deterioration from force platform balance test data obtained for nearly 8000 people. Impaired performance was present already at the age of 40 and the deterioration accelerated after 60 years of age. The cross-sectional findings have been confirmed by longitudinal studies showing significant age-related changes in the balance control systems (Era et al. 2002, Onder et al. 2002, Baloh et al. 2003, Kerber et al. 2005) and suggesting that the decline in balance with age is even more pronounced than shown by the cross -sectional data (Era et al. 2002).

Older people show considerable variation in postural balance. Control of posture relies on contributions of the visual, vestibular and somatosensory systems and their interaction, which is organized by the central nervous system (CNS). One or more of these systems may and usually does undergo changes with age, leading to a decline in the function in question. To some extent, deterioration in one system can be compensated by enhanced usage of the other, but the possibility of balance impairment increases with the severity of the deterioration and the number of systems affected (Woollacott et al. 1986, Horak et al. 1990, Wolfson et al. 1992, Winter 1995). Changes in these control systems may also become affected by diseases such as Parkinson's, diabetes, and other neurological diseases, the prevalence of which increases with advancing age. The early signs of age-related or disease-induced changes may be so slight, that their effect on balance control may be difficult to detect (Manchester et al. 1989).

Although deterioration in visual functions are frequent in older people, the reliance on vision has repeatedly been reported (Horak et al. 1989, Lord et al. 1991, Perrin et al. 1997, Speers et al. 2002, Low Choy et al. 2003). Both Lord & Ward (1994) and Low Chou et al. (2003) showed increased reliance on vision among women up until their 70s. The age-related changes most often suggested as having debilitating effect on postural control are those in visual acuity, contrast sensitivity, depth perception and stereopsis (Lord & Ward 1994, Era et al. 1996, Lord & Mentz 2000, West et al. 2002, Lee & Scudds 2003). However, associations between functional tests of balance and age related impairments in the operation of such visual systems as oculomotor functioning, visual attention and visual processing speed have also been reported (Owsley & McGwin 2004, Kerber et al. 2005).

Vestibular information for control of posture is of utmost importance especially when adapting to changes in environmental conditions (Lackner 1992). The basic contribution of the vestibular systems to balance control is to provide a reference against which visual and somatosensory systems can be compared and calibrated (Nashner et al. 1982). Alterations of vestibular functioning with age, consequent on anatomical changes in the vestibular organs (Rosenhall 1973), lead to problems of conflicting information collected from other sensory systems, inefficiency in stabilizing the head, and difficulties in negotiating changes in the environment. The central nervous system, however, effectively compensates for the decrease in vestibular function (Peterka et al. 1990), and the somatosensory and vestibular systems work close by together when controlling balance (Fitzpatrick et al. 1994, Inglis et al. 1995).

The proprioceptors of the muscles provide information about body movements and the positions of body segments relative to each other (Dietz 1992). Additionally, information about properties of the support surface and support contact forces is obtained from deep pressure and cutaneous receptors. Peripheral sensation is important in maintaining balance, especially in unchallenging conditions (Brocklehurst et al. 1982, Era et al. 1996, Lord & Mentz 2000). Age-related deterioration in sense of position and detection of movement and an association between impaired proprioception, poor balance control an increased risk for falls have been found (Teasdale & Stelmach 1991, Lord et al. 1994, Lord & Clark 1996).

Muscle function declines with age. The central phenomenon underlying this decline is quantitative loss of muscle mass, described as sarcopenia (Lindle et al. 1997, Metter et al. 1997, Rantanen et al. 1998, Frontera et al. 2000, Roubenoff & Hughes 2000, Hughes et al. 2001). In balance control, the main role of muscle function is to produce coordinative and corrective movements, which seldom require maximal strength or power. Therefore, in healthy older people, impairment in lower extremity muscle function seldom becomes a limiting factor for balance control. In frail older people, the level of muscle functioning may be extremely low. In such people, for example, acute illness-related inactivity may rapidly cause a decline in muscle force detrimental to balance control and walking, and increase risk for falls (Moxley Scarborough et al. 1999, Roubenoff & Hughes 2000, Bean et al. 2003, Greenlund & Nair 2003, Moreland et al. 2004). Impaired ankle muscle function is thought to make the largest contribution to balance control and to susceptibility to falls (Whipple et al. 1987, Studenski et al. 1991, Daubney & Culham 1999, Moreland et al. 2004, Lin & Woollacott 2005).

In addition to changes in sensory systems with age, the ability of the CNS to organize the inputs from these systems and provide appropriate output for balance control often undergoes age related deterioration. The slowing of information processing (Salthouse & Somberg 1982, Welford 1984, Welford 1988) has been previously acknowledged. Recent research utilizing the dual task paradigm has provided evidence on the importance of higher central regulation, cognitive functioning and the ability to allocate attention in postural control (Maylor & Wing 1996, Teasdale & Simoneau 2001, Woollacott & Shumway-Cook 2002). Age changes in cognitive capacity and functioning are typically related to various neurological diseases. However, recent studies have shown that also in seemingly neurologically intact older people white matter lesions (WMLs) commonly occur (Liao et al. 1997, Kuo & Lipsitz 2004, Longstreth et al. 2005, Launer et al. 2006). This is important as the association between the volume of WMLs and impaired balance and gait in older people has been found (Longstreth et al. 1996, Guttmann et al. 2000, Whitman et al. 2000, Benson et al. 2002, Baloh et al. 2003, Starr et al. 2003, Rosano et al. 2005). The mechanism through which WMLs, gait and balance are interconnected is not known. WML is thought either to interfere with the long loop reflexes that are crucial for gait and balance, and are mediated by deep white matter sensory and motor tracts, or to interrupt the long descending motor tracts which arise from the medial cortical areas and are important for lower extremity motor control (Baloh et al. 2003).

Dual tasking while standing and walking in older people

Once acquired, the maintenance of balance while standing and walking has been considered a highly automated skill. The dual task paradigm, a traditional approach in psychological research, has been adopted in studies to examine the need of central processing and attentional resources in balance control. This research has typically combined various tasks requiring cognitive processing or motor skills such as walking or standing in different positions and environmental conditions. Thus far, most studies on dual tasking balance tests have compared the performance between young and older people (Maylor & Wing 1996, Shumway-Cook et al. 1997, Brown et al. 1999, Rankin et al. 2000, Marsh & Geel 2000, Shumway-Cook & Woollacott 2000, Redfern et al. 2001, Teasdale &

Simoneau 2001, Brown et al. 2002, Condron & Hill 2002, Hauer et al. 2003, Weeks et al. 2003, Dault & Frank 2004, Melzer & Oddsson 2004). The majority of these studies have provided evidence that with age, dual tasking imposes additional requirements on central control, which in turn, may adversely affect postural control. The link between postural control and central processing is thought to lie in competition for the systems and processes necessary for both maintenance balance and performing a second task simultaneously (Shumway-Cook & Woollacott 2000, Li et al. 2001). Age-related degenerations in the CNS may reduce its capacity to allocate attention between tasks and lead to deterioration in the performance in one or other tasks when attempting dual tasking. In addition, task prioritization among older people may be more unconscious and related to a more limited central capacity whereas among young people there may be greater intentionality (Lindenberger et al. 2000, Shumway-Cook & Woollacott 2000, Li et al. 2001).

The central mechanisms responsible for the modifications required in postural and/or the second tasks while dual tasking remain unclear. Quant et al. (2004) found a significant decrease in the magnitude of early cortical activity (measured with perturbation-evoked potentials, PEP) and greater COP displacement during a manual tracking task done while balancing compared to the control condition without the second task. Some theoretical explanations for behaviour in dual task performance have been proposed but a consensus has not yet been reached. For a long time, the resource competition theory (Woollacott & Shumway-Cook 2002) was the dominant explanation for dual tasking induced changes in older adults' balance performance. However, as a result of the series of studies showing both increases and decreases in displacement of the COP during dual tasking, the adaptive resource–sharing framework has been presented (Mitra 2003, Mitra 2004, Mitra & Fraizer 2004). This theory states that the different patterns found in postural control in dual task situations may originate either in limitations of capacity or in intentional activity to facilitate the completion of the second task, or both.

An increased risk for falls among residents in sheltered accommodation who stopped walking when they started a conversation with the therapist was first shown by Lundin-Olsson et al. (1997). Since then, a number of studies have examined further the association between dual tasking and falls, using various measures of postural balance and second tasks done simultaneously. Probably due to disparities in study designs, the age of the study participants and the measures utilized, the findings have been conflicting (Shumway-Cook et al. 1997, Bloem et al. 2000, Shumway-Cook & Woollacott 2000, Condron & Hill 2002, Bootsma-van der Wiel et al. 2003, Hauer et al. 2003). Beauchet et al. (2005) showed that among frail older adults, aged 85 years and older, dual-task related gait changes were correlated with polymedication, poor distance vision, abnormal mobility and cognitive impairment (intrinsic risk factors for falls). Only few studies of dual tasking and falls with prospective fall surveillance exist (Bootsma-van der Wiel et al. 2003, Bergland & Wyller 2004). The association between dual tasking and fall risk has most often been studied among people of 75 years and older. In this age group, however, the manifestation of age-related deteriorations in physical and mental functions as well as diseases may affect dual tasking differently than among 'younger' old people.

The role of genetic and environmental influences accounting for individual differences in postural balance in older people

A relatively small number of studies have reported on the contribution of genetic influences to traits related to physical functioning, especially among older people (Frederiksen & Christensen 2003). Among younger people, the genetic influences on such physical fitness-related traits such as running speed, flexibility, and limb movement have been studied but the results vary depending on age group, gender, and the study population (Bouchard & Malina 1983, Malina 1984).

Recently, there has been an increased interest in determining the genetic influence on phenotypes important for performing the activities of daily life and for independent living at home. The most widely studied have been muscle function and related phenotypes (Perusse et al. 1987, Reed et al. 1991, Arden & Spector 1997, Thomis et al. 1997, Carmelli & Reed 2000, Katzmarzyk et al. 2001, Frederiksen et al. 2002, Tiainen et al. 2004, Tiainen et al. 2005). However, evidence for genetic influences on postural balance is limited. In young children, 46% of the individual differences in the ability to hold the flamingo stance were accounted for by genetic influences (Maes et al. 1996). Only Carmelli and colleagues (2000) have reported estimates of the genetic influences contributing to balancing ability among older people. They tested standing balance with tandem, semi-tandem and side-by-side stance tests in 68 to 79–year-old men. The composite score of the balance tests was not accounted for by genetic influences, although 39% of the overall lower extremity sum scale (including tests of walking 8-feet, repeated chair stands and balance) was accounted for by additive genetic influences. The reason why this study did not find genetic influences responsible for the variability in test performance may arise from the ceiling effect. Most of the older male participants had the highest test score.

2.2 Falls in older people

Of the various definitions of a fall, lately the most favoured has become that presented by the Kellogg International Work Group on Prevention of Falls by the Elderly (1987): a fall is 'an event in which the person unintentionally comes to rest on the ground, floor, or other lower level for other that sudden onset of acute illness or overwhelming external force'. Standardization of the definition of a fall as well as methods of identifying falls across studies is essential for comparing and pooling research results in order to provide a foundation for assessment and preventive interventions.

Much research has been performed to determine the risk factors for falls in older people. Most studies have been retrospective, using information on falls obtained for a given period, most often from the preceding year. Recall bias may distort the results in retrospective studies, as older people who have had multiple falls or falls without serious consequences may not remember all their falls. In addition, in retrospective studies, particularly in case-control studies, previous falls may already have adversely influenced the risk factors under study. Therefore, studies with a prospective design provide more reliable information on risk factors for identifying people at risk for future falls (Stalenhoef et al. 1997, Stalenhoef et al. 2002, Chu et al. 2005, Ganz et al. 2005).

Falling once increases an older person's susceptibility to fall again, with 15% of older people falling at least twice a year (Tinetti et al. 1988, Nevitt et al. 1989, O'Loughlin et al. 1993, Tromp et al. 1998). To sustain a minor injury when falling increases the probability of suffering from a future fall with more serious consequences (Herala et al. 2000). Recent research suggests that the mechanism of falls as well as an individual's propensity to fall are even more important predictors of hip fracture than decreased bone mineral density (Wei et al. 2001, Marks et al. 2003). Women sustain more non-fatal fall-related injuries than men (Stevens 2005, Stevens & Sogolov 2005). As osteoporosis is also more common in women, they have been considered to be more prone than men to fall related hip fractures. Nevertheless, falling and fall-related injuries in older people precipitate impairments in daily functioning, premature institutionalization, morbidity, and even mortality (Tinetti 1986, Cumming 1996, Tinetti & Williams 1997, Brown et al. 1999, Nurmi et al. 2004). For these reasons, the efficient identification of people at risk for falls and early prevention are of paramount importance in a rapidly growing older population.

Risk factors for falls

In recent years, the accumulated results of numerous fall studies have been collated in several reviews and guidelines. This work has been done with clinical practice in mind (Stalenhoef et al. 1997, AGS guideline 2001, Gillespie et al. 2003, Moreland et al. 2003, Skelton & Beyer 2003, Gillespie et al 2004, Skelton & Todd 2004, NICE 2004, Kannus et al. 2005a). The risk factors for falls are numerous and the risk factors for community dwelling persons and those in extended care facilities are different, which makes risk factor assessment complex. Pooling the findings of the studies done to elucidate the most important risk factors has also been difficult due to the heterogeneity of study designs and methods (Stalenhoef et al. 1997). Most important risk factors for falls suggested by the guidelines laid down by the American Geriatrics Society (2001) and The National Institute for Clinical Excellence (2004) include personal history of falls, mobility/ADL impairment, balance and gait deficits, muscle weakness, cognitive and visual impairment, incontinence, depression, multiple medication, fear of falling and environmental hazards.

The key issue in identifying people at the highest risk for falls is to use methods relevant to the setting and characteristics of the older population for whom the assessment is done (Perell et al. 2001). Fall risk factors are typically categorized into intrinsic and extrinsic risk factors. These factors are multifaceted and interact with each other; thus, it is very seldom that any one of these factors alone is found to underlie a single fall (Tinetti et al. 1988, Campbell et al. 1989, Lipsitz et al. 1991, AGS guideline 2001, NICE 2004).

Intrinsic risk factors for falls

Characteristic of intrinsic risk factors for falls is that they are often related to age- or disease-induced impairments or deficits in physical or sensory functions. Intrinsic risk factors include age, gender, history of falls, living alone, ethnicity, medication (digitaloids, neuroleptics, antidepressants), medical conditions, sedentary behaviour, psychological status, nutritional deficiencies, anemia, impaired cognition/dementia, visual impairment, foot problems and pain (Tinetti et al. 1986, Nahit et al. 1998, Rawsky 1998, Bueno-Cavanillas et al. 2000, Leveille et al. 2002, Skelton & Todd 2004, Pennix et al. 2005, Volpato et al. 2005). These factors typically underlie falls among older ”old” and frail people, who often are long–term care residents (Robbins et al. 1989, Luukinen et al. 1994, Feder et al. 2000). An association between intrinsic factors and, especially, recurrent falls has been established in several studies, including those among community-dwelling older people (Tinetti et al. 1988, Nevitt et al. 1989, Graafmans et al. 1996, Lord et al 1994, Stalenhoef et al. 1997, Stalenhoef et al. 2000, Tromp et al. 2001, Fletcher & Hirdes 2002, Chu et al. 2005, Pluijm et al. 2006). Intrinsic factors often seem to be related to falls that occur indoors (Bath & Morgan 1999, Bergland et al. 2003).

Extrinsic risk factors for falls

A hazardous environment can cause a person in any age group to fall. For older people, challenges presented by the environment may cause a fall more easily. Due to decreased functional capacity, along with carelessness or intentional risk-taking behaviour, older people are prone to failure in negotiation with the environment. Extrinsic fall risk factors include, for example, poor lighting, uneven surfaces, stairs, inappropriate footwear or slippery conditions. Extrinsic factors are considered principally to underlie the falls of people under 75 and living in the community. Inconsistent evidence, however, exists as to the effectiveness of prevention targeted at the management of hazardous factors in the home environment alone (Tinetti et al. 1995, van Haagstregt et al. 2000, Hogan et al. 2001, Day et al. 2002, Gillespie et al. 2003). The most physically active people fall due to their behaviour (Gregg et al. 2000), but many seemingly healthy older people also suffer from undetected intrinsic risk factors for falls, which may make them more prone to falls following extrinsic exposures.

Genetic risk factors for falls

The role of genetic influences on falls has not previously been studied. The only existing study providing some information of the role of genetic influences on falls is that by Kannus and colleagues (1999). They studied genetic influences on osteoporotic fractures among twins 55 years of age and older. In most cases, fractures were associated with a fall. These data showed that variation in the risk for fall-related osteoporotic fracture among older women was only weakly associated with genetic factors. The association was somewhat stronger among men, but the authors comment that this finding should not be emphasized because of the low statistical power of the study due to the low incidence of fractures and thus low number of concordant pairs among the male participants.

Such intrinsic risk factors for falls as muscle function, cognitive abilities and physical activity include a genetic contribution (Arden & Spector 1997, Carmelli et al. 2000, Carmelli & Reed 2000, deGeus et al. 2001, Frederiksen & Christensen 2003, Tiainen et al. 2004). In addition, the symptoms and consequences of some diseases that predispose older people to fall have a genetic etiology (Kaprio et al. 1992, Spector et al. 1996, Tesfaye et al. 1996, Vague et al 1997, Carmelli et al. 1998). Hence, one might assume that genes play a role in determining older people's susceptibility to falls.

2.3 Quantitative genetic methods

Quantitative genetic theory is built on the universal Mendelian principles according to which every individual has two copies of each gene. Genes can exist in various forms that are called alleles. Alleles account for the variation in traits and they are located in a specific site on a chromosome called loci. A single allele for each locus is inherited from each parent and alleles at a given locus are randomly inherited with equal probability in the offspring. According to Mendel's second law, alleles of genes at different loci are usually transmitted independently of each other. However, this independence is limited by a phenomenon called linkage: alleles from loci of the same chromosome may tend to be transmitted together (Plomin et al. 2001).

The science of quantitative genetics was introduced at the beginning of the 20th century. Sir Francis Galton (1822-1911) is called as a father of human behavioral genetics. The first explicit descriptions of the classical twin design were stated in 1924 by Curtis Merriman and Herman Siemens (Rende et al. 1990). Quantitative genetics is based on the proposition that genetic variation leads to phenotypic variation. With the statistical methods of quantitative genetics it is possible to disentangle the relative contribution of genetic and environmental sources of variance in a given trait, but not to identify the specific genes that determine a particular phenotype. A phenotype is determined by effects of genes and environment and/or their interaction, and can be defined as the observable status of a trait. Determination of genetic and environmental influences can be done by utilizing data from the subjects who are at least to some degree genetically or environmentally related. For this purpose, family, adoption or twin designs are applied. Classical twin method, in which the data comprise mono- and dizygotic twins, has several advantages over the pure family or adoption designs. Family design, does not allow for differentiation of the role of genetic and shared environmental influences on a trait if no twins are included. This can be done with the twin and adoption designs. Adoption data, however, are more laborious to obtain, and may be biased by prenatal conditions or selective placement (Neale & Cardon 1992, Falconer & Mackay 1996, Martin et al. 1997, Rijsdiik & Sham 2002, Posthuma et al. 2003).

The basic assumptions of the classical twin design include random mating, the absence of or only minor interaction between genes and environment, an environment that affects similarly to both MZ and DZ twins, and that the twin pairs selected are a representative sample of the general population (Martin et al. 1997, Rijsdiik & Sham 2002).

Components of variance

The total phenotypic variance of a trait is the sum of the following components: Additive genetic influences (A) represent the effects of the individual alleles at all loci that influence the trait. Non-additive genetic influences (D) represent interactions between alleles at the same locus (dominance) or at different loci (epistasis). Shared environmental influences (C) denote such influences of environment that affect similarly both siblings and may originate in conditions throughout the lifespan, from uterus to old age. Non-shared environmental influences (E) include all influences that make twins more dissimilar and these influences can act either in childhood (e.g. distinct parental treatment of co-twins) or in adulthood (e.g. accidents, workload). E also includes possible measurement error. In the classical twin design which includes a sample of twins reared together, C and D are confounded and, thus, cannot be estimated simultaneously. Moreover, to disentangle the effects of shared environmental and genetic dominance, data from half-sibs or non-biological relatives reared together are needed (Neale & Cardon 1992, Falconer & Mackay 1996, Lynch & Walsh 1998, Plomin et al. 2001, Rijsdiik & Sham 2002).

Determining the genetic and environmental influences on a trait or phenotype

Comparison of MZ and DZ twin similarity is the basis of estimation of the relative importance of genetic and environmental influences. The core of this comparison and further genetic modelling is the knowledge that MZ twins share all their genetic material, whereas DZ twins share on average 50% of their segregating genes. For co-twins who are reared together, environmental influences are partially shared and, in consequence, the correlation of the influence of C is 1 for both MZ and DZ co-twins whereas non-shared environmental influences do not correlate between twins.

Correlations (or concordances) between mono- and dizygotic twins offer a tentative clue as to the importance of the underlying genetic and environmental influences contributing to the studied trait. According to the quantitative genetic theory, a greater correlation between MZ twins compared to DZ twins demonstrates the importance of the contribution of additive genetic influences to the phenotypic variability of a given trait. When genetic dominance is more pronounced, the DZ twin correlation is below half the MZ twin correlation.

Structural equation modelling (SEM) is currently the most often used method to analyse twin data, and it provides a detailed estimation of the genetic and environmental influences on the phenotypic variance of a trait. The advantages of SEM over examining the effect of genetic influences by comparing MZ and DZ correlations are that from SEM parameter estimates are obtained with confidence intervals and standard errors. Again modelling allows testing of the relative goodness of the fit of the different models with the data.

Assessment of genetic influences on categorical data

The maximum information about complex traits such as related to physical functioning and health resides in their measurement on a continuous scale; therefore any attempt to divide the scale into discrete categories will cause a loss of analytical power (Neale et al. 1994). However, in some cases data are measured on a nominal scale. The traditional statistics calculated for binary traits is twin concordance. Pairwise concordance is the relative number of twin pairs in whom an event has affected both co-twins. The casewise concordance rate reflects the probability that if one co-twin is affected his/her co-twin will also become affected. When the data collection is done by complete ascertainment, the casewise concordance rate is identical to probandwise concordance rate and indicates the risk for recurrence (Smith 1974, Rijsdiik & Sham 2002). Within categorical data, estimation of the genetic and environmental factors can be obtained by model fitting when the distribution of the likelihood of a measured trait is assumed to be continuous and it is possible to specify one or more thresholds to define categories (Falconer & Mackay 1996, Lynch & Walsh 1998, Neale & Maes 2004).

Multivariate modelling

Quantitative genetic research has traditionally examined whether and to what extent genetic influences contributes to a given trait. Recent advances in the statistical techniques of genetic modelling have broadened the possibilities of investigating the relationships between traits or various aspects of the same trait assessed by different measurements. The quantification of whether genetic and environmental influences are in common or specific for various traits can be done using multivariate genetic design (Plomin et al. 2001, Rijsdiik & Sham 2002, Neale et al. 2003, Posthuma et al. 2003). These allow calculation of the genetic and environmental correlation between two variables and estimation of the genetic and environmental influences contributing to the observed covariance. Genetic, as well as environmental correlation cannot be interpreted as a direct indicator of phenotypic correlation or to show the direction of the causation; merely it exposes the nature of the causes of covariation between two traits. Genetic influences in common may have very distinct effects on each of the traits, which genetic correlation cannot elucidate (Posthuma et al. 2003).

The multivariate models commonly used to assess genetic and environmental influences on the covariation of phenotypically intercorrelated traits are common-factor independent pathway (biometric) model and common-factor common pathway (psychometric) model. The basic disparity between these models is that in the psychometric model, covariation between variables is first modelled as an underlying latent factor. Then the genetic and environmental influences contributing to this factor are estimated. In the biometric model, estimation of genetic and environmental influences in common accounting for the covariation of the measured variables is performed. Both models also determine variable specific genetic and environmental influences (Neale & Cardon 1992, Martin et al. 1997, Rijsdiik & Sham 2002). Because it takes into account not only within-pair covariances but also within-person and cross-trait information, multivariate analysis is thought to increase the power of the estimation of genetic and environmental components of variation (Schmitz et al. 1998).

When interpreting the results of studies in which the estimates of genetic and environmental influences are determined, some caveats need to be considered. The estimates generated from a given study refer only to that particular population. The estimated value of the genetic influences does not permit conclusions to be drawn about how a trait or phenotype in a single individual can be explained by his or her genes. Moreover, these estimates do not refer to particular genes or to specific environmental factors. In addition to referring to a specific population, the estimates of genetic and environmental influences are also age- and sex-specific.

Knowledge of the contribution of genetic and environmental influences strengthens understanding the relative role of different types of influence on a given trait, such as whether the family environment or other environmental influences are of major importance. In addition, genetic epidemiological studies showing that genetic influences account for population variation in a certain trait, serve as a useful starting point for gene identification.

3 AIMS OF THE STUDY

The first aim of the present study was to explore the role of genetic influences in determining variation in postural balance, measured as a single task and when dual tasking, among a population-based sample of older women. Secondly, this study aimed to determine the possible genetic influences contributing to susceptibility to falls. The third aim was to the study the ability of force platform balance tests to predict falls among community-dwelling older women.
The specific aims of this study were:

1. to estimate the relative contribution of genetic and environmental influences to individual differences in balance performance while standing and walking
2. to study the effect of dual tasking on balance performance while standing and walking
3. to estimate the relative contribution of genetic and environmental influences to individual differences in dual task performance while standing and walking
4. to estimate the relative contribution of genetic and non-genetic influences to variation in fall susceptibility
5. to study the utility and validity of force platform-based balance measures in assessing postural balance and predicting risk for falls

4 PARTICIPANTS AND METHODS

4.1 Participants

Recruitment

This study was a part of the Finnish Twin Study on Aging (FITSA), which began in year 2000 at the University of Jyväskylä in collaboration with the University of Helsinki. The FITSA participants were recruited from the Finnish Twin Cohort (Kaprio et al. 1978, Kaprio & Koskenvuo 2002), which comprises all the same-sex twin pairs born before 1958 and in which both co-twins were alive in 1975 (n=13 888 twin pairs). In August 2000, there were 1260 female twin pairs in the age group 63 to 76 years. From this group, those who had participated in Finnish Twin Cohort study in 1975 were selected for the FITSA study. To obtain the most powerful sample for the genetic analyses, it was aimed to recruit as equivalent number of MZ and DZ twin pairs as possible. Hence, 178 MZ, 212 DZ pairs and 24 pairs of previously undetermined zygosity (XZ) were invited. Three participation criteria were set: participation of both co-twins, ability to walk 2 km and ability to travel independently to the research center. The number of participants in the final sample is presented in figure 1.

The FITSA study protocol was approved by the ethics committee of the Central Hospital of Central Finland and each participant signed a written informed consent.

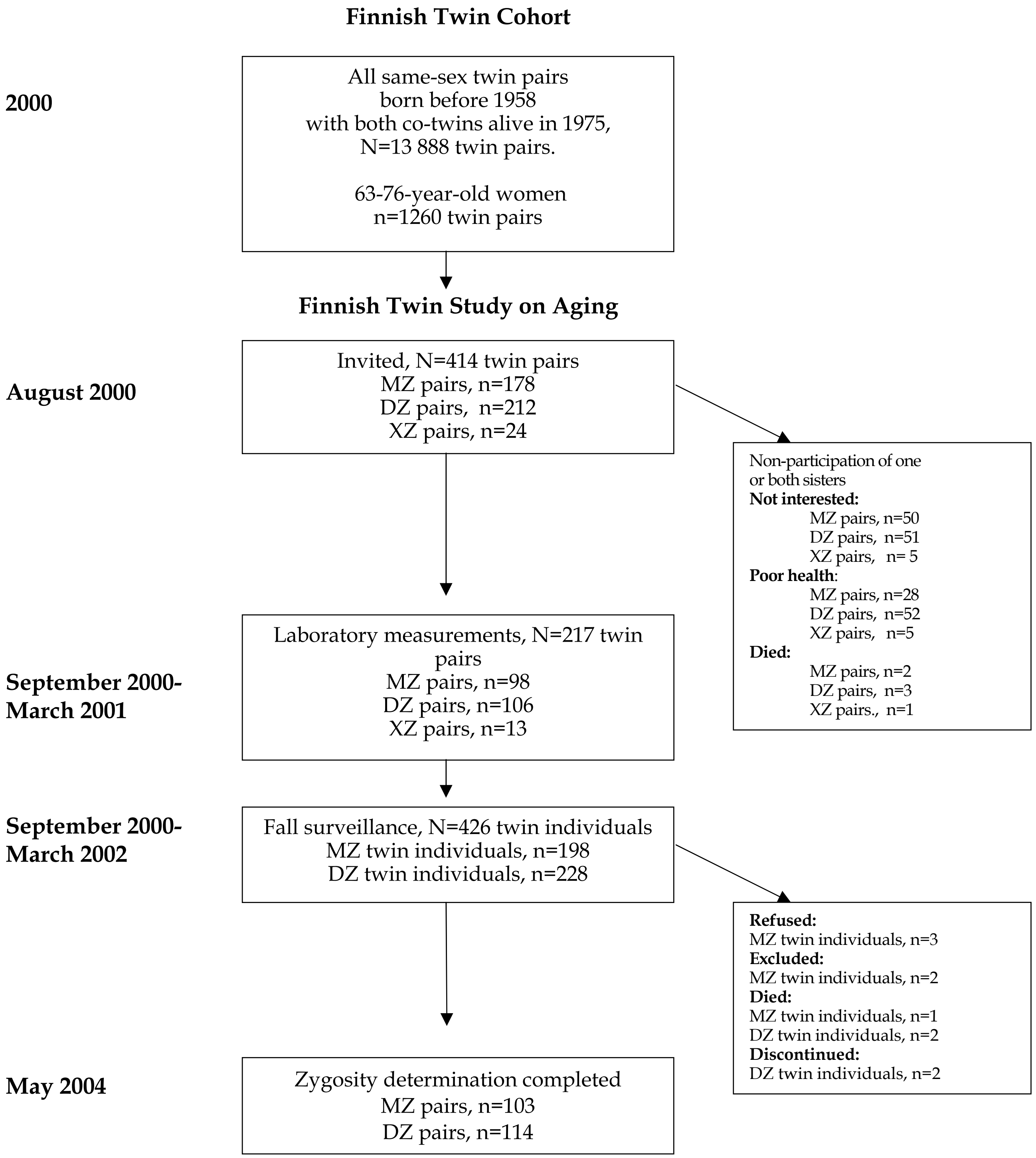

FIGURE 1 Recruitment of the participants, participation in the laboratory measurements and follow-up for falls, and reasons for non-participation and dropout.

Zygosity

Initially, in conjunction with the Finnish Twin Cohort study, twins were determined as MZ, DZ or XZ twins in 1975 using a validated questionnaire (Kaprio et al. 1978, Sarna et al. 1978) in which both twins answered questions about their similarity of appearance in childhood. For the FITSA participants, zygosity was confirmed using genomic DNA and a battery of ten highly polymorphic gene markers. After this procedure, the FITSA participants consisted of 103 MZ and 114 DZ twin pairs.

Background information of health, functional ability and physical activity

Participants' body height and weight were measured and maximal isometric knee extension strength (method described in Tiainen et al. 2004) and the Mini-Mental State Examination (MMSE) (Folstein et al. 1975) tests were done in the laboratory. The questionnaire used to assess physical health status, diseases, mobility problems and smoking was based on questionnaires used in the earlier epidemiological (Guralnik et al. 1995, Heikkinen 1997) and twin studies (Kaprio et al. 1978). Participants indicated the chronic conditions they had from the following list: Coronary heart disease, cardiac failure, hypertension, pulmonary diseases, asthma, multiple sclerosis, Parkinson's disease, arthrosis, rheumatoid arthritis, fibromyalgia, gout, deficiency or hyperactivity of the thyroid gland, diabetes and cancer. Disease status was ascertained during a clinical examination by a physician. Data on the use of prescribed medication was obtained by interviewing the subjects and noting prescriptions. Physical activity was assessed using the scale initially developed by Grimby (1986). Accordingly, participants were classified as sedentary (light walking two or fewer times a week), moderately active (walking or comparable light exercise, at least three times a week) or active (moderate or vigorous exercise at least three times per week).

4.2 Measurements of balance and walking

Measurement protocol

The balance and walking test data for the present study were collected together with the laboratory measurements of the FITSA participants that took place at the Sports and Health Laboratory at the University of Jyväskylä. The complete battery of laboratory examinations lasted approximately 5 hours per participant and comprised measurements of physical functions, tests of functional abilities, and an examination and an interview by a physician. Balance and walking tests, were conducted during the afternoon for all participants. The balance tests were preceded by a 30-min rest interval. The balance tests were carried out by two and the walking tests by three trained physiotherapists working on alternate days. Testers were not informed about the zygocity of the participants.

Force platform balance tests

The purpose of force platform measurements of balance is to register and analyze the vertical forces a person positioned on the platform applies to the base of support. The Good Balance system (Metitur Ltd., Jyväskylä, Finland) was utilized to gather the present force platform data. The main components of the system are a triangular force platform with sides of 800 mm, strain-gauge transducers connected to a three-channel DC amplifier, and a 12-byte analogue-to-digital converter and computer. During measurement, analogue signals from the transducers are amplified for A/D conversion and then transformed into digits at a frequency of 50 Hz. The digits are then passed and stored in the computer.

Measurement data processing was done using Good Balance software. The medio-lateral (x) and antero-posterior (y) coordinates of the center of pressure (COP) were calculated. The calculated error in the x and y coordinates of the COP is less than 1.0 mm when the mass of the subject is at least 40 kg (Good Balance-User's manual 2000).

Four variables were derived from the measurement data: the velocity (mm/s) of the medio-lateral (ML) and antero-posterior (AP) movement of the centre of pressure (COP) was calculated on the basis of the displacement of the COP during each second of the test; the mean moment of velocity (VEL; mm^2/s), which was calculated as the mean of the areas covered by the movement of the COP during each second of the test; and the length of the medio-lateral bandwidth (ML-BW; mm), which represents the smallest distance of COP movement in the medio-lateral direction from the center point of the test and includes 90% of the registered measurement data. To control for possible influence of a higher location of the centre of mass among the taller subjects, balance measures were adjusted for the subject's height [(balance variable/subject height) x 180] (Era et al. 1996). Previous studies have proven the reliability of the standing balance tests (Hofmann 1998, Sihvonen & Era 1999).

Six balance tests were conducted on the force platform. During the side-by-side Eyes Open (side-by-side EO), side-by-side Eyes Closed (side-by-side EC), dual tasking with a motor task (DT handmotor) and dual tasking with an arithmetic task (DT arithmetic) tests, the participant stood in stockinged feet in a self-selected, natural and comfortable stance, with the feet side-by-side 15 to 25 cm apart. In these tests, the arms were held in a relaxed position in front of the body with the hands clasped together. In the semi tandem eyes open test (semi tandem EO) one foot was placed half a foot length ahead of the other, with feet touching and in the tandem eyes open test (tandem EO) the feet were positioned heel-to-toe along the midline of the platform. During the semi tandem EO and tandem EO tests, the participants were instructed to keep their arms down by their sides. Under eyes open tests, gaze was fixed at the marked point at eye level, two meters in front of the participant.

In the DT handmotor test, the participant held a switch in her hand and was asked to press the button, using only the thumb, as rapidly possible whenever she saw a light signal at the gaze fixation point. Eight signals were given with varying intervals between them. In the DT arithmetic test, the participant was asked to count backwards in threes, starting with a randomly selected number between 90 and 100 which was revealed to the participant just before the test commenced. Calculation was done mentally and answers were spoken out loud. The participant was encouraged to maintain a motionless stance while doing the calculations, which were to be performed as rapidly and as free from errors as possible.

One trial was performed in each test and the tests were performed in the following order for all participants: Side-by-side EO, side-by-side EC, side by side, semi-tandem EO, tandem EO, DT handmotor and DT arithmetic. Between tests the participant was allowed to sit and rest for a few minutes. In all tests, recording started when a balanced stance had been attained and lasted 30 seconds. In the semi-tandem EO and tandem EO tests, the recording time was 20 seconds.

Walking tests

Walking over 10 meters was measured in the laboratory corridor with three tests: walking at maximal speed (MWS), walking at maximal speed while doing a second motor task (MWSmanual) and walking at maximal speed while doing a second verbal task (MWSverbal). MWS was done twice and the fastest performance recorded as a result. In the MWSmanual, the participant carried a glass full of water. In the MWSverbal, the participant was asked to recite as many male or female names starting with a given letter (K, S, or T) as possible. Participants were encouraged to perform as best they could in all these tests, without compromising their safety. Timing was done using photocells and started after a three-meter acceleration path. Participants wore walking shoes or sneakers, and were allowed to use a walking aid if needed. Safety was ensured by an examiner walking behind the participant. For the analyses, walking speed (m/s) was calculated by dividing the 10-m distance by the time taken.

The reliability of the walking tests was studied among a sample of 20 women aged 60-70 years by replicating the tests after an interval of 1–2 weeks. The coefficients of variation for MWS, MWSmanual, and MWSverbal were 4.6%, 7.2%, and 8.7%, respectively.

The effect of a second task on balance and walking test performance

The effect of a second task on the force platform balance test performance and walking speed was studied by calculating the percentage change in the dual task test result compared to the single task test according to the following formula: $|[(\text{single task} - \text{dual task}) / \text{single task}] \times 100|$ (Li et al. 2001, deRibaupierre & Ludvig 2003). The absolute value obtained from the equation was used to express dual task cost (DTC).

4.3 Fall surveillance

Fall data were gathered over the twelve-months following to the participants visit to the laboratory, using the fall calendar method (Tinetti et al. 1993). At the end of each month, the participant mailed the calendar page, each day marked fall or no fall, to the research center. If the participant forgot to mail the calendar, she was reminded by a telephone. When a fall was reported, a research assistant called the participant and asked about the occurrence, location, circumstances, causes and consequences of the fall. Participants reporting multiple falls during a one-month period were not always able to recall each fall in detail and, therefore, complete interview data were obtained for 89% of all falls reported. The number of those excluded, refused and dropouts during the follow-up are shown in figure 1, page 34.

For study IV, three dichotomous outcome variables were constructed. Fallers with 'at least one fall' included participants who fell at least once, and fallers with 'at least one injurious fall' comprised those who sustained at least one fall resulting in an injury during the follow-up period. Injuries included fractures or bruises, laceration or pain. Participants with two or more falls during the follow-up, regardless whether the falls caused an injury or not, were classified as 'recurrent fallers'. In study V the number of falls was entered into the models as continuous variables and analyses were performed separately for those with falls overall, with indoor falls and with outdoor falls only.

4.4 Statistical analyses

Data handling, assessment of the normality of the distributions of the variables, and calculation of the phenotypic and intra-class correlations (ICCs) were performed with the SPSS program (Rel.11.5.1, 2001). Differences in the means and distributions of the continuous background variables between the zygocity groups and between the fall groups were examined using a design-corrected t-test (adjusted Wald test). This was done to account for the lack of statistical independence of the twin observations. That is, when sampling twin pairs, the statistical interdependence of co-twins has to be taken into account in order to derive correct standard errors and p-values. For these procedures STATA statistical software was utilized (Stata Corp., 2003).

Individual based analyses

In study V, twins were analyzed as individuals and therefore the modelling was performed using STATA software because the software can accommodate the statistical interdependence of twins. Associations between the balance variables and falls were assessed using negative binomial regression models. Fall events are non-independent observations since falls tend to be recurrent events and the occurrence of a single fall makes a subsequent incident more likely (overdispersion). Negative binomial regression models estimate the number of occurrences of an event when the event has Poisson variation with overdispersion. The model also allows variable follow-up times for participants. Strength of the association was expressed as Incidence Rate Ratios (IRR), which represent the risk associated with the expected unit increase in the predictor variable or as the risk for persons in the categories of the predictor variable relative to those in the reference category.

For the regression modelling, each of the movement of COP variables was categorized as follows: those who were not able to perform the tests were assigned the value zero ('unable'); the categories 'high', 'middle' and 'low' were formed on the basis of tertiles of each test variable distribution. Number of falls was a count variable. IRRs with 95% confidence intervals (CIs) were estimated, first, by comparing those unable to complete the balance test with those who had a test result and secondly, for the occurrence of falls between each COP tertile, using the lowest tertile (best performers) as the reference group. IRRs were calculated separately for falling indoors, falling outdoors and falling overall. P-values <0.001 were applied to show the significance of the risk estimates. The significance level was set at $p < 0.05$ after Bonferroni correction.

Analyses of the twin data

In studies I-III twin analysis was applied to assess the contribution of genetic and environmental influences on falls, balance, walking and dual tasking. The preliminary information on the possible role of genetic influences on these traits was obtained by comparing within-twin pair correlations between MZ and DZ twins (studies I-III). In study IV, a similar analysis was done by using pairwise and casewise concordances owing to the dichotomous nature of the variables.

The estimates of the genetic and environmental influences accounting for the individual differences in phenotypes were obtained by using structural equation modelling and statistical programs suited to the research questions and the data. In study I, the data were first condensed with a measurement model and the genetic models elucidating the relative contribution of genetic and environmental influences to the factors in the measurement model were constructed using LISREL software (Jöreskog & Sörbom 1999). In studies II-III, bivariate Cholesky composition models and independent pathway models were applied to estimate the genetic and environmental influences in common and specific to the phenotypes included in the model. Modelling was carried out using the MX program (Neale et al. 2003). In study II, genetic and environmental correlations were used to assess the extent to which genetic or environmental influences in common contributed to balance performance in single and dual task situations. In study IV, the genetic models for the categorical outcome variables were constructed by applying the liability threshold model approach (Posthuma et al. 2003).

5 RESULTS

5.1 Baseline characteristics of the study participants

Baseline age, BMI, MMSE, number of prescription medications and chronic conditions, maximal isometric knee extension strength, difficulty in walking and climbing up one flight of stairs, physical activity level, self rated health and present smoking for MZ and DZ twins are shown in table 1. There were no significant differences between MZ and DZ twins in these physical characteristics. Participants who had at least one fall or had only outdoor falls during the fall follow-up did not differ significantly from non-fallers with respect to their physical characteristics. However, those who fell indoors had higher BMI, more prescribed medication, reported more difficulties in mobility and more often had a history of falls compared to those with only outdoor falls or no falls.

5.2 Dual task cost of balance and walking performance

On average, dual tasking while balancing or walking impaired the test performance. Mean COP movement in dual tasking with the arithmetic task was significantly ($p<0.05$) greater than the mean COP values of the single task balance test, but no significant difference in mean COP movement in dual tasking with the handmotor task compared to single task test values were found. Dual tasking while balancing caused either an increase or decrease in COP movement. When performing the DT handmotor test, COP movement increased in 50% of the participants and decreased in 50%, whereas in the DT arithmetic test COP movement increased on average by 70% and decreased by 30%. In the walking tests, most of the participants slowed their walking speed while concurrently performing either the manual or verbal task, but the decrease in walking speed was greater when performing the verbal task.

TABLE 1 Baseline physical characteristics of monozygotic (MZ) and dizygotic (DZ) twins. Means and standard deviations (SDs) of the continuous variables, and frequency and percentages for the categorical variables are given.

Variable	MZ twin individuals n = 206 mean (SD)	DZ twin individuals n = 228 mean (SD)	*p value*
Age (year)	68.3 (3.7)	68.9 (3.1)	*0.252*
BMI (kg/m^2)	28.0 (4.8)	28.0 (4.7)	*0.938*
MMSE (score)	27.2 (2.4)	26.7 (2.2)	*0.076*
Number of prescription medication	2.1 (2.4)	2.0 (1.9)	*0.728*
Number of chronic conditions	2.1 (1.5)	1.9 (1.4)	*0.386*
Maximal isometric knee extension strength (Newton)	296.3 (81.0)	287.0 (85.6)	*0.338*
	n (%)	n (%)	
Physical activity			
- sedentary	56 (27)	67 (29)	*0.605*
- moderately active	102 (50)	118 (52)	
- active	48 (23)	43 (19)	
Self-rated health			
- poor/fair	12 (6)	10 (4)	*0.270*
- good	129 (63)	162 (71)	
- very good/excellent	65 (32)	56 (25)	
Difficulty in walking 2 km	18 (9)	19 (8)	*0.889*
Difficulty in climbing up one flight of stairs	50 (24)	68 (30)	*0.209*
Present smoking	7 (3)	13 (3)	*0.323*
Fallen within 12 months before the follow-up	40 (19)	44 (19)	*0.977*
Fear of falling	93 (45)	80 (35)	*0.051*

BMI=body mass index, MMSE=Mini-Mental State Examination

TABLE 2 Percentage change (dual task cost, %) in force platform balance test performance and maximal walking test performance while dual tasking compared to the single task performance.

Tests	Dual-task cost (%) mean (SD)
Force platform balance tests	
DT handmotor	
Medio-lateral velocity	29.5 (28.1)
Antero-posterior velocity	20.4 (16.0)
Velocity moment	48.1 (49.0)
Medio-lateral bandwidth	39.3 (45.1)
DT arithmetic	
Medio-lateral velocity	36.4 (23.8)
Antero-posterior velocity	31.3 (21.6)
Velocity moment	56.2 (47.6)
Medio-lateral bandwidth	55.6 (71.5)
Walking tests	
MWSmanual	11.2 (8.0)
MWSverbal	20.8 (10.4)

DT=dual tasking, MWS=maximal walking speed

The dual task costs of the balance and walking tests, denoting the absolute percentage change in balance or walking performance when doing second tasks compared to the single task are presented in table 2. In the DT arithmetic test, the average number of correct answers was 10.6 (SD 5.7) and the number of errors was 1.2 (SD 1.6). In the maximal walking speed test with the verbal task, the mean number of names recited during the test was 5.9 (SD 1.9).

5.3 Genetic and environmental influences contributing to balance and walking in single and dual task situations

Force platform balance test performance in single and dual task situations

The results of the force platform balance tests in single and dual task situations are presented in the table 3 for MZ and DZ twins separately.

TABLE 3 Results of the force platform balance tests in single and dual task situations for MZ and DZ twins.

COP movement variables of force platform balance tests	MZ twin individuals Mean (SD)	DZ twin individuals Mean (SD)	***Equality of means*** *p value*
Medio-lateral velocity (mm/s)			
Side-by-side EO	4.6 (1.8)	4.5 (1.7)	*0.390*
Side-by-side EC	6.1 (3.1)	5.7 (2.8)	*0.210*
Semi-Tandem EO	15.5 (4.4)	14.8 (3.9)	*0.174*
Tandem EO	23.8 (6.4)	23.4 (6.3)	*0.705*
DT, handmotor task	4.4 (1.7)	4.6 (1.9)	*0.169*
DT, arithmetic task	6.0 (3.1)	7.2 (4.3)	*0.006*
Antero-posterior velocity (mm/s)			
Side-by-side EO	8.0 (2.7)	8.1 (2.7)	*0.761*
Side-by-side EC	12.3 (5.4)	12.6 (6.6)	*0.536*
Semi tandem EO	11.7 (3.9)	11.7 (4.1)	*0.955*
Tandem EO	17.2 (6.6)	17.8 (7.9)	*0.645*
DT, handmotor task	7.7 (2.8)	8.2 (2.5)	*0.061*
DT, arithmetic task	10.8 (6.5)	12.2 (7.2)	*0.025*
Velocity moment (mm^2/s)			
Side-by-side EO	14.4 (8.9)	14.2 (8.6)	*0.736*
Side-by-side EC	26.1 (27.6)	24.3 (28.0)	*0.626*
Semi tandem EO	47.1 (26.5)	47.8 (31.6)	*0.628*
Tandem EO	85.4 (47.8)	94.4 (76.1)	*0.413*
DT, handmotor task	12.7 (8.4)	14.0 (9.2)	*0.118*
DT, arithmetic task	24.5 (32.4)	32.9 (38.2)	*0.005*
Bandwidth (mm)			
Side-by-side EO	9,1 (4.2)	8.7 (3.7)	*0.427*
Side-by-side EC	10.4 (5.8)	9.6 (4.9)	*0.173*
Semi tandem EO	23.3 (6.4)	22.7 (6.4)	*0.390*
Tandem EO	24.8 (6.3)	25.4 (7.3)	*0.575*
DT, handmotor task	8.2 (4.3)	8.5 (4.4)	*0.570*
DT, arithmetic task	10.5 (6.3)	12.4 (9.1)	*0.015*

COP=center of pressure, MZ=monozygotic, DZ=dizygotic, EO=eyes open, EC=eyes closed, DT=dual tasking, SD=standard deviation

The within-pair correlations of the COP displacement variables for MZ twins exceeded those of DZ twins. In study I, the information on the measured balance test variables was first combined into the measurement model as shown in figure 2. In this model, the majority of the variance of the measured COP displacement variable loaded on to the second-order BALANCE factor.

The contribution of genetic and environmental influences to the factors BALANCE, AP sway and Semi-Tandem EO in the measurement model was then estimated. The model providing the best explanation for the data suggested that additive genetic influences (A) accounted for 35% and individual environmental influences shared with the twin pairs (C) for 24% of the variation in the BALANCE factor. Additionally, the genetic and individual environmental influences specific to the AP Sway factor accounted for 51% and 49% of the factor variance, respectively. Further, the variance of the Semi-Tandem EO factor was partially mediated by genetic and environmental influences contributing to the BALANCE factor and partially due to influences specific to this factor.

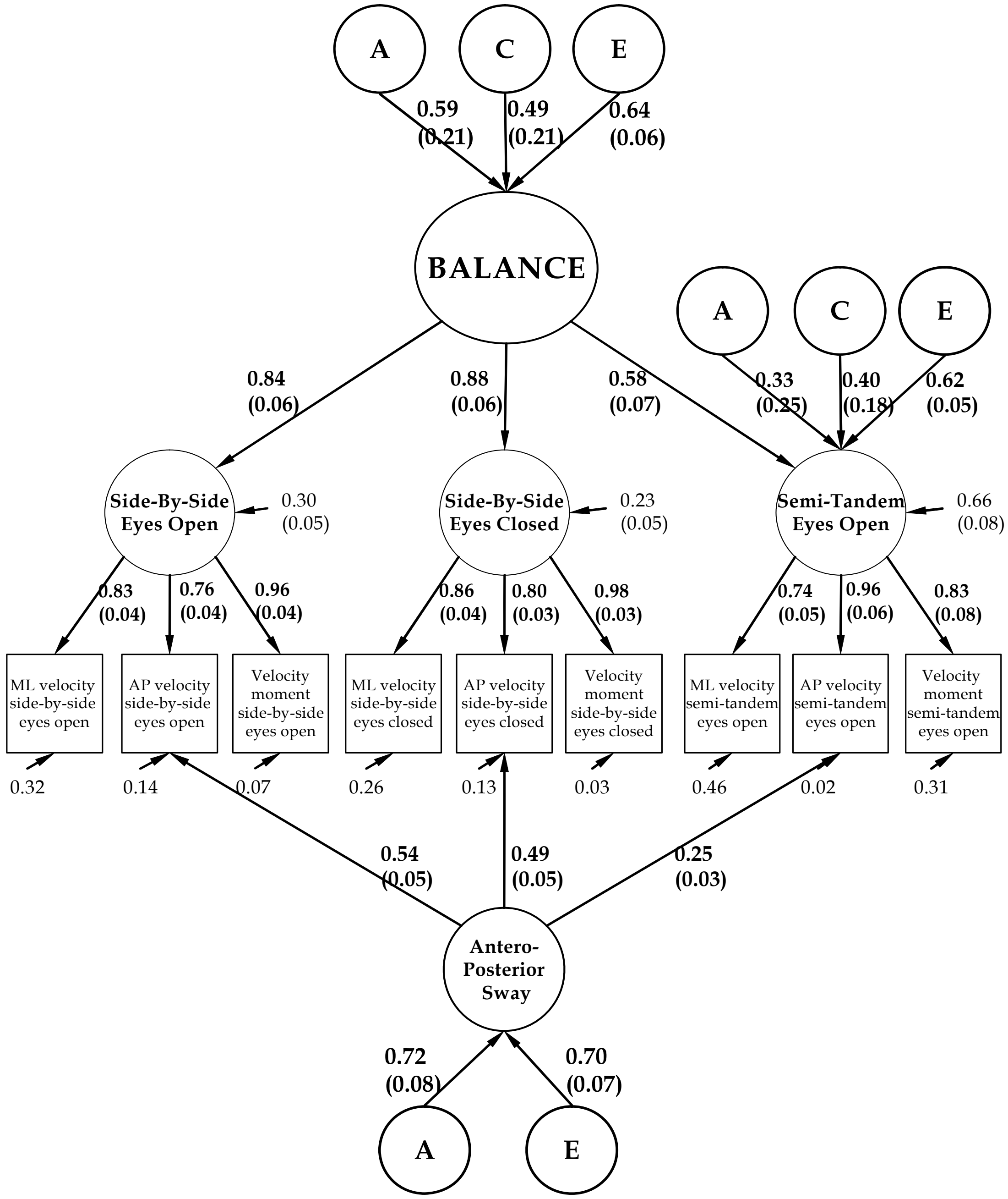

FIGURE 2 The path diagram of the model comprising the measurement model for the balance test variables and the additive genetic (A), non-additive, familial influences (C) and specific environmental effects (E) explaining the variance in the latent factors of the measurement. The measured balance test variables are shown in boxes and latent factors in circles. Path coefficients (standard errors) for first- and second-order factors and residuals for the balance test variables and first-order factors are shown. The contribution of A, C and E to the variance of BALANCE factor is 35%, 24% and 41%, respectively. For Semi-Tandem EO factor, A accounted for 11%, C 16% and E 38% of the variance. For Antero-Posterior factor, 51% of the variance was accounted for by A and 49% for by C. (ML=medio-lateral, AP=antero-posterior)

As in study I, in the analyses of the study II the balance test data from the single- and dual task tests were first combined into two factors, Single task Balance and Dual Task Balance (figure 3). Additive genetic influences accounted for 14% of the variation in Single Task Balance factor and 28% of the Dual Task Balance factor. Both shared and non-shared environmental effects accounted for the remaining variance of these phenotypes. The genetic and environmental correlations showed, that the majority of both genetic and shared environmental influences were in common to these phenotypes (r_g=1.00, 95% CI 0.00-1.00, r_c= 0.81, 95% CI 0.1-1.0). The non-shared environmental effects were mainly specific to the performance of the single and dual tasks (r_e= 0.06, 95% CI 0.00-0.14).

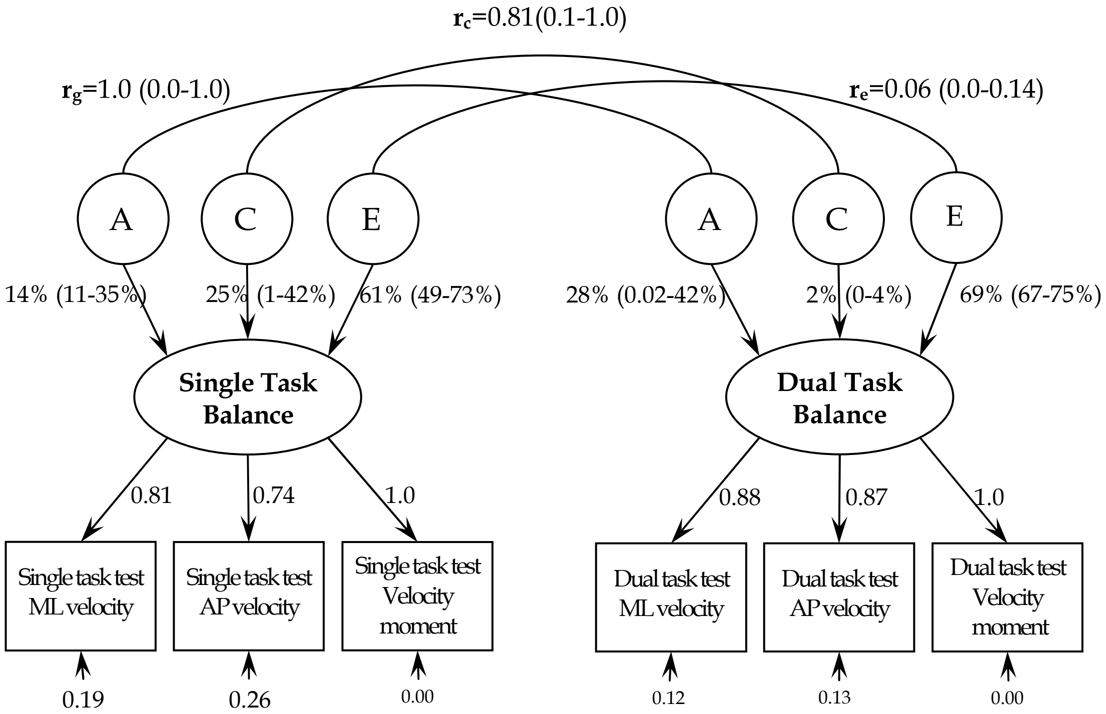

FIGURE 3 Path diagram of the model with the Single Task Balance factor and Dual Task Balance factor, and the additive genetic (A), shared environmental (C), and non-shared environmental (E) influences explaining the variation in these factors. Factor loadings and residuals of the balance variables are shown. r_g represents genetic correlation, r_c denote correlation between shared environmental influences, and r_e is correlation between shared environmental influences. (ML=medio-lateral, AP=antero-posterior)

Genetic and environmental influences accounting for the variation in maximal walking speed in single and dual task situation

The results of the walking tests are presented in table 4 for MZ and DZ twins separately. No significant differences between the MZ and DZ groups were found.

TABLE 4 Results of the walking tests with and without a second task, and within-twin pair correlations for mono- (MZ) and dizygotic (DZ) twins.

	MZ twin individuals	DZ twin individuals	*Equality of means*	Pairwise correlations	
	Mean (SD)	Mean (SD)	*p value*	ICC_{MZ}	ICC_{DZ}
Walking tests					
MWS (m/s)	1.74 (0.35)	1.70 (0.31)	*0.405*	0.61	0.48
MWSmanual (m/s)	1.52 (0.28)	1.52 (0.24)	*0.759*	0.53	0.29
MWSverbal (m/s)	1.35 (0.29)	1.37 (0.25)	*0.362*	0.47	0.27

MWS = Maximal walking speed, MZ=monozygotic, DZ= Dizygotic, ICC = Intraclass correlation

The pattern of the MZ and DZ twin correlations for the walking tests implied the presence of genetic influences (Table 4). First, bivariate models for MWS and MWSmanual, and MWS and MWSverbal were fitted to the data. These models showed that genetic, shared and non-shared environmental influences contributing to walking speed with or without another task overlapped. With the trivariate independent pathway model, the magnitude of the genetic and environmental influences underlying MWS, MWSmanual, and MWSverbal in common or specific to each test was specified. The reduced ACE model provided the best explanation to the data, showing that 17%, 19% and 12% of the variability in MWS, MWSmanual and MWSverbal, respectively, was accounted for by additive genetic influences (A_c) in common. MWSverbal had specific A which accounted for 10% of the variability. In addition, the model suggested that shared (C_c) and unique environmental (E_c) factors in common explained individual differences in the walking tests with and without a second task, and specific E for each test separately. Standardized estimates with 95% CIs are shown in figure 4.

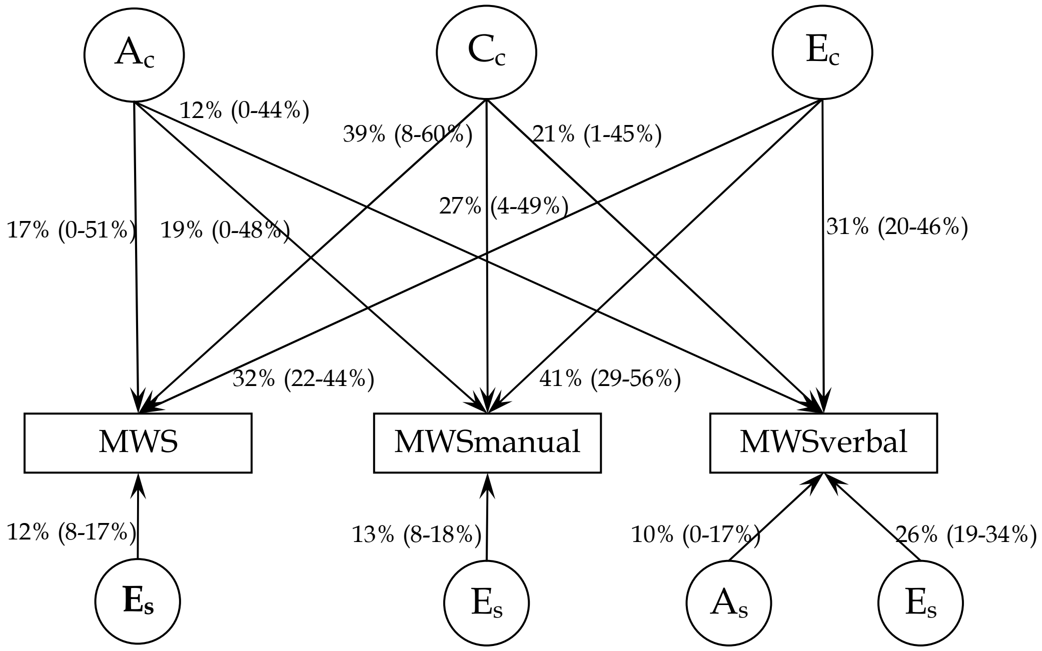

FIGURE 4 Reduced best-fitting independent pathway model for maximal walking speed measured without a second task (MWS), with manual task (MWSmanual) and with verbal task (MWSverbal). Additive genetic influences (A), shared environmental influences (C), and unique environmental influences (E) accounting for the variance are shown. Lowercase *c* refers to influences common to all traits and lowercase *s* refers to influences specific to each trait.

5.4 Genetic factors accounting for susceptibility to falls

Incidence of falls

Fall data over the follow-up period of 12 months (4854 person months) was obtained from 426 participants. The fall incidence was 8.9 falls per 100 person months (0.75 falls/year/person). Mean follow-up time was 344 (SD 41) days and median time to first fall was 106 days. At least one fall was sustained by 198 participants, 118 had at least one injurious fall and 91 had recurrent falls. The participants who experienced a fall during the follow-up year had significantly more often had a fall during the preceding year (24%), than non-fallers (15%). The majority of falls (79%) occurred outdoors and during daytime (80%), with most of the falls taking place in home backyard or on the street or walkway. In all, 132 participants experienced 213 outdoor falls. Fifty-seven participants had 81 indoor falls and almost half of them had at least one outdoor fall. Of 188 fall-related injuries (in 43% of all falls during the follow-up) reported, only a few had serious consequences: one head injury, five upper limb or arm fractures, one knee and one ankle fracture. The mean monthly number of falls in winter (from November to April, 37.5, SD 6.8) did not differ from the number of falls the summer (from May to October, 34.8, SD 9.2). Table 5 summarizes the total number of falls and fallers in different fall groups.

TABLE 5 Number of falls and number of participants with at least one occurrence in different fall groups.

Fall variable	n
Number of	
all falls	434
injurious falls	188
indoor falls	81
outdoor falls	213
Participants	
with at least one fall	198
with at least one injurious fall	118
with recurrent (≥2) falls	91
with at least one indoor fall	57
with at least one outdoor fall	160
with outdoor falls only	132

The genetic modelling of susceptibility to falls was done utilizing three outcome variables: 'at least one fall', 'at least one injurious fall' and 'recurrent falls'. Numerically higher pairwise and probandwise concordances for MZ than DZ pairs for each of these outcome variables (Table 6) suggested that familial influences may contribute to falls. Genetic modelling showed that additive genetic influences accounted for 35% (95% CI 8-58%) and 45% (95% CI 16-69%) of the susceptibility to at least one fall and recurrent falls, respectively. For the susceptibility to injurious falls, shared familial influences contributed 20% (95% CI 0-42%) to susceptibility to at least one injurious fall, while the rest of the variance was explained by non-shared non-familial influences.

TABLE 6 Pairwise distributions of twins with at least one fall, at least one injurious fall and recurrent falls.

Falls	Individuals with a fall n	Discordant pairs n	Concordant pairs n	Pairwise concordance‡ (95% CI†)	Probandwise concordance§ (95% CI)
At least one fall					
MZ	99	39	30	0.43 (0.32- 0.56)	0.61 (0.49- 0.72)
DZ	97	49	24	0.33 (0.23- 0.45)	0.49 (0.37- 0.62)
At least one injurious fall					
MZ	64	39	12	0.24 (0.13- 0.38)	0.38 (0.23- 0.53)
DZ	54	36	9	0.20 (0.07- 0.37)	0.33 (0.17- 0.50)
Recurrent falls					
MZ	52	29	11	0.28 (0.16- 0.45)	0.43 (0.26- 0.60)
DZ	39	25	7	0.22 (0.10- 0.40)	0.36 (0.17- 0.55)

† Confidence interval, ‡ Pairwise concordance is calculated by the following formula: concordant pairs / concordant pairs + discordant pairs, § Probandwise concordance is calculated by the following formula: 2 x concordant pairs / (2 x concordant pairs + discordant pairs)

5.5 Force platform balance measures as predictors of falls

In all, 82 participants were unable to complete the tandem EO test. For these people, IRR for falling indoors was 4.33 (95% CI 2.17- 8.52, $p<0.05$ after Bonferroni correction), for falling outdoors 1.01 (95% CI 0.54- 1.92, $p>0.05$) and for falling overall 1.96 (95% CI 1.15- 3.34, $p<0.05$) compared to those who did obtain a result for tandem EO test.

IRRs were also computed for falling indoors or outdoors according to the COP movement tertiles for each balance test. The results of these analyses showed that those in the highest tertile for antero-posterior COP movement in the side-by-side stance tests done with the eyes open or with the eyes closed as well as those in highest tertile for the semi-tandem EO test had an approximately four-fold risk for falling indoors as compared to those in the lowest tertile for the distribution of same variables (table 7). These values remained significant after Bonferroni correction for multiple tests. The dual tasking balance test was not found in the present data to predict people at increased risk for falls. When considering outdoor falls or all falls as outcomes, no systematic predictive effects of the COP variables were observed.

TABLE 7 Incidence rate ratios (IRRs) and confidence intervals (95 % CIs) from negative binomial regression models for falls indoors in the middle and highest COP movement tertiles in force platform balance tests in community-dwelling 63- to 76-year-old women. The lowest tertile of COP movement is the reference group.

Balance test/ COP movement variable	Indoor falls Middle IRR (95% CI)	 *p-value*	 Highest IRR (95% CI)	 *p-value*
Side-by-side EO				
ML velocity	0.99 (0.49-2.00)	*0.985*	2.71 (1.26-5.82)	*0.011*
AP velocity	0.92 (0.41-2.07)	*0.845*	**3.76 (1.76-8.13)**	***0.001****
Velocity moment	0.99 (0.47-2.09)	*0.985*	3.00 (1.40-6.45)	*0.005*
Bandwidth	0.74 (0.35-1.56)	*0.427*	2.40 (1.21-4.74)	*0.012*
Side-by-side EC				
ML velocity	0.79 (0.40-1.57)	*0.506*	2.18 (1.11-4.30)	*0.024*
AP velocity	1.90 (0.86-4.19)	*0.113*	**4.33 (1.91-9.84)**	***≤0.001****
Velocity moment	1.53 (0.72-3.26)	*0.272*	3.59 (1.58-8.13)	*0.002*
Bandwidth	1.36 (0.68-2.75)	*0.388*	2.96 (1.44-6.06)	*0.003*
Side-by-side DT arithmetic task				
ML velocity	0.74 (0.38-1.45)	*0.387*	1.64 (0.83-3.24)	*0.155*
AP velocity	1.56 (0.78-3.13)	*0.210*	2.27 (1.03-5.01)	*0.043*
Velocity moment	0.99 (0.50-1.97)	*0.984*	1.76 (0.85-3.66)	*0.126*
Bandwidth	1.24 (0.63-2.44)	*0.535*	1.64 (0.76-3.56)	*0.206*
Semi-tandem EO				
ML velocity	1.21 (0.66-2.24)	*0.535*	1.50 (0.74 -3.47)	*0.234*
AP velocity	2.54 (1.17-5.53)	*0.019*	**4.08 (1.84-9.06)**	***0.001****
Velocity moment	0.93 (0.46-1.88)	*0.834*	2.65 (1.32-5.31)	*0.006*
Bandwidth	0.93 (0.48-1.79)	*0.822*	1.69 (0.85-3.34)	*0.132*
Tandem EO				
ML velocity	1.24 (0.55-2.81)	*0.607*	1.07 (0.51-2.25)	*0.850*
AP velocity	0.78 (0.32-1.90)	*0.582*	1.06 (0.53-2.13)	*0.865*
Velocity moment	1.61 (0.65-3.97)	*0.300*	2.35 (0.97-5.69)	*0.057*
Bandwidth	1.44 (0.66-3.14)	*0.357*	1.20 (0.52-2.76)	*0.663*

COP = center of pressure, EO = eyes open, EC = eyes closed, DT = dual tasking, ML=medio-lateral, AP=antero-posterior,

* Significant at the level P = 0.05 after Bonferroni correction

6 DISCUSSION

This population-based study among 63- to 76-year-old community-dwelling women suggested that the genetic influences on postural balance while standing or walking accounted for 14 to 35% of individual differences. However, it is noteworthy that the role of genetic influences in explaining individual variation in balance tasks in which performance was challenged by stance difficulty or by dual tasking, was more pronounced than the genetic contribution to the more simple balancing tests. This finding was consistent for dual tasking while standing and dual tasking while walking. In addition, the present study showed that familial factors explained 35-45% of the variability in susceptibility to falling and recurrent falls. Individual differences in risk for injurious falls, however, were accounted for solely by non-genetic influences. Finally, the present study showed the force platform balance method to be a valid measure for the assessment of postural balance as it was able to identify older people at an increased risk for falling indoors.

Genetic influences on postural balance when standing, walking and dual tasking, and on susceptibility to falls

Comparison of the estimates obtained by the present study on the genetic contribution to postural balance, dual tasking and fall susceptibility in older people with those of other studies is limited. Only few prior studies exist and these studies differ in the age and gender of samples as well as the methods to assess postural balance. Among 10-year–old children, 46% of the variability in the ability to hold one-leg stance on a narrow beam for one minute was accounted for by genetic influences (Maes et al. 1996) and among 70- to 76-year-old men no evidence of genetic influences on variability in standing balance test performance was observed. However, in an 8-foot walk at the participant's usual speed, genetic influences accounted for 42% of the test score variance (Carmelli et al. 2000). In that study, most participants reached the maximum score of the balance test battery suggesting a ceiling effect, which caused lack of variability in the test scores and made the estimation of the genetic and environmental components difficult. Another study among 75- to 79-year-old women showed 15-35% heritability in a functional ability score which was based on self-report and included several items related to walking ability (Christensen et al. 2000, Christensen et al. 2003). To our knowledge, no previous reports of genetic influences on risk for falls in older people exist. In the study by Kannus et al. (1999) there was no genetic contribution to variation in fall-related osteoporotic fractures. With due precaution, this result can be considered to support the present finding that solely non-genetic influences contribute to susceptibility to injurious falls.

The present study is first to present estimates of genetic and environmental influences on postural balance and falls. The data, obtained on a population-based sample of older people, and the use of methods that provide itemized information on balance and falls to capture distinct phenotypic variation in these traits, enhanced the reliability of the present estimates of genetic and environmental influences. Due to lack of comparable previous studies, we proceeded to seek explanations for our findings from existing knowledge of the role of genetic and non-genetic influences underlying phenotypes such as the balance control systems and the risk factors for falls.

Central information processing is basic to postural control. With increasing age, the capacity of the central nervous system to process appropriately the afferent signals from multiple sources may deteriorate and consequently impair postural control. Situations in which dual tasking challenges balance control pose additional strain on the central nervous system (Lajoie et al. 1993, Maylor & Wing 1996, Marsh & Geel 2000, Teasdale & Simoneau 2001). Many phenotypes of CNS functioning such as cognitive functioning (McGue & Christensen 2001, Reynolds et al. 2002, Lee 2003, Reynolds et al. 2005), executive control (Swan & Carmelli 2002), and information processing speed (Reynolds et al. 2002, Swan & Carmelli 2002) are known to be highly heritable. On that account, it is plausible that genetic influences contributing to postural balance are partially mediated through genetic influences involved in the central nervous structure and processing.

The present results showed that when balance was performed under dual task situations the role of genetic influences was more pronounced than when balancing was done as a single task. In addition, a task-specific genetic factor was found to account for the variation in the walking test while doing a cognitively challenging verbal task. Performing two tasks simultaneously has been found to require additional attention and cognitive resources (Teasdale et al. 1993, Maylor & Wing 1996). As central functions and processing are substantially heritable, it can be concluded that the more pronounced role of genetic influences in explaining individual variation in dual task performance arises from underlying mental processes. In addition, measures of attention have found to be at least moderately correlated to genetic factors in children and young adults, but their heritability in older people is not known (Doyle et al. 2005). However, recent molecular genetic studies have suggested an association between attention deficit hyperactivity disorder (ADHD) and the polymorphism of several genes, such as the genes coding for nicotine acetylcholine receptor alpha 4 subunit (CHRNA4) (Todd et al. 2003) and dopamine transporter (DAT1) (Bellgrove et al. 2005). These deficits in turn may influence the performance of complex tasks, making them more challenging for older than young adults (Verhagen & Cerella 2002), and indicating that age-related deficits possibly exist in attention-related processes. Therefore, attentional abilities may also be a potential underlying phenotype mediating the genetic influences on dual tasking in the case of balance and a second cognitively challenging task.

Phenotypes related to brain structure deserve to be taken into account as possible candidates mediating genetic control of postural balance. For example overall volume of the brain, midline cross-sectional area of the corpus callosum, and lateral ventricle size are suggested to remain highly heritable, even in old age (Pfefferbaum et al. 2000, Thompson et al. 2001). However, thus far, limited evidence exists of the genetic influences on specific brain areas known to contribute to postural control. The cerebellum is of particular importance to postural control (Ouchi et al. 1999) but thus far, a genetic contribution to variance in cerebellar volume has been found only among young adults (Posthuma et al. 2000).

Recently, evidence on the correlation of cerebral white matter abnormalities with gait and postural balance dysfunction in older persons has been presented (Longstreth et al. 1996, Whitman et al. 2000, Benson et al. 2002, Baloh et al. 2003, Starr et al. 2003, Rosano et al. 2005). Carmelli et al. (2002) showed that genetic influences accounted for 70% of the variability in white matter hyperintensities and, in the multivariate genetic model, overlapping genes explained 12% of the phenotypic association between WMHs and lower extremity functioning. Similarly, with multivariate genetic analyses, it would be possible to ascertain to what extent the genetic influences responsible for the central nervous system are in common with postural balance.

During quiet stance, as under stationary force platform test conditions, peripheral sensation has a significant role in maintaining balance (Brocklehurst et al. 1982, Era et al. 1997, Lord & Mentz 2000). In the present study, most of the variability in the COP movement parameters obtained from the test done with eyes open and with eyes closed could be combined into a single factor in the measurement model. Such a factor would describe the functions of postural control systems other than vision, such as tactile sensitivity and proprioception. Among non-clinical populations, only a limited amount of information about the heritability of tactile sensitivity exists. In the present study, we observed that, among our sample of rather healthy older women, the correlation of vibrotactile threshold in the foot was higher in MZ twins (r_{MZ}=0.40) than in DZ twins (r_{DZ}=0.11) (unpublished data), which may suggest that genetic influences are also important in sensation perception in the population at large. Peripheral neuropathies often underlie distal sensory loss, which in turn may have a debilitating effect on balance control (Bergin et al. 1995). To date causative mutations in 17 genes have been identified to underlie monogenetically inherited neuropathies (Kuhlenbaumer et al. 2002) and genetic variation in intron 4 of the TNF-R2 gene (TNFRSF1B) (Benson et al. 2002) and the presence of the ATP1 A1 gene variant (Vague et al. 1997) have been identified to predispose their carriers to diabetic peripheral neuropathy. Thus, genetic mechanisms governing postural balance may also include genetic influences on tactile sensitivity. More studies are needed to disentangle the association.

For the older women in the present study, COP movement was greater during the force platform test with eyes closed than with eyes open. When maintaining balance during walking, visual feedback may be even more important and poor vision is reported to be one of the major risk factors for falls. In older people, 75% heritability of hyperopia has been shown (Teikari et al. 1990) and the genetic contribution to such common age-related diseases as cataract has been suggested to be 48 to 58% (Hammond et al. 2000). Among the women in the present study, 81 (19%) reported cataract in one or both eyes, but almost half of the cases had been treated surgically. Nevertheless, the genes contributing to the visual system and the etiology of the age- or disease-related deteriorations in visual functioning may mediate genetic influences contributing to walking ability and falls in particular.

Relatively common diseases among older people such as diabetes and arterial and venous diseases have been shown to be associated with impaired mobility and increased risk for walking limitations (Lamb et al. 2000, Volpato et al. 2003). These diseases have been shown to have familial background (Kaprio et al. 1992, van't Hoof et al. 1999, Pistorius 2003). Although the prevalence of acute diseases and chronic conditions was low among the present participants, for example only 25 (6%) participants reported that they had physician diagnosed diabetes, we cannot rule out that genetic predisposition to specific diseases may also underlie the genetic effects on postural balance, walking and fall risk.

Muscle function plays a central role in maintaining an upright stance and walking (Moreland et al. 2004) and impaired strength is one of the main risk factors for falls (AGS guideline 2001, NICE 2004). In balance control, however, the co-ordination and timing of corrective movements are essential, and muscle force is usually produced at sub-maximal levels. In healthy people with good postural control, walking requires only minimum strength. However, among people with impaired balance, some deficits may be compensated for by using more muscle force (Rantanen et al. 1999, Rantanen et al. 2001). The heritability of muscle function has been reported to vary from 31% to 48% depending on the muscle group and function of which is measured (Arden & Spector 1997, Tiainen et al. 2004, Tiainen et al. 2005). Among the present sample of older women, genetic influences in common were found to account for the variance of maximal walking speed, isometric knee extension strength and leg extensor power (Tiainen et al. 2006). However, no evidence exists to show that muscle strength and postural stability share a genetic component. It is nevertheless a possibility that genetic influences on muscle function may mediate genetic influences contributing to balance and susceptibility to falls.

Greater body size increases the challenge to the different postural control systems (Era et al. 1997). Obesity is a risk factor for walking limitation (Lamb et al. 2000). On the other hand, in frail older people, especially, low BMI is related to risk for injurious falls (Davis et al. 1999, Willig et al. 2003). Body height and weight are highly heritable (Korkeila et al. 1991, Maes et al. 1997, Silventoinen et al. 2000). In the present study, even after adjusting the force platform balance results for height, COP movement in the more difficult standing positions confirmed to correlate with height. Antero-posterior COP movement, especially, correlated with body mass. Moreover, overweight was relatively common in the present sample, with 28% of the women having BMI > 30. Thus, there may be genetic correlation between body size and postural balance, walking and risk for falls.

As described above, cognitive abilities, muscle function, body height and weight, and diseases, which are often considered as intrinsic risk factors for falls, have been shown to have a moderate to high genetic component. Intrinsic factors predispose older people, especially, to recurrent falls. Therefore, although our data were limited to disentangling whether familial factors contributing to susceptibility to falls arise from genetic or shared non-genetic familial influences, it is reasonable to suggest that genetic factors are involved in determining fall susceptibility and in particular, susceptibility to recurrent falls. Regardless of whether familial influences arise from genes, shared environment or both of these sources, the current findings underline the importance of taking the familial history of falls into account in fall risk assessment. Fall injuries typically take place when the impact of the fall is increased such as when falling on stairs or landing on a hard surface (Hill et al. 1999). Moreover, active older people are often exposed to unexpected situations or to a hazardous environment, and therefore may be more prone to injurious falls (Gillespie et al. 2003). Thus, given that an injurious fall is usually a consequence of intervening situational or behavioral factors, our finding that it is non-genetic factors that predominantly account for the susceptibility to injurious falls is a plausible one.

Non-familial sources of variability in postural balance when standing, walking and dual tasking, and on susceptibility to falls

A clinically important finding of the present study was that factors that are related to the environment and to behaviour, for example, health habits, are the major contributors to postural balance when standing, walking and dual tasking and to susceptibility to falls. However, a more specific definition of these factors and whether there is any one external factor that can explain a major part of the variance in balance control remains to be elucidated in future studies. Although attempts to specify the most important environmental factors are warranted, it should be emphasized that genetic and environmental factors are in continuous interplay. Changing one component changes the relative role of the others in explaining individual differences in a given trait. Therefore, further information is also needed about the nature of the interaction between genetic and environmental factors in determining balance and walking ability before interventions to modify this interaction can be developed.

In terms of falls, our finding of a substantial association between non-genetic factors and susceptibility to falls may be explained by the relatively good health and young age of our study sample. Among people aged 75 years and younger, falls are more often related to situational factors or specific activities. In the present study, falls often occurred when the participant was walking on an uneven surface or while engaged in outdoor activities. This pattern of falls is comparable to that found in previous studies among 'young old' people (Luukinen et al. 1994, Bath & Morgan 1999). However, since the relative importance of functional limitations and diseases as risk factors for falls increases with age (Feder et al. 2000), further studies are needed to determine the role of genetic and non-genetic influences in susceptibility to falls among older 'old' people.

Dual tasking while balancing on a force platform and while walking

In keeping with previous findings, dual tasking impaired balance performance while standing and walking in the older women in the present study. Cognitively more challenging tasks, such as counting or memorizing caused greater change in balance performance than for example motor tasks. This supports to former conceptions that second tasks have to be difficult enough to impose a sufficient load on the attentional capacity. Among older people, attentional resources are often limited due to age-related deterioration in central information processing capacity. Dual tasking creates competition for attentional resources, which typically results decrements in one or both tasks (Shumway-Cook et al. 1997). Change in balance performance may thus occur when the difficulty of the second task taxes the central nervous system beyond its capacity (Lajoie et al. 1993, Teasdale et al. 1993).

Dual tasking is common in the activities of daily life. Performing two cognitively challenging tasks simultaneously impairs performance in either or both tasks in both young and old people. In old people, however, dual tasking taxes performance more than among young adults (Lindenberger et al. 2000). Several theoretical frameworks have been established to explain the dual tasking phenomenon. However, the validity of these theories remains undetermined in older people. Traditionally, studies have adduced the resource competition theory to explain the dual task phenomena (Woollacott & Shumway-Cook 2002). Our finding that COP movement both increases and decreases when balancing while dual tasking is in line with the adaptive resource sharing framework. Adaptive resource sharing emphasises that the different patterns found in postural control in dual task situations may originate either in limitations of capacity or in intentional activity to facilitate the completion of the second task, or both (Mitra 2003, Mitra 2004, Mitra & Fraizer 2004). The applicability of the adaptive resource-sharing framework has been neglected among older adults. However, on the basis of the present findings we are inclined to propose this framework a candidate in explaining dual tasking performance in older people as well.

The older women in the present study did not have major cognitive impairments or such diseases that would have considerable impact on central capacity. Thus, capacity limitations may not have contributed exclusively to balance control when dual tasking. It is also possible that balance performance was adapted in accordance with how difficult the second task was perceived to be, how the attention was best allocated between the tasks or how closely the participant followed the instruction given. Behavioural choices on whether to perform each task separately or both tasks concurrently may also have their origin in individual differences attributable to genetics.

The dual task tests utilized in the present study were selected on the basis that similar tests have been used in previous studies among older people. Our tasks provided to be feasible for the present participants, as most of them were capable to complete the dual task tests. However, the handmotor task may have been too easy to challenge the allocation of attentional resources and thus produce a marked dual task effect on balance performance. As we did not record the reaction time of the handmotor task, we were unable to conclusively to determine the reasons for the lack of a dual task effect. It is probable that fixing the gaze at the point where light signal was located may have augmented the stability of the upright posture while doing the hand motor task. In the balance test with the arithmetic task, we cannot exclude the possibility that the increase in displacement of the COP may be partially due to the additional head movement caused by giving verbal responses. Tasks including articulation may also produce an increase in COP movement due to changes in respiration or the motor performance of speaking (Dault et al. 2003). Nevertheless, it is arguable that movement of the head or trunk originated in the inability to concentrate on the balance task, i.e. maintain a motionless stance, and thus in fact reflected the dual task effect.

The protocol of the present study did not permit the participant to rehearse the tasks and each participant did the tests in same order. However, adequate test-retest reliability of balance tests with a second task have been found previously (Condron & Hill 2002) and evidence for a systematic learning effect in a dual task test in older people is inconsistent (Condron & Hill 2002, Dault et al. 2003).

In contrast with our presupposition, dual tasking while balancing on a force platform did not predict fall risk among the present sample of older people. Bergland & Wyller (2004) were able to find an association between falls and dual tasking while balancing on a force platform among women aged 75 and over. In our study, balance performance deteriorated while dual tasking, but it is possible that second tasks did not challenge central control of posture sufficiently to reveal such balance impairments that would have exposed the women of the present study to falls.

Prospective fall surveillance in older people

On average, every second participant had at least one fall during the 12- month follow-up, which is in accordance with previous studies in community-dwelling older women (Tinetti et al. 1988, Nevitt et al. 1989, Bath & Morgan 1999, Hill et al. 1999). However, the present rates of injurious and recurrent falls were somewhat higher than in previous studies. Of fallers, almost 60% had at least one fall with an injury and 50% had an additional fall or falls during the follow-up year. The higher rates are possibly due to good compliance by the present participants and the effectiveness of the calendar method of collecting fall data. Further, interviews about the details of falls were carried out very shortly after the fall incident. This is important, as older people with recurrent falls, especially, tend to forget the causes and consequences of falls.

In the present data, serious injuries were rare, only eight people sustaining a fracture or other serious injury. However, over half of the falls caused minor injuries such as pain, strains and contusions. In older people fall injury events that require medical attention are significant due to the burden they impose on public health resources. However, older people with soft tissue or other minor fall-related injuries have an increased risk for nursing home placement (Tinetti & Williams 1997) and increased risk for falls with more severe consequences. (Herala et al. 2000). Falls with minor consequences may trigger a vicious circle of adverse effects, with fear of falling limiting the performance of daily activities, leading to deterioration in health and mobility, and eventually predisposing older people to additional falls. The present study supported the previous findings of a rather high incidence of falls with minor injuries, which suggests that falls with non-serious injuries should receive more attention in fall assessment and in targeting preventive actions. Our data showing that susceptibility to injurious falls was influenced primarily by non-genetic factors supports the importance of interventions to prevent the development of the vicious circle of falls leading to more serious falls.

The force platform method in assessment of balance and predicting falls in older people

The force platform method provides accurate and detailed information on the success of the postural control systems in balance maintenance when standing. The present study showed that among older community dwelling people, the majority of whom had no evident balance impairment, poor performance on the force platform balance test predicted increased risk for indoor falls. Prior to the present study, Bergland et al. (2003) also found a relationship between force platform balance test performance and indoor falls. In both studies, people who fell indoors had several diseases, multiple medication and poor mobility, suggesting a relationship between these intrinsic risk factors and indoor falls. Interestingly, this relationship was present even though our participants were seemingly healthy and had no major balance or mobility disability. This finding emphasizes the importance of assessing balance with sufficiently sensitive instruments to capture slight, but clinically important deteriorations in postural control. Noted by Piirtola & Era (2006), only few prospective studies have addressed force platform measures of balance as predictors for falls and the findings have been conflicting. The present study provides evidence that supports the suitability and validity of this method in predicting fall risk among older people.

Of the COP variables, increased antero-posterior COP movement, in particular, predicted falls in the present study. Most of the earlier studies, however, have found medio-lateral COP movement to best predict future falls (Maki et al. 1994, Bergland et al. 2003, Stel et al. 2003, Piirtola & Era 2006). Such differences in study designs as the older age of the participants, type of force platform tests used and the COP movement parameters derived from the measurement data, together with variation in the determination of fall outcome may partially explain the differences between the present and previous findings. In the present force platform tests with feet side-by-side, stance width was not predetermined. Therefore, participants with balance deficits may have chosen a wider stance, which may in turn have affected the ability of these tests to capture real deficiencies in medio-lateral COP control. Indirect evidence that impaired medio-lateral control predicts falls, however, was obtained from our finding that inability to complete the tandem stance test, in which balance is compromised by a narrow base of support, predicted increased risk for falling indoors. Our finding that inability to complete the force platform test is predictive for falls is in agreement with studies showing an association between inability to complete the 10-second tandem test and fall risk (Guralnik et al. 1994, Davis et al. 1999, Stel et al. 2003).

Analytical considerations

The present study comprised a genetically informative population-based sample of older community-dwelling women. As a result of the recruitment criteria that both co-twins were required to participate and difficulties to travel to the research laboratory may have caused that around half of the invited twin pairs eventually took part to the study. In addition, the present sample of older women possibly included more concordant pairs of twins with respect to health and functional ability. It has been suggested that discordant twin pairs are less willing to participate in studies (Lykken et al. 1987), although there is evidence that even if section bias may exist, especially in terms of measures of health and physical functioning the findings on older twins are comparable to those of the general older population (Christensen et al. 1995, Herskind et al. 1996, Simmons et al. 1997). Because sample of the present study consisted women only, in the generalization of the present results it should be reminded that the estimates of genetic influences are gender and population specific.

Due to the sample size, the statistical power of the current study was limited to conclusively determine whether additive genetic or shared environmental influences were of greater importance in most of the genetic models constituted. The final selection of the most appropriate model to explain the sources of variability in the phenotypes and traits under scrutiny was done by combining the results of the statistical analyses and underlying theories concerning this phenotype. The estimates of genetic influence found in this study need to be interpreted with caution. Studies restricted to twin data typically produce the upper limit of the genetic effect on the trait or phenotype because gene-environment interactions are incorporated into the estimates of genetic effects in the classic twin model. Therefore, including other siblings in other types of family studies would provide the kind of additional information needed to confirm the present observations.

Conclusions and prospects for future studies

The incidence of falls increases with age, and the consequences of falls are more severe, even life-threatening, among frailer people. It is therefore of great importance to determine the role of genetic influences on balance and falls among frailer and older 'old' people, who usually include those at 'high' risk for falls. Female gender has been considered as one of the risk factors for falls, and in older women hip fractures due to falls is a major issue in the health care and well being of this population segment. Recently, Kannus et al. (2005b) showed that during the period from 1971 to 2003 fall-induced deaths became the leading category of unintentional mortal injury among Finnish men. Consequently, future studies should seek to determine specific risk factors and the role of genetic influences on falls among older men.

Currently, multifactorial fall prevention programs appear to be the most efficacious among older people (Day et al. 2002, Gillespie et al. 2003, Tinetti 2003). In other words, modifications of factors related to health and functioning, for example physical activity interventions, are insufficient by themselves to decrease the risk for falls of older people. However, it remains unknown which factors in these multi-interventions contribute most to fall risk. The present study, by showing that genetic influences underlie postural balance and falls, suggests that owing to their genetic makeup the responsiveness of older individuals to strength or balance training, for example, may vary greatly. Some people may benefit more from modifications of the factors related to behavioural habits or environment. Knowledge of the factors through which the genetic influences contributing to postural balance and falls are mediated can in turn increase understanding of the etiology and relative roles of the factors underlying postural balance and risk factors for falls. In the future, by utilizing multivariate genetic analyses, it would be useful to study the extent to which the genetic influences underlying phenotypes, postural balance and falls have genetic or non-genetic influences in common. In addition, due to the complex nature of postural balance and falls, interaction between genetic and non-genetic influences is also likely to characterize these traits. This interaction may modify the effects of both genetic and environmental factors and thus would be an important object of future research.

With this study, we have gained knowledge of how much of the population variance of balance and fall risk is accounted for by genetic and non-genetic influences. At the individual level, however, we cannot determine whether a person has poor balance or is at increased risk for falls due to his or her genetic constitution. What we do know is that due to their genes some people have more functional capacity reserve that protects them from deterioration in their balance or from falling, whereas others may be genetically more vulnerable and thus more prone to balance impairment and falls. Genetic screening to identify such people would not be feasible due to the relatively low genetic contribution to postural balance, and the fact that the individual genes responsible for the genetic effects have not been identified. Therefore, phenotypic identification of people with impaired balance and other fall risk factors remains the best way to find people at increased risk for falls. In clinical practice this means that for efficient prevention it is essential to identify those groups of people who are most likely to benefit from interventions that lower their risk of balance impairment and falling.

The present results deepen understanding of the interrelationships between the traits associated with balance and falls, and may thus help in planning effective interventions to prevent loss of mobility and consequent balance impairments and falls. Thus not only will it be possible to cut the costs of health and social care but, more importantly, to provide successful services, for example rehabilitation or physical activity programs that enable older people to preserve their independence and their prospects of living in their own homes for as long as possible.

The present results also provide a foundation for future research into whether the relative roles of genes and environmental influences on postural balance and fall susceptibility change with increasing age.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions can be summarized as follows

1. Genetic influences accounted for 14 to 35% of postural balance while standing and 17 to 22% while walking. The role of genetic influences in explaining individual variation in performance in the dual task balance tests when standing and walking was more pronounced than the genetic contribution the performance of balance as a single task. Non-genetic influences, including influences that are shared between twins and unique to each individual were shown to make a substantial contribution to the variability in postural balance.

   Genetic influences that contribute to phenotypic variation in postural balance are likely to include genes which also contribute to such postural control systems as CNS, peripheral sensation, muscle function, and vision. Moreover, genes accounting for diseases or age- related conditions such as diabetes or white matter lesions may also contribute to postural balance.

2. Dual tasking while standing and walking impaired performance in the force platform tests and increased walking speed. Cognitively challenging verbal and arithmetic tasks impaired the balance while dual tasking more than did handmotor tasks. The result provide additional evidence on the importance of central control to balance in older people and on the possible deleterious effects on balance control of attempting a second, simultaneous task requiring central resources.

3. Familial influences contributed 35% of the variance in susceptibility to at least one fall during the follow-up year and 45% of the variance in risk for recurrent falls. The fact that many phenotypes related to known risk factors for falls, such as balance, muscle function, cognitive capacity or diseases are under genetic control supports the notion that familial factors contributing to falls at least partially include genetic influences. Susceptibility to injurious falls was due entirely to other than familial factors. This finding is plausible as injurious falls are often the result of extrinsic risk

factors, often related to a hazardous environment or risk taking behaviour, among ‘younger’ and community-dwelling older people.

4. Poor performance in the force platform balance tests proved to predict risk for indoor falls in the present sample of older community-dwelling people without evident balance impairment. This finding highlights the necessity to assess postural balance with methods that accurately detect slight balance deficits and testifies to the force platform method as a reliable and valid balance assessment tool. Dual tasking while balancing on the force platform showed no additional predictive value for falls among the rather healthy older participants of the present study.

Knowledge of the relative role of genetic and non-genetic influences on balance and falls in older people increases understanding of the etiology and factors underlying balance control as well as other risk factors for falls. This information aids in planning and targeting efficient interventions to improve and maintain balance ability in older people and to prevent falls.

YHTEENVETO

Iäkkäiden naisten tasapainokyky yksinkertaisissa sekä huomion jakamista vaativissa tilanteissa ja kaatumisriski – perimän merkitys yksilöiden välisten erojen selittäjinä

Ikääntyessä tasapainon hallinta heikkenee pystyasennon säätelyyn osallistuvissa elinjärjestelmissä tapahtuvien muutosten ja sairauksien seurauksena. Hyvä tasapaino on turvallisen liikkumisen ja toimintakyvyn perusedellytys ja heikentynyt tasapaino keskeisimpiä kaatumisten riskitekijöitä iäkkäillä. Joka kolmas yli 65-vuotias kaatuu vuosittain ja iän lisääntyessä riski kaatua lisääntyy. Kaatumisten seuraukset uhkaavat usein iäkkään henkilön terveyttä ja itsenäistä toimintakykyä. Tasapainon säätely vaatii jatkuvaa keskushermostollista kontrollointia. Ikääntyessä keskushermostollinen kapasiteetti usein heikkenee. Tällöin tasapainon säätely voi vaarantua ja kaatumisriski lisääntyä tilanteissa, joissa iäkäs henkilö joutuu jakamaan huomion samanaikaisesti tasapainon ylläpitämiseen ja toiseen toimintaan (dual tasking), esimerkiksi kävellessä puhumiseen. Tasapainokykyä arvioidaan nykyisin hyvin yleisesti mittaamalla kehon huojuntaa voimalevytekniikalla. Tutkimustieto menetelmän kyvystä osoittaa iäkkään henkilön lisääntynyt kaatumisriski on kuitenkin vielä puutteellista.

Iäkkäiden tasapainokykyyn ja kaatumisiin liittyvää tutkimusta on viime vuosikymmeninä tehty paljon, mutta perimän merkitystä ei toistaiseksi ole selvitetty. Tämän tutkimuksen tarkoituksena oli selvittää, mikä osuus perimällä on iäkkäiden naisten tasapainokyvyn ja kaatumisriskin yksilöiden välisten erojen selittäjänä. Toiseksi tässä tutkimuksessa selvitettiin iäkkäiden henkilöiden tasapainokykyä dual task -tilanteissa sekä geneettisten tekijöiden osuutta dual task -testeistä suoriutumisen selittäjinä. Kolmanneksi tutkimuksessa selvitettiin kehon huojuntamittausten luotettavuutta kaatumisriskin ennustajana iäkkäillä kotona asuvilla naisilla.

Tutkimus on osa Finnish Twin Study on Aging (FITSA) -projektia. FITSA tutkimukseen osallistuneet kaksosparit olivat aiemmin osallistuneet Suomen kaksoskohorttitutkimukseen. Tämän väitöskirjatutkimuksen aineisto on kerätty v. 2000–2001, jolloin tutkittavat olivat 63-76-vuotiaita. Tutkimukseen osallistui 103 monotsygoottista (MZ) ja 114 ditsygoottista (DZ) kaksosparia. Tasapainokykyä mitattiin tutkimuslaboratoriossa kehon huojunnan ja maksimaalisen kävelynopeuden testeillä, jotka tehtiin ensin ilman toista tehtävää ja sen jälkeen siten, että samanaikaisesti tehtiin toista joko motorista, verbaalista tai laskutehtävää. Laboratoriokäyntiä seuraavan vuoden ajan tutkittavat raportoivat kaatumisistaan kuukausittain postitse. Kaatumiset varmistettiin puhelinhaastattelulla.

Geneettiset tekijät selittivät 14–35% kehon huojuntana mitatun tasapainokyvyn ja 17–22% kävelynopeuden vaihtelusta tutkituilla 63–76-vuotiailla naisilla. Tasapainon säätely on monen elinjärjestelmän, kuten näön, tuntoaistin, lihasjärjestelmän ja keskushermoston yhteistoimintaa. Geneettisillä tekijöillä on osuutta näiden järjestelmien rakenteen tai toiminnan määrittäjinä. Ilmeisesti tasapainokyvyn vaihtelua määrittävät geneettiset tekijät ovat ainakin osin samoja, jotka määrittävät tasapainon säätelyjärjestelmiä.

Tämän tutkimuksen iäkkäillä naisilla suoriutuminen huojunta- ja kävelytestistä huonontui dual task -tilanteessa: kognitiivista kapasiteettia kuormittava verbaalinen tai laskutehtävä heikensi suoritusta enemmän kuin motorinen tehtävä. Tulos tukee aiempia tutkimuksia ja osoittaa, että iäkkäillä kahden tehtävän samanaikainen suorittaminen ylittää helposti kognitiivisen kapasiteetin ja vaikeuttaa suoriutumista dual task -tilanteissa. Keskushermoston rakenne ja kognitiiviset toiminnot ovat vielä iäkkäänäkin vahvasti geneettisten tekijöiden määrittämiä, mikä selittänee sitä, että tässä tutkimuksessa geneettisten tekijöiden osuus dual task -tilanteissa mitatun tasapainokyvyn yksilöiden välisten erojen selittäjänä oli suurempi kuin ilman toista toimintoa mitatun tasapainokyvyn selittäjänä.

Tutkittavista noin puolet kaatui vähintään kerran seurannan aikana, 91 kaatui kahdesti tai useammin. Kaatumisen seurauksena 118 henkilölle aiheutui jokin vamma. Suurin osa kaatumisista tapahtui päiväsaikaan ja kotiympäristössä. Tämän tutkimuksen iäkkäillä naisilla perhetekijät, jotka voivat olla geneettisiä tekijöitä tai samalla tavoin perheenjäseniin vaikuttavia ympäristö- ja elintapatekijöitä, selittivät 35% kaatumisalttiuden vaihtelusta. Alttiudesta kaatua toistuvasti perhetekijät selittivät 45%. Alttiutta kaatua niin, että seurauksena oli vamma, selittivät pelkästään ympäristö- ja elintapatekijät. Kaatuminen, joka johtaa vammaan, tapahtuu usein olosuhteissa, joissa ympäristön olosuhteet ja vaatimukset ylittävät iäkkään henkilön suoriutumiskyvyn.

Niillä naisilla, jotka suoriutuivat heikommin voimalevymenetelmällä suoritetuissa tasapainotesteissä eli jotka huojuivat runsaasti, oli lisääntynyt riski erityisesti sisällä tapahtuviin kaatumisiin. Tässä aineistossa eritoten suuri eteen -taakse -suuntainen huojunta oli yhteydessä lisääntyneeseen kaatumisriskiin. Lisäksi niillä henkilöillä, jotka eivät kyenneet suorittamaan tasapainotestiä vaikeimmassa seisoma-asennossa (tandemseisonta) oli nelinkertainen riski kaatua sisällä verrattuna testistä suoriutuneisiin. Tulokset osoittavat, että voimalevytekniikalla mitattu kehon huojunta antaa luotettavaa tietoa iäkkäiden kotona asuvien henkilöiden tasapainosta ja kaatumisriskistä. Tutkimus osoitti myös, että monilla suhteellisen hyväkuntoisilla naisilla on alkavia tasapainokyvyn ongelmia, jotka lisäsivät erityisesti sisällä kaatumisten riskiä. Sisällä tapahtuvien kaatumisten taustalla on useimmin iän tai sairauksien seurauksista johtuva toiminta- ja suorituskyvyn heikentyminen, kun taas ulkona kaatumisten riskitekijät liittyvät useammin ympäristön vaaratekijöihin. Iäkkäiden kaatumisriskin arvioinnissa on siten tärkeää käyttää sellaisia tasapainokyvyn mittausmenetelmiä, joilla tasapainon heikkeneminen voidaan havaita mahdollisimman varhain.

Tämä tutkimus on ensimmäinen, jossa on määritetty, mikä on perimän osuus luotettavin ja monipuolisin mittarein mitatun tasapainokyvyn ja kaatumisalttiuden vaihtelun selittäjänä iäkkäillä naisilla. Tutkimus antaa perustan jatkotutkimukselle, jolla voidaan selvittää, missä määrin tasapainokyvyn ja kaatumisten taustalla olevat geneettiset tekijät ovat yhteisiä tasapainon säätelyjärjestelmiin ja kaatumisten riskitekijöihin vaikuttavien geneettisten tekijöiden kanssa. Tällainen tieto lisää ymmärrystä eri järjestelmien tai riskitekijöiden suhteellisesta merkityksestä tasapainon säätelyssä ja kaatumisten kannalta. Koska tasapainokyky ja kaatumiset ovat niin monitekijäisiä ilmiöitä, on epätodennäköistä, että geenikartoituksella olisi mahdollista paikantaa yksittäisiä geenejä, jotka määrittävät näitä ominaisuuksia.

Vaikka perimä osin määrittääkin tasapainokyvyn ja kaatumisriskin yksilöiden välisiä eroja vielä iäkkäänä, on ympäristöön ja elintapoihin liittyvillä tekijöillä kuitenkin selkeästi suurempi merkitys. Kuitenkin tämänkin tutkimuksen tuloksia tulkittaessa on muistettava, että kukin ominaisuus ja sen ilmiasu muodostuu perimän, ympäristötekijöiden ja elintapojen yhteisvaikutuksen tuloksena. Perimä voi siis vaikuttaa elintapoihin tai ympäristön olosuhteet siihen, miten geenit toimivat. Käytännön terveydenhuollon ja kuntoutuksen näkökulmasta tutkimusta kannattanee tulevaisuudessa entisestään keskittää sellaisten elintapoihin ja -ympäristöön liittyvien tekijöiden määrittämiseen, jotka ovat tasapainokyvyn ja kaatumisriskin kannalta keskeisimpiä ja joihin voidaan vaikuttaa interventioilla. Koska kaatumisalttius näyttää olevan perheittäistä, iäkkäiden henkilöiden kaatumisriskin arvioinnissa perhehistorian huomioiminen on hyödyllistä. Turvallisen liikkumiskyvyn säilyminen ja mahdollisimman vähäinen kaatumisriski ovat iäkkäiden henkilöiden mielekkään ja riippumattoman elämän keskeisiä tekijöitä.

REFERENCES

Alexander, N., B. Postural control in older adults. 1994. Journal of the American Geriatrics Society 42, 93-108.

American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. 2001. Guideline for the prevention of falls in older persons. Journal of the American Geriatrics Society 49, 664-672.

Arden, N. K., Spector, T. D. 1997. Genetic influences on muscle strength, lean body mass, and bone mineral density: A twin study. Journal of Bone Mineral Research 12, 2076-2081.

Baloh, R. W., Fife, T. D., Zwerling, L., Socotch, T., Jacobson, K., Bell, T., Beykirch, K. 1994. Comparison of static and dynamic posturography in young and older normal people. Journal of the American Geriatrics Society 42, 405-412.

Baloh, R. W., Ying, S. H., Jacobson, K. M. 2003. A longitudinal study of gait and balance dysfunction in normal older people. Archives of Neurology 60, 835-839.

Bath, P. A., Morgan, K. 1999. Differential risk factor profiles for indoor and outdoor falls in older people living at home in Nottingham, UK. European Journal of Epidemiology 15, 65-73.

Bean, J. F., Leveille, S. G., Kiely, D. K., Bandinelli, S., Guralnik, J. M., Ferruci, L. 2003. A comparison of leg power and leg strength within the InCHIANTI study: Which influences mobility more? Journal of Gerontology 58A, M728-M733.

Beauchet, O., Dubost, V., Gonthier, R., Kressig, R. W. 2005. Dual-task-related gait changes in transitionally frail older adults: the type of the walking-associated cognitive task matters. Gerontology 51, 48-52.

Bellgrove, M. A., Hawi, Z., Kirley, A., Gill, M., Robertson, I. H. 2005. Dissecting the attention deficit hyperactivity disorder (ADHD) phenotype: Sustained attention, response variability and spatial attentional asymmetries in relation to dopamine transporter (DAT1) genotype. Neuropsychologia 43, 1847-1857.

Benson, R. R., Guttman, C. R. G., Wei, X., Warfield, S. K., Hall, C., Schmidt, J. A., Kikins, R., Wolfson, L. I. 2002. Older people with impaired mobility have specific loci of periventricular abnormality on MRI. Neurology 58, 48-55.

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., Wood-Dauphinee, S. L. 1992. Clinical and laboratory measures of postural balance in an elderly population. Archives of Physical Medicine and Rehabilitation 73, 1073-1080.

Berg, K., Wood-Dauphinee, S., Williams, J. I. 1995. The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. Scandinavian Journal of Rehabilitation Medicine 27, 27-36.

Bergin, P. S., Bronstein, A. M., Murray, N. M., Sancovic, S., Zeppenfeld, D. K. 1995. Body sway and vibration perception thresholds in normal aging and in patients with polyneuropathy. Journal of Neurology Neurosurgery & Psychiatry 58, 335-340.

Bergland, A., Wyller, T. B. 2004. Risk factors for serious fall related injury in elderly women living at home. Injury Prevention 10, 308-313.

Bergland, A., Jarnlo, G-B., Laake, K. 2003. Predictors of falls in the elderly by location. Aging Clinical and Experimental Research 15, 43-50.

Blake, A. J., Morgan, K., Bendall, M. J., Dallosso, H., Ebrahim, S. B., Arie, T. H., Fentem, P. H., Bassey, E. J. 1988. Falls by elderly people at home: prevalence and associated factors. Age and Ageing 17, 365-372.

Bloem, B. R., Grimbergen, Y. A., Cramer, M., Valkenburg, V. V. 2000. "Stops walking when talking" does not predict falls in Parkinson's disease. Annals of Neurology 48, 268.

Bloem, B. R., Valkenburg, V. V., Slabbekoorn, M., Willemsen, M. D. 2001. The multiple task test development and normal strategies. Gait & Posture 14, 191-202.

Bohannon, R. W., Larkin, P.A., Cook A. C, Gear J, Singer J. 1984. Decrease in timed balance test scores with aging. Physical Therapy 64, 1067-1070.

Bootsma-van der Wiel, A., Gussekloo, J., de Craen, A. J., van Exel, E., Bloem, B. R., Westendorp, R. G. 2003. Walking and talking as predictors of falls in the general population: the Leiden 85-Plus Study. Journal of the American Geriatrics Society 51, 1466-1471.

Bouchard, C., Malina, R. M. 1983. Genetics of physiological fitness and motor performance. Exercise and Sport Sciences Reviews 11, 306-339.

Boulgarides, L. K., McGinty, S. M., Willet, J. A., Barnes, C. W. 2003. Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. Physical Therapy 83, 328-339.

Brocklehurst, J. C., Robertson, D., James-Groom, P. 1982. Clinical correlates of sway in old age-sensory modalities. Age and Ageing 11, 1-10.

Brown, M., Sinacore, D. R., Host, H. H. 1995. The relationship of strength to function in the older adult. Journal of Gerontology 50, M55-M59.

Brown, L. A., Shumway-Cook, A., Woollacott, M. H. 1999. Attentional demands and postural recovery: the effects of aging. Journal of Gerontology 54, M165-M171.

Brown, L. A., Sleik, R. J., Polych, M. A., Cage, W. H. 2002. Is prioritization of postural control altered in conditions of postural threat in younger and older adults? Journal of Gerontology 57A, M785-M792.

Bueno-Cavanillas, A., Padilla-Ruiz, F., Jimenez-Moleon, J. J., Peinado-Alonso, C. A., Galvez-Vargas, R. 2000. Risk factors in falls among the elderly according to extrinsic and intrinsic precipitating causes. European Journal of Epidemiology 16, 849-859.

Campbell, A. J., Reinken, J., Allan, B. C., Martinez, G. S. 1981. Falls in old age: a study of frequency and related clinical factors. Age and Ageing 10, 264-270.

Campbell, A. J., Borrie, M. J., Spears, G. F. 1989. Risk factors for falls in a community-based prospective study of people 70 years and older. Journal of Gerontology 44, M112-M117.

Campbell, A. J., Borrie, M. J., Spears, G. F., Jackson, S. L., Brown, J. S., Fitzgerald, J. L. 1990. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age and Ageing 19, 136-141.

Carmelli, D., Reed, T. 2000. Stability and change in genetic and environmental influences on hand-grip strength in older male twins. Journal of Applied Physiology 89, 1879-1883.

Carmelli, D., DeCarli, C., Swan, G. E., Jack, L. M., Reed, T., Wolf, P. A., Miller, B. L. 1998. Evidence for genetic variance in white matter hyperintensity volume in normal elderly male twins. Stroke 29, 1177-1181.

Carmelli, D., Kelly-Hayes, M., Wolf, P. A., Swan, G. E., Jack, L. M., Reed, T., Guralnik, J. M. 2000. The contribution of genetic influences to measures of lower-extremity function in older male twins. Journal of Gerontology 55, B49-B53.

Carmelli, D., Reed, T., DeCarli, C. 2002. A bivariate genetic analysis of cerebral white matter hyperintensities and cognitive performance in elderly male twins. Neurobiology of Aging 23, 413-420.

Christensen, K., Vaupel, J. W., Holm, N. V., Yashin, A. I. 1995. Mortality among twins after age 6: fetal origins hypothesis versus twin method. British Medical Journal 18, 432-436.

Christensen, K., McGue, M., Yashin, A., Iachine, I., Holm, H. V., Vaupel, J. W. 2000. Genetic and environmental influences on functional abilities in Danish twins aged 75 years and older. Journal of Gerontology 55A, M446-M452.

Christensen, K., Frederiksen, H., Vaupel, J. W., McGue, M. 2003. Age trajectories of genetic variance in physical functioning: A longitudinal study of Danish twins ages 70 years and older. Behavior Genetics 33, 125-136.

Chaudhry, H., Findley, T., Quigley, K. S., Bukiet, B., Ji, Z., Sims, T., Maney, M. 2004. Measures of postural stability. Journal of Rehabilitation Research Development Service 41, 713-720.

Chu, L. W., Chi, I., Chiu, A. Y. Y. 2005. Incidence and predictors of falls in the Chinese elderly. Annals Academy of Medicine Singapore 34, 60-72.

Close, J. C. T. 2005. Prevention of falls in older people. Disability and Rehabilitation 27, 1061-1071.

Colledge, N. R., Cantley, P., Peaston, I., Brash, H., Lewis, S., Wilson, J. A. 1994. Ageing and balance: The measurement of postural sway by posturography. Gerontology 40, 273-278.

Condron, J. E., Hill, K. D. 2002. Reliability and validity of a dual-task force platform assessment of balance performance: effect of age, balance impairment, and cognitive task. Journal of the American Geriatrics Society 50, 157-162.

Cumming, R. G. 1996. Nursing home residence and risk of hip fracture. American Journal of Epidemiology 15, 1191-1194.

Daubney, M. E., Culham, E. G. 1999. Lower-extremity muscle force and balance performance in adults aged 65 years and older. Physical Therapy 79, 1177-1185.

Dault, M. C., Frank, J. S. 2004. Does practice modify the relationship between postural control and the execution of a second task in young and older individuals? Gerontology 50, 157-164.

Dault, M. C., Yardley, L., Frank, J. S. 2003. Does articulation contribute to modifications of postural control during dual-task paradigms? Brain Research. Cognitive Brain Research 16, 434-440.

Day, L., Fildes, B., Gordon, I., Fitzharris, M., Flamer, H., Lord, S. 2002. Randomised factorial trial of falls prevention among older people living in their own homes. British Medical Journal 20, 128.

Davis, J. W., Ross, P. D., Nevitt, M. C., Wasnich, R. D. 1999. Risk factors for falls and for serious injuries on falling among older Japanese women in Hawaii. Journal of the American Geriatrics Society 47, 792-798.

Dietz, V. 1992. Human neuronal control of automatic functional movements: interaction between central programs and afferent input. Physiological Reviews 72, 33-69.

Doyle, A. E., Willcutt, E. G., Seidman, L. J., Biederman, J., Chouinard, V-A., Silva, J., Faraone, S. V. 2005. Attention-Deficit/Hyperactivity disorder endophenotypes. Biological Psychiatry 57, 1324-1335.

Era, P., Schroll, M., Ytting, H., Gause-Nilsson, I., Heikkinen, E., Steen, B. 1996. Postural balance and its sensory-motor correlates in 75-year-old men and women: A cross national comparative study. Journal of Gerontology 51, M53-M63.

Era, P., Avlund, K., Jokela, J., Gause-Nilsson, I., Heikkinen, E., Steen, B., Schroll, M. 1997. Postural balance and self-reported functional ability in 75-year-old men and women: A cross-national comparative study. Journal of the American Geriatrics Society 45, 21-29.

Era, P., Heikkinen, E., Gause-Nilsson, I., Schroll, M. 2002. Postural balance in elderly people: Changes over a five-year follow-up and its predictive value for survival. Aging Clinical and Experimental Research 14, 37-46.

Era, P., Sainio, P., Koskinen, S., Haavisto, P., Vaara, M., Aromaa, A. 2006. Postural balance in a random sample of 7,979 subjects aged 30 years and over. Gerontology 159, 204-213.

Falconer, D. S., Mackay, T. F. C. 1996. Introduction to Quantitative Genetics. 4th ed. UK: Longman Group Ltd.

Feder, G., Colin, C., Donovan, S., Carter, Y., on behalf of the guidelines' development group. 2000. Guidelines for prevention of falls in older people over 65. British Medical Journal 321, 1007-1011.

Fitzpatrick, R., Burke, D., Gandevia, S. C. 1994. Task-dependent reflex responses and movement illusions evoked by galvanic vestibular stimulation in standing humans. Journal of Physiology 15, 363-372.

Fletcher, P. C., Hirdes, J. P. 2002. Risk factors for falling among community-based seniors using home care services. Journal of Gerontology 57, M504-M510.

Folstein, M. F., Folstein, S. E., McHugh, P. R. 1975. Mini-mental state: a practical method for grading the cognitive state of the patient for the clinician. Journal of Psychiatric Research 12, 189-198.

Frederiksen, H., Christensen, K. 2003. The influences of genetic factors on physical functioning and exercise in second half of life. Scandinavian Journal of Medicine and Science in Sports 13, 9-18.

Frederiksen, H., Gaist, D., Petersen, H. C., Hjelmborg, J., McGue, M., Vaupel, J. W., Christensen, K. 2002. Hand grip strength: a phenotype suitable for identifying genetic variants affecting mid- and late-life physical functioning. Genetic Epidemiology 23, 110-122.

Frontera, W. R., Hughes, V. A., Fielding, R. A., Fiatarone, M. A., Evand, W. J., Roubenoff, R. 2000. Aging of skeletal muscle: a 12–year longitudinal study. Journal of Applied Physiology 88, 1321-1326.

Gantz, D. A., Higashi, T., Rubenstein, L. Z. 2005. Monitoring falls in cohort studies of community-dwelling older people. Effect of the recall interval. Journal of the American Geriatrics Society 53, 2190-2194.

de Geus, E. J., Wright, M. J., Martin, N. G., Boomsma, D. I. 2001. Genetics of brain function and cognition. Behavior Genetics 31, 489-495.

Gillespie, L. D., Gillespie, W. J., Robertson, M. C., Lamb, S. E., Cumming, R. G., Rowe, B. H. 2003. Interventions for preventing falls in elderly people. The Cochrane Database of Systematic Reviews, Issue 4. Art. No.: CD000340. DOI: 10.1002/14651858.CD000340.

Gillespie, L. D., Gillespie, W. J., Robertson, M. C., Lamb, S. E., Cumming, R. G., Rowe, B. H. 2004. Interventions for preventing falls in elderly people (Cochrane Review). The Cochrane Library, Issue 3. Chichester, UK: John Wiley & Sons, Ltd.

Good Balance-User's Manual 2000. Metitur Ltd. (www.metitur.com).

Graafmans, W. C., Ooms, M. E., Hofstee, H. M., Bezemer, P. D., Bouter, L. M., Lips, P. 1996. Falls in the elderly: a prospective study of risk factors and risk profiles. American Journal of Epidemiology 143, 1129-1136.

Greenlund, L. J. S., Nair, K. S. 2003. Sarcopenia - consequences, mechanisms, and potential therapies. Mechanisms of Aging and Development 123, 287-299.

Gregg, E. W., Pereira, M. A., Caspersen, C. J. 2000. Physical activity, falls, and fractures among older adults: A review of the epidemiologic evidence. Journal of the American Geriatrics Society 48: 883-893.

Grimby, G. 1986. Physical activity and muscle training in the elderly. Acta Medica Scandinavica 711(suppl), 233-237.

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., Sherr, P. A., Wallace, R. B. 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. Journal of Gerontology 49, M82-M88.

Guralnik, J. M., Fried, L. P., Simonsick, E. M., Kasper, J. D., Lafferty, M. E., eds. 1995. Women'shealth and aging study: Health and social characteristics of older women with disability. Bethesda, MD: National Institute on Aging; NIH Pub. No. 95-4009. www.nih.gov/nia/edb/whasbook/title.htm.

Guttmann, C. R. G., Benson, R., Warfielf, S. K., Wei, X., Anderson, M.C., Hall, C. B., Abu-Hasaballah, K., Mugler, J. P., Wolfson, L. 2000. White matter abnormalities in mobility-impaired older persons. Neurology 45, 1277-1283.

van Haastregt, J. C., Diederiks, J. P., van Rossum, E., de Witte, L. P., Crebolder, H. F. 2000. Effects of preventive home visits to elderly people living in the community: systematic review. British Medical Journal 320, 754-758.

Hageman, P. A., Leibowitz, J. M., Blanker, D. 1995. Age and gender effects on postural control measures. Archives of Physical Medicine and Rehabilitation 76, 961-965.

Hall, J. G. 2003. Twinning. The Lancet 362, 735-743.

Hammond, C. J., Snieder, H., Spector, T. D., Gilbert, C. E. 2000. Genetic and environmental factors in age-related nuclear cataracts in monozygotic and dizygotic twins. New England Journal of Medicine 342, 1786-1790.

Harris, J. R., Pedersen, N. L., McClearn, G. E., Plomin, R., Nesselroade, J. R. 1992. Age differences in genetic and environmental influences for health from the Swedish Adoption/Twin Study of Aging. Journal of Gerontology 47, P213-P220.

Hauer, K., Pfisterer M., Weber, C., Welzer, N., Kliegel, M., Oster, P. 2003. Cognitive impairment decreases postural control during dual tasks in geriatric patients with a history of severe falls. Journal of the American Geriatrics Society 51, 1638-1644.

Heikkinen, E. 1997. Functional capacity and health of elderly people - the Evergreen project. Background, design and methods of the project. Scandinavian Journal of Social Medicine Suppl. 53, 1-18.

Herala, M., Luukinen, H., Honkanen, R., Koski, K., Laippala, P., Kivelä, S-L. 2000. Soft tissue injury from falling predicts a future major falling injury in the home-dwelling elderly. Journal of Epidemiology and Community Health 54, 557-558.

Herskind, A. M., McGue, M., Holm, N. V., Sorensen, T. I., Harvald, B., Vaupel, J. W. 1996. The heritability of human longevity: a population-based study of 2872 Danish twin pairs born 1870-1900. Human Genetics 97, 319-323.

Hill, K., Schwarz, J., Flicker, L., Carroll, S. 1999. Falls among healthy, community-dwelling, older women: a prospective study of frequency, circumstances, consequences and prediction accuracy. Australian and New Zealand Journal of Public Health 23, 41-58.

Hofmann, C. 1998. The implementation of normative data in a force platform based postural balance measurement system. Diplomarbeit. Westsächsische Hochschule Zwickau, Deutschland.

Hogan, D. B., MacDonald, F. A., Betts, J., Bricker, S., Ebly, E. M., Delarue, B., Fung, T. S., Harbidge, C., Hunter, M., Maxwell, C. J., Metcalf, B. 2001. A randomized controlled trial of a community-based consultation service to prevent falls. Canadian Medical Association Journal 165, 537-543.

van't Hoof, F., von Bahr, S. F. J., Silveira, A., Iliadou, A., Eriksson, P., Hamsten, A. 1999. Two common functional polymorphisms in the promoter region of the β-fibrinogen gene contribute to regulation of plasma fibrinogen concentration. Arteriosclerosis Thrombosis and Vascular Biology 19, 3063–3070.

Horak, F. B., Shupert, C. L., Mirka, A. 1989. Components of postural dyscontrol in the elderly: a review. Neurobiology of Aging 10, 727-738.

Horak, F. B., Nashner, L. M., Diener, H. C. 1990. Postural strategies associated with somatosensory and vestibular loss. Experimental Brain Research 82, 167-177.

Horak, F. B., Henry, S. M., Shumway-Cook, A. 1997. Postural perturbations: new insights for treatment of balance disorders. Physical Therapy 77, 517-533.

Hughes, V. A., Frontera, W. R., Wood, M., Evans, W. J., Dallal, G. E., Roubenoff, R., Fiatarone Singh, M. A. 2001. Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. Journal of Gerontology 56, B209-B217.

Hyndman, D., Ashburn, A. 2004. Stops walking when talking as a predictor of falls in people with stroke living in the community. Journal of Neurology Neurosurgery and Psychiatry 75, 994-997.

Hytönen, M., Pyykkö, I., Aalto, H., Starck, J. 1993. Postural control and age. Acta Otolaryngologica 113, 119-122.

Inglis, J. T., Shupert, C. L., Hlavacka, F., Horak, F. B. 1995. Effect of galvanic vestibular stimulation on human postural responses during support surface translations. Journal of Neurophysiology 73, 896-901.

Jarnlo, G. B. 2003. Functional balance tests related to falls among elderly people living in the community. European Journal of Gerontology 5, 7-14.

Jöreskog, K., Sörbom, D., du Toit, S., du Toit, M. 1999. LISREL 8: New statistical Features. Chicago: Scientific Software International, Inc.

Kannus, P., Palvanen, M., Kaprio, J., Parkkari, J., Koskenvuo, M. 1999. Genetic factors and osteoporotic fractures in elderly people: Prospective 25 years follow up of a nationwide cohort of elderly Finnish twins. British Medical Journal 319, 1334-1337.

Kannus, P., Sievänen, H., Palvanen, M., Parkkari, J. 2005a. Prevention of falls and consequent injuries in elderly people. Lancet 366, 1885-1893.

Kannus, P., Parkkari, J., Niemi, S., Palvanen, M. 2005b. Fall-induced deaths among elderly people. American Journal of Public Health 95, 422-424.

Kaprio, J., Koskenvuo, M. 2002. Genetic and environmental factors in complex diseases: The Older Finnish Twin Cohort. Twin Research 5, 358-365.

Kaprio, J., Sarna, S., Koskenvuo, M., Rantasalo, I. 1978. The Finnish Twin Registry: formation and compliation, questionnaire study, zygocity determination procedures and research program. Progress in Clinical and Biological Research 24B, 179-184.

Kaprio, J., Tuomilehto, J., Koskenvuo, M., Romanov, K., Reunanen, A., Eriksson, J., Stengard, J., Kesäniemi, Y. A. 1992. Concordance for type 1 (insulin dependent) and type 2 (non-insulin-dependent) diabetes mellitus in a population-based cohort of twins in Finland. Diabetologia 35, 1060–1067.

Katzmarzyk, P. T., Gledhill, N., Perusse, L., Bouchard, C. 2001. Familial aggregation of 7-year changes in musculoskeletal fitness. Journal of Gerontology 56, B497-B502.

Kerber, K. A., Ishiyama, G. P., Baloh, R. W. 2005. A longitudinal study of oculomotor function in normal older people. Neurobiology of Aging, doi:10.1016/j.neurobiolaging.2005.07.009.

Kellogg International work group on the prevention of falls by the elderly. 1987. The prevention of falls in later life. Dan Med Bull 4, 1-24.

King, M. B., Tinetti, M. E. 1995. Falls in community-dwelling older persons. Journal of the American Geriatrics Society 43, 1146-1154.

Korkeila, M., Kaprio, J., Rissanen, A., Koskenvuo, M. 1991. Effects of gender and age on the heritability of body mass index. International Journal of Obesity 10, 647-654.

Kuhlenbaumer, G., Young, P., Hunermund, G., Ringelstein, B., Stogbauer, F. 2002. Clinical features and molecular genetics of hereditary peripheral neuropathies. Journal of Neurology 249, 1629-1650.

Kuo, H-K., Lipsitz, L. A. 2004. Cerebral white matter changes and geriatric syndromes: Is there a link? Journal of Gerontology 59A, M818-M826.

Lackner, J. R. 1992. Multimodal and motor influences on orientation: implications for adapting to weightless and virtual environments. Journal of Vestibular Research 2, 307-322.

Lajoie, Y., Teasdale, N., Bard, C., Fleury, M. 1993. Attentional demands for static and dynamic equilibrium. Experimental Brain Research 97, 139-144.

Lamb, S. E., Guralnik, J. M., Buchner, D. M., Ferrucci, L. M., Hochberg, M. C., Simonsick, E. M., Fried, L. P. 2000. Factors that modify the association between knee pain and mobility limitation in older women: the Women's Health and Aging Study. Annals of the Rheumatic Diseases 59, 331–337.

Latash, M. L. 1998. Neurophysiological Basis of Movement. Champaign, Illinois, USA: Human Kinetics.

Launer, L. J., Berger, K., Breteler, M. M., Dufouil, C., Fuhrer, R., Giampaoli, S., Nilsson, L. G., Pajak, A., de Ridder, M., van Dijk, E. J., Sans, S., Schmidt, R., Hofman, A. 2006. Regional variability in the prevalence of cerebral white matter lesions: an MRI study in 9 European countries (CASCADE). Neuroepidemiology 26, 23-29.

Lee, J. H. 2003. Genetic evidence for cognitive reserve: variations in memory and related cognitive functions. Journal of Clinical and Experimental Neuropsychology 25, 594-613.

Lee, H. K., Scudds, R. J. 2003. Comparison of balance in older people with and without visual impairment. Age and Aging 32, 643-649.

Leveille, S. G., Bean, J., Bandeen-Roche, K., Jones, R., Hochberg, M., Guralnik, J. M. 2002. Musculoskeletal pain and risk for falls in older disabled women living in the community. Journal of the American Geriatrics Society 50, 671-678.

Li, K. Z. H., Lindenberger, U., Freund, A. M., Baltes, P. B. 2001. Walking while memorizing: age-related differences in compensatory behavior. Psychological Science 12, 230-237.

Liao, D., Cooper, L., Cai, J., Toole, J., Bryan, N., Burke, G., Shahar, E., Nieto, J., Mosley, T., Heiss, G. 1997. The prevalence and severity of white matter lesions, their relationship with age, ethnicity, gender, and cardiovascular disease risk factors: the ARIC Study. Neuroepidemiology 16, 149-162.

Lin, S. I., Woollacott, M. 2005. Association between sensorimotor function and functional and reactive balance control in the elderly. Age and Ageing 34, 358-363.

Lindenberger, U., Marsiske, M., Baltes, P. B. 2000. Memorizing while walking: increase in dual-task costs from young adulthood to old age. Psychology and Aging 15, 417-436.

Lindle, R. S., Metter, E. J., Lynch, N. A., Fleg, J. L., Fozard, J. L., Tobin, J., Roy, T. A., Hurley, B. F. 1997. Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. Journal of Applied Physiology 83, 1581-1587.

Lipsitz, L. A., Jonsson, P. V., Kelley, M. M., Koestner, J. S. 1991. Causes and correlates of recurrent falls in ambulatory frail elderly. Journal of Gerontology 46, M114-M122.

Longstreth, W. T. Jr., Manolio, T. A., Arnold, A., Burke, G. L., Bryan, N., Jungreis, C. A., Enright, P. L., O'Leary, D., Fried, L. 1996. Clinical correlates of white matter findings on cranial magnetic resonance imaging of 3301 elderly people. The Cardiovascular Health Study. Stroke 27, 1274-1282.

Longstreth, W. T., Jr., Arnold, A. M., Beauchamp, N. J. Jr., Manolio, T. A., Lefkowitz, D., Jungreis, C., Hirsch, C. H., O'Leary, D. H., Furberg, C. D. 2005. Incidence, manifestations, and predictors of worsening white matter on serial cranial magnetic resonance imaging in the elderly: the Cardiovascular Health Study. Stroke 36, 56-61.

Lord, S. R., Ward, J. A. 1994. Age-associated differences in sensori-motor function and balance in community dwelling women. Age and Ageing 23, 452-460.

Lord, S. R., Clark, R. D. 1996. Simple physiological and clinical tests for the accurate prediction of falling in older people. Gerontology 42, 199-203.

Lord, S. R., Menz, H. B. 2000. Visual contributions to postural stability in older adults. Gerontology 46, 306-310.

Lord, S. R., Clark, R. D., Webster, I. W. 1991. Postural stability and associated physiological factors in a population of aged persons. Journal of Gerontology 46, M69-M76.

Lord, S. R., Ward, J. A., Williams, P., Anstey, K. J. 1994. Physiological factors associated with falls in older community-dwelling women. Journal of the American Geriatrics Society 42, 1110-1117.

Low Choy, N., Brauer, S., Nitz, J. 2003. Changes in postural stability in women aged 20 to 80 years. Journal of Gerontology 58A, M525-M530.

Lundin-Olsson, L., Nyberg, L., Gustafson, Y. 1997. “Stops walking when talking” as a predictor of falls in elderly people. Lancet 349, 617.

Luukinen, H., Koski, K., Hiltunen, L., Kivelä, S-L. 1994. Incidence rate of falls in aged population in northern Finland. Journal of Clinical Epidemiology 47, 843-850.

Lykken, D. T., McGue, M., Tellegen, A. 1987. Recruitment bias in twin research: the rule of two-thirds reconsidered. Behavioral Genetics 17, 343-362.

Lynch, M., Walsh, B. 1998. Genetics and analysis of quantitative traits. USA: Sinauer Associates, Inc.

Maes, H. H., Beunen, G. P., Vlietinck, R. F., Neale, M. C., Thomis, M., Vanden Eynde, B., Lysens, R., Simons, J., Derom, C., Derom, R. 1996. Inheritance of physical fitness in 10-yr-old twins and their parents. Medicine and Science in Sports and Exercise 28, 1479-1491.

Maes, H. M., Neale, M. C., Eaves, L. J. 1997. Genetic and environmental factors in relative body weight and human adiposity. Behavior Genetics 27, 325–351.

Maki, B. E., Holliday, P. J., Topper, A. K. 1994. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. Journal of Gerontology 49, M72-M84.

Malina, R. M. 1984. Genetics of motor development and performance. pp.23-58 In: Malina, R.M., Bouchard, C. Sport and Human Genetics. The 1984 Olympic Scientific Congress Proceedings, vol 4. USA: Human Kinetics Publishers Inc.

Manchester, D., Woollacott, M., Zederbauer-Hylton, N., Marin, O. 1989. Visual, vestibular and somatosensory contributions to balance control in the older adult. Journal of Gerontology 44, M118-M127.

Marks, R., Allegrante, J. P., Ronald MacKenzie, C., Lane, J. M. 2003. Hip fractures among the elderly: causes, consequences and control. Ageing research reviews 2, 57-93.

Marsh, A. P., Geel, S. E. 2000. The effect of age on the attentional demands of postural control. Gait Posture 12, 105-113.

Martin, N., Boomsma, D., Machin, G. 1997. A twin-pronged attack on complex traits. Nature Genetics 17, 387-392.

Matsumura, B.A., Ambrose, A. F. 2006. Balance in the elderly. Clinics in Geriatric Medicine 22, 395-412.

Maylor, E. A., Wing, A. M. 1996. Age differences in postural stability are increased by additional cognitive demands. Journal of Gerontology 51, P143-P154.

Maylor, E. A., Allison, S., Wing, A. M. 2001. Effects of spatial and nonspatial cognitive activity on postural stability. British Journal of Psychology 92, 319-338.

McClearn, G. E., DeFries, J. C. 1973. Introduction to behavioral genetics. San Fransisco: W.H.Freeman and Company.

McClearn, G. E., Johansson, B., Berg, S., Pedersen, N. L., Ahern, F., Petrill, S. A., Plomin, R. 1997. Substantial genetic influence on cognitive abilities in twins 80 or more years old. Science 276, 1560–1563.

McGue, M., Christensen, K. 2001. The heritability of cognitive functioning in very old adults: Evidence from Danish twins aged 75 years and older. Psychology and Aging 16, 272-280.

Melzer, I., Oddsson, L. I. 2004. The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. Journal of the American Geriatrics Society 52, 1255-1262.

Metter, E. J., Conwit, R., Tobin, J., Fozard, J. L. 1997. Age-associated loss of power and strength in the upper extremities in women and men. Journal of Gerontology 52, B267-B276.

Mitra, S. 2003. Postural costs of suprapostural task load. Human Movement Science 22, 253-270.

Mitra, S. 2004. Adaptive utilization of optical variables during postural and suprapostural dual-task performance: Comment on Stoffgren, Smart, Bardy, and Pagulayan (1999). Journal of Experimental Psychology. Human Perception and Performance 30, 28-38.

Mitra, S., Fraizer, E. V. 2004. Effects of explicit sway-minimization on postural - suprapostural dual-task performance. Human Movement Science 23, 1-20.

Moreland, J., Richardson, J., Chan, D. H., O'Neill, J., Bellissimo, A., Grum, R. M., Shanks, L. 2003. Evidence-based guidelines for the secondary prevention of falls in older adults. Gerontology 49, 93-116.

Moreland, J. D., Richardson, J. A., Goldsmith, C. H., Clase, C. M. 2004. Muscle weakness and falls in older adults: a systematic review and meta-analysis. Journals of the American Geriatrics Society 52, 1121-1129.

Moxley Scarborough, D., Krebs, D. E., Harris, B. A. 1999. Quadriceps muscle strength and dynamic stability in elderly persons. Gait & Posture 10, 10-20.

Nahit, E. S., Silman, A. J., Macfarlane, G. J. 1998. The occurrence of falls among patients with a new episode of hip pain. Annals of Rheumatological Diseases 57, 166-168.

Nashner, L. M., Black, F. O., Wall, C. 1982. Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. The Journal of Neuroscience 2, 536-544.

Nevitt, M. C., Cummings, S. R., Kidd, S., Black, D. 1989. Risk for recurrent nonsyncopal falls. Journal of American Medical Association 261, 2663-2668.

Neale, M. C., Cardon, L. R. 1992. Methodology for Genetic Studies of Twins and Families. Dortrecht, The Netherlands: Kluwer Academic Publishers.

Neale, M. C., Maes, H. H. M. 2004. Methodology for genetic studies of twins and families. ibgwww.colorado.edu/workshop2004/cdrom/HTML/book2004a.pdf

Neale, M. C., Eaves, L. J., Kendler, K. S. 1994. The power of the classical twin study to resolve variation in threshold traits. Behavior Genetics 24, 239-258.

Neale, M. C., Boker, S. M., Xie, G., Maes, H. H. 2003. MX: Statistical Modeling. VCU Box 900126, Richmond, VA 23298: Department of Psychiatry. 6th Edition.

Nurmi, I. S., Luthje, P. M., Kataja, J. M. 2004. Long-term survival after falls among the elderly in institutional care. Archives of Gerontology and Geriatrics 38, 1-10.

O´Loughlin, J. L., Robitaille, Y., Boivin, J. F., Suissa, S. 1993. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. American Journal of Epidemiology 137, 342-354.

Onder, G., Penninx, B. W., Lapuerta, P., Fried, L. P., Ostir, G. V., Guralnik, J. M., Pahor, M. 2002. Change in physical performance over time in older women: the Women's Health and Aging Study. Journal of Gerontology 57, M289-M293.

Ouchi, Y., Okada, H., Yoshikawa, E., Nobezawa, S., Futatsubashi, M. 1999. Brain activation during maintenance of standing postures in humans. Brain 122, 329-338.

Overstall, P. W., Exton-Smith, A. N., Imms, F. J., Johnson, A. L. 1977. Falls in the elderly related to postural imbalance. British Medical Journal 29, 261-264.

Owsley, C., McGwin, G. 2004. Association between visual attention and mobility in older adults. Journal of the American Geriatrics Society 52, 1901-1906.

Penninx, B. W., Pluijm, S. M., Lips, P., Woodman, R., Miedema, K., Guralnik, J. M., Deeg, D. J. 2005. Late-life anemia is associated with increased risk of recurrent falls. Journal of the American Geriatrics Society 53, 2106-2111.

Perell, K. L., Nelson, A., Goldman, R. L., Luther, S. L., Prieto-Lewis, N., Rubenstein, L. Z. 2001. Fall risk assessment measures: an analytic review. Journal of Gerontology 56, M761-M766.

Perrin, P. P., Jeandel, C., Perrin, C. A., Bene, M. C. 1997. Influence of visual control, conduction, and central integration on static and dynamic balance in healthy older adults. Gerontology 43, 223-231.

Perusse, L., Lortie, G., Leblanc, C., Tremblay, A., Theriault, G., Bouchard, C. 1987. Genetic and environmental sources of variation in physical fitness. Annals of Human Biology 14, 425-434.

Peterka, R. J., Black, F. O., Schoenhoff, M. B. 1990. Age-related changes in human vestibulo-ocular reflexes: sinusoidal rotation and caloric tests. Journal of Vestibular Research 1, 49-59.

Pfefferbaum, A., Sullivan, E. V., Swan, G. E., Carmelli, D. 2000. Brain structure in men remains highly heritable in the seventh and eight decades of life. Neurobiology of Aging 21, 63-74.

Piirtola, M., Era, P. 2006. Force platform measurements as predictors of falls among older people - A review. Gerontology 52, 1-16.

Pistorius, M. A. 2003. Chronic venous insufficiency: the genetic influence. Angiology 54(Suppl 1), S5-S12.

Plomin, R., DeFries, J. C., McClearn, G. E., McGuffin, P. 2001. Behavioral Genetics. 4th ed. New York: Worth Publishers.

Pluijm, S. M., Smit, J. H., Tromp, E. A., Stel, V. S., Deeg, D. J., Bouter, L. M., Lips, P. 2006. A risk profile for identifying community-dwelling elderly with a high risk of recurrent falling: results of a 3-year prospective study. Osteoporosis International 17, 417-425.

Podsiadlo, D., Richardson, S. 1991. The timed ”Up and Go”: A test of basic functional mobility for frail persons. Journal of the American Geriatrics Society 39, 142-148.

Posthuma, D., deGeus, E. J. C., Neale, M. C., Hulhoff Pol, H. E., Baaré, W. E. C., Kahn, R. S., Boomsma, D. 2000. Multivariate genetic analysis of brain structure in an extended twin design. Behavior Genetics 30, 311-319.

Posthuma, D., Beem, A. L., de Geus, E. J., van Baal, G. C., von Hjelmborg, J. B., Iachine, I., Boomsma, D. I. 2003. Theory and practice in quantitative genetics. Twin Research 6, 361-376.

Prudham, D., Evans, J. G. 1981. Factors associated with falls in the elderly: a community study. Age and Ageing 10, 141-146.

Quant, S., Adkin, A. L., Staines, W. R., Maki, B. E., McIlroy, W. E. 2004. The effect of a concurrent cognitive task on cortical potentials evoked by unpredictable balance perturbations. BMC Neuroscience 5:18. http://www. biomedcentral.com/1471-2202/5/18

Rao, S. S. 2005. Prevention of falls in older patients. American Family Physician 72, 81-88.

Rankin, J. K., Woollacott, M. H., Shumway-Cook, A., Brown, L. A. 2000. Cognitive influence on postural stability: a neuromuscular analysis in young and older adults. Journal of Gerontology 55, M112- M119.

Rantanen, T., Masaki, K., Foley, D., Izmirlian, G., White, L., Guralnik, J. M. 1998. Grip strength changes over 27 yr in Japanese-American men. Journal of Applied Physiology 85, 2047-2053.

Rantanen, T., Guralnik, J. M., Ferrucci, L., Leveille, S., Fried, L. P. 1999. Coimpairments: strength and balance as predictors of severe walking disability. Journal of Gerontology 54, M172-M176.

Rantanen, T., Guralnik, J. M., Ferrucci, L., Penninx, B. W., Leveille, S., Sipilä, S., Fried, L. P. 2001. Coimpairments as predictors of severe walking disability in older women. Journal of the American Geriatrics Society 49, 21-27.

Rawsky, E. 1998. Review of the literature on falls among the elderly. Image-Journal of Nursing Scholarship 30, 47-52.

Reed, T., Fabsitz, R. R., Selby, J. V., Carmelli, D. 1991. Genetic influences and grip strength norms in the NHLBI twin study males aged 59-69. Annals of Human Biology 18, 425-432.

Redfern, M. S., Jennings, J. R., Martin, C., Furman, J. M. 2001. Attention influences sensory integration for postural control in older adults. Gait & Posture 14, 211-216.

Rende, R. D., Plomin, R., Vanderberg, S. G. 1990. Who discovered twin method? Behavior Genetics 20, 277-285.

Reynolds, C. A., Finkel, D., Gatz, M., Pedersen, N. 2002. Sources of influence on rate of cognitive change over time in Swedish twins: An application of latent growth models. Experimental Brain Research 28, 407-433.

Reynolds, C. A., Finkel, D., McArdle, J. J., Gatz, M., Berg, S., Pedersen, N. L. 2005. Quantitative genetic analysis of latent growth curve models of cognitive abilities in adulthood. Developmental Psychology 41, 3-16.

Rijsdijk, F. V., Sham, P. C. 2002. Analytic approaches to twin data using structural equation models. Briefings in Bioinformatics 3, 119-133.

de Ribaupierre, A., Ludwig, C. 2003. Age differences and divided attention: is there a general deficit? Experimental Aging Research 29, 79-105.

Robbins, A. S., Rubenstein, L. Z., Josephson, K. R., Schulman, B. L., Osterweil, D., Fine, G. 1989. Predictors of falls among elderly people. Results of two population-based studies. Archives of Internal Medicine 149, 1628-1633.

Rosano, A., Kuller, L. H., Chung, H., Arnold, A. M., Longstreth, W. T., Newman, A. B. 2005. Subclinical brain magnetic resonance imaging abnormalities predict physical functional decline in high-functioning older adults. Journal of the American Geriatrics Society 53, 649-654.

Rosenhall, U. 1973. Degenerative patterns in the aging human vestibular neuro-epithelia. Acta Otolaryngologica 76, 208-220.

Roubenoff, R., Hughes, V. A. 2000. Sarcopenia: current concepts. Journal of Gerontology 55, M716-M724.

Rubenstein, L. Z., Powers, C. M., MacLean, C. H. 2001. Quality indicators for the management and prevention of falls and mobility problems in vulnerable elders. Annals of Internal Medicine 135, 686-693.

Sarna, S., Kaprio, J., Sistonen, P., Koskenvuo, M. 1978. Diagnosis of twin zygocity by mailed questionnaire. Human Heredity 28, 241-254.

Salthouse, T. A, Somberg, B. L. 1982. Time-accuracy relationship in young and old adults. Journal of Gerontology 37, 349-353.

Schmitz, S., Cherny, S. S., Fulker, D. W. 1998. Increase in power through multivariate analyses. Behavior Genetics 5, 357-363.

Sheldon, J. H. 1963. The effect of age on the control of sway. Gerontologica Clinica 5, 129-138.

Shumway-Cook, A., Woollacott, M. 2000. Attentional demands and postural control: the effect of sensory context. Journal of Gerontology 55, M10-M16.

Shumway-Cook, A., Woollacott, M., Kerns, K. A., Baldwin, M. 1997. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology 52A, M232-M240.

Sihvonen, S., Era, P. 1999. Test-retest reliability of easy and more demanding balance tests in young, middle-aged, and elderly participants (abstract). Journal of Aging and Physical Activity 7, 312.

Silventoinen, K., Kaprio, J., Lahelma, E., Koskenvuo, M. 2000. Relative effects of genetic and environmental factors on body height: Differences across birth cohorts among Finnish men and women. American Journal of Public Health 90, 627-630.

Simmons, S. F., Johansson, B., Zarit, S. H., Ljungquist, B., Plomin, R., McClearn, G. E. 1997. Selection bias in samples of older twins? A comparison between octogenarian twins and singletons in Sweden. Journal of Aging and Health 9, 553-567.

Skelton, D. A., Beyer, N. 2003. Exercise and injury prevention in older people. Scandinavian Journal of Medicine and Science in Sports 13, 77-85.

Skelton, D., Todd, C. 2004. What are the main risk factors for falls amongst older people and what are the most effective interventions to prevent these falls? How should interventions to prevent falls should be implemented? WHO Europe, Health Evidence Network, Evidence for Decision Makers. March 2004; 1-28. www.euro.who.int/document/E82552.pdf.

Smith, C. 1974. Concordance it twins: Methods and interpretation. American Journal of Human Genetics 26, 454-466.

Spector, T. D., Cicuttini, F., Baker, J., Loughlin, J., Hart, D. 1996. Genetic influences on osteoarthritis in women: a twin study. British Medical Journal 312, 940-943.

Speers, R. A., Kuo, A. D., Horak, F. B. 2002. Contributions of altered sensation and feedback responses to changes in coordination of postural control due to aging. Gait & Posture 16, 20-30.

SPSS for Windows, Rel. 11.5.1. 2001. Chicago: SPSS Inc. www.spss.com/terms.htm.

Stalenhoef, P. A., Crebolder, H. J. M., Knottnerus, J. A., van der Horst, F. G. E. M. 1997. Incidence, risk factors and consequences of falls among elderly subjects living in the community. European Journal of Public Health 7, 328-334.

Stalenhoef, P. A., Diederiks, J. P., Knottnerus, J. A., de Witte, L. P., Crebolder H.F. 2000. The construction of a patient record-based risk model for recurrent falls among elderly people living in the community. Family Practice 17, 490-496.

Stalenhoef, P. A., Diederiks, J. P., Knottnerus, J. A., Kester, A. D., Crebolder, H. F. 2002. A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study. Journal of Clinical Epidemiology 55, 1088-1094.

Starr, J. M., Leaper, S. A., Murray, A. D., Lemmon, H. A., Staff, R. T., Deary, I. J., Whalley, L. J. 2003. Brain white matter lesions detected by magnetic resonance imaging are associated with balance and gait speed. Journal of Neurology Neurosurgery and Psychiatry 74, 94-98.

Stata Corp. 2003; Stata Statistical Software: Release 8.0. College Station, TX: Stata Corporation. www.stata.com

Stel, V. S., Smit, J. H., Pluijm, S. M., Lips, P. 2003. Balance and mobility performance as treatable risk factors for recurrent falling in older persons. Journal of Clinical Epidemiology 56, 659-668.

Stevens, J. A. 2005. Falls among older adults-risk factors and prevention strategies. Journal of Safety Research 36, 409-411.

Stevens, J. A, Sogolow, E. D. 2005. Gender differences for non-fatal unintentional fall related injuries among older adults. Injury Prevention 11, 115-119.

Studenski, S., Duncan, P. W., Chandler, J. 1991. Postural responses and effector factors in persons with unexplained falls: results and methodological issues. Journal of the American Geriatrics Society 39, 229-234.

Swan, G., Carmelli, D. 2002. Evidence for genetic mediation of executive control: A study of aging male twins. Journal of Gerontology 57B, P133-P143.

Teasdale, N., Stelmach, G. E. 1991. Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. Journal of Gerontology 46, B238-B244.

Teasdale, N., Simoneau, M. 2001. Attentional demands for postural control: The effects of aging and sensory reintegration. Gait & Posture 14, 203-210.

Teasdale, N., Bard, C., LaRue, J., Fleury, M. 1993. On the cognitive penetrability of posture control. Experimental Aging Research 19, 1-13.

The National Institute for Clinical Excellence (NICE). 2004. Clinical practice guideline for assessment and prevention of falls in older people. London: The Royal College of Nursing. http://www.nice.org.uk/page.aspx?o=cg021fullguideline

Teikari, J., Koskenvuo, M., Kaprio, J., O'Donnell, J. 1990. Study of gene-environment effects on development of hyperopia: a study of 191 adult twin pairs from the Finnish Twin Cohort Study. Acta Geneticae Medicae Gemellologiae (Roma) 39, 133-136.

Tesfaye, S., Stevens, L. K., Stephenson, J. M., Fuller, J. H., Plater, M., Ionescu-Tirgoviste, C., Nuber. A., Pozza, G., Ward, J. D. 1996. Prevalence of diabetic peripheral neuropathy and its relation to glycaemic control and potential risk factors: the EURODIAB IDDM Complications Study. Diabetologia 39, 1377-1384.

Thompson, P. M., Cannon, T. D., Narr, K. L., van Erp, T., Poutanen, V. P., Huttunen, M., Lonnqvist, J., Standertskjold-Nordenstam, C. G., Kaprio, J., Khaledy, M., Dail, R., Zoumalan, C. I., Toga, A. W. 2001. Genetic influences on brain structure. Nature Neuroscience 4, 1253-1258.

Thomis, M. A., Van Leemputte, M., Maes, H. H., Blimkie, C. J., Claessens, A. L., Marchal, G., Willems, E., Vlietinck, R. F., Beunen, G. P. 1997. Multivariate genetic analysis of maximal isometric muscle force at different elbow angles. Journal of Applied Physiology 82, 959-967.

Tiainen, K., Sipilä, S., Alén, M., Heikkinen, E., Kaprio, J., Koskenvuo, M., Tolvanen, A., Pajala, S., Rantanen, T. 2004. Heritability of maximal isometric muscle strength in older female twins. Journal of Applied Physiology 96, 173-180.

Tiainen, K., Sipilä, S., Alén, M., Heikkinen, E., Kaprio, J., Koskenvuo, M., Tolvanen, A., Pajala, S., Rantanen, T. 2005. Shared genetic and environmental effects on strength and power in older female twins. Medine and Science in Sports Exercise 37, 72-78.

Tiainen, K., Pajala, S., Sipilä, S., Kaprio, J., Koskenvuo, M., Alén, M., Heikkinen, E., Tolvanen, A., Rantanen, T. 2006. Genetic effects in common on maximal walking speed and muscle performance in older women. Scandinavian Journal for Medicine and Science in Sport. (DOI: 10.1111/j.1600-0838.2006.00553.x)

Tinetti, M. E. 1986. Performance-oriented assessment of mobility problems in elderly patients. Journal of the American Geriatrics Society 34, 119-126.

Tinetti, M. E. 2003. Preventing falls in elderly persons. New England Journal of Medicine 348, 42-49.

Tinetti, M. E., Speechley, M. 1989. Prevention of falls among the elderly. New England Journal of Medicine 320, 1055-1059.

Tinetti, M. E., Williams, C. S. 1997. Falls, injuries due to falls, and the risk of admission to a nursing home. New England Journal of Medicine 337, 1279-1284.

Tinetti, M. E., Williams, T. F., Mayewski, R. 1986. Fall risk index for elderly patients based on number of chronic disabilities. The American Journal of Medicine 80, 429-434.

Tinetti, M., Speechley, M., Ginter, S. 1988. Risk factors for falls among elderly persons living in the community. New England Journal of Medicine 319, 1701-1707.

Tinetti, M. E., Liu, W-L., Claus, E. B. 1993. Predictors and prognosis of inability to get up after falls among elderly persons. Journal of American Medical Association 269, 65-70.

Tinetti, M. E., Douchette, J. T., Claus, E. B. 1995. The contribution of predisposing and situational risk factors to serious fall injuries. Journal of the American Geriatrics Society 43, 1207-1213.

Teasdale, N., Simoneau, M. 2001. Attentional demands for postural control: the effects of aging and sensory reintegration. Gait & Posture 14, 203-210.

Todd, R. D., Lobos, E. A., Sun, L-W., Neuman, R. J. 2003. Mutational analysis of the nicotine acetylcholine receptor alpha 4 subunit gene in attention deficit/hyperactivity disorder: evidence for association of an intronic polymorphism with attention problems. Molecular Psychiatry 8, 103-108.

Tromp, A. M., Smit, J. H, Deeg, D. J., Bouter, L. M., Lips, P. 1998. Predictors for falls and fractures in the Longitudinal Aging Study Amsterdam. Journal of Bone Mineral Research 13, 1932-1939.

Tromp, A. M., Pluijm, S. M. F., Smit, J. H., Deeg, D. J. H., Bouter, L. M., Lips, P. 2001. Fall-risk screening test: A prospective study on predictors for falls in community-dwelling elderly. Journal Clinical Epidemiology 54, 837- 844.

Vague, P., Dufayet, D., Coste, T., Moriscot, C., Jannot, M. F., Raccah, D. 1997. Association of diabetic neuropathy with Na/K ATPase gene polymorphism. Diabetologia 40, 506-511.

Verhagen, P., Cerella, J. 2002. Aging, executive control, and attention: a review of meta-analyses. Neuroscience Biobehavioral Reviews 26, 849-857.

Volpato, S., Ferrucci, L., Blaum, C., Ostir, G., Cappola, A., Fried, L. P., Fellin, R., Guralnik, J. M. 2003. Progression of lower-extremity disability in older women with diabetes: the Women's Health and Aging Study. Diabetes Care 26, 70-75.

Volpato, S., Leveille, S. G., Blaum, C., Fried, L. P., Guralnik, J. M. 2005. Risk factors for falls in older disabled women with diabetes: the women's health and aging study. Journal of Gerontology 60, M1539-M1545.

Weeks, D. L., Forget, R., Mouchnino, L., Gravel, D., Bourbonnais, D. 2003. Interaction between attention demanding and cognitive tasks and static postural stability. Gerontology 49, 225-232.

Wei, T. S., Hu, C. H., Wang, S. H., Hwang, K. L. 2001. Fall characteristics, functional mobility and bone mineral density as risk factors of hip fracture in the community-dwelling ambulatory elderly. Osteoporosis International 12, 1050-1055.

Welford, A. T. 1984. Between bodily changes and performance: Some possible reasons for slowing with age. Experimental Aging Research 10, 73-88.

Welford, A. T. 1988. Reaction time, speed of performance, and age. Annals of the New York Academy of Sciences 515, 1-17.

West, C. G., Gildengorin, G., Haegerstrom-Portnoy, G., Schneck, M. E., Lott, L., Brabyn, J. A. 2002. Is vision function related to physical functional ability in older adults? Journal of the American Geriatrics Society 50, 136-145.

Whipple, R. H., Wolfson, L. I., Amerman, P. M. 1987. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. Journal of the American Geriatric Society 35, 13-20.

Whitman, G. T., Tang, T., Lin, A., Baloh, R. W. 2000. A prospective study of cerebral white matter abnormalities in older people with gait dysfunction. Neurology 57, 990-994.

Willig, R., Luukinen, H., Jalovaara, P. 2003. Factors related to occurrence of hip fracture during a fall on the hip. Public Health 117, 25-30.

Winter, D. A. 1995. Human balance and posture control during standing and walking. Gait & Posture 3, 193-214.

Wolfson, L., Whipple, R., Derby, C. A., Amerman, P., Murphy, T., Tobin, J. N., Nashner, L. 1992. A dynamic posturography study of balance in healthy elderly. Neurology 42, 2069-2075.

Wolfson, L., Whipple, R., Derby, C. A., Amerman, P., Nashner, L. 1994. Gender differences in the balance of healthy elderly as demonstrated by dynamic posturography. Journal of Gerontology 49, M160-M167.

Winter, D. A. 1995. Human balance and posture control during standing and walking. Gait & Posture 3, 193-214.

Woollacott, M. H. 1993. Age-related changes in posture and movement. Journal of Gerontology 48 (special issue), 56-60.

Woollacott, M. H. 2000. Systems contributing to balance disorders in older adults. Journal of Gerontology 55, M424-M428.

Woollacott, M. H., Shumway-Cook, A., Nashner, L. M. 1986. Aging and posture control: changes in sensory organization and muscular coordination. International Journal of Aging and Human Development 23, 97-114.

Woollacott, M., Shumway-Cook, A. 2002. Attention and the control of posture and gait: a review of an emerging area of research. Gait & Posture 16, 1-14.