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Sari Iinattiniemi

FALL ACCIDENTS AND EXERCISE AMONG A VERY OLD HOME-DWELLING POPULATION

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Abstract

High age is a distinguished risk factor of falling, but there remains gaps in epidemiological data among very old people. Also, effects of exercise-oriented intervention implemented by geriatric teams is not known.

The aims were to describe the incidence and risk factors of falls, the risk of fall-related injuries associated with physical activity, and to investigate the effect of pragmatic exercise intervention on fall risk among a home-dwelling population aged 85 years and older.

The target population consisted of home-dwelling citizens of Oulu aged 85 years or more (N = 827). Altogether 555 people (mean age 88 SD ± 3), representing 67% of the population sample, were evaluated by interviews and clinical assessments. Falls and physical activity were monitored via telephone nine times during a 27-month follow-up constituting 1114 person years. Risk factors of falls were determined during an 11-month period before intervention, as were the effects of the intervention during a 16-month period thereafter. Negative binomial regression, pooled logistic regression and Cox regression analyses were used to analyze data.

The incidence rates of falls, major soft tissue injuries and fractures were 1039 (95% CI 974–1093), 74 (58–92) and 89 (72–108), respectively. The probability of getting injured was higher in the morning and evening than in the daytime. The contribution of the ongoing activity and the type of falling to the risk of injury was less than that previously reported among younger home-dwellers. The risk factors of falls were a history of recurrent falling, trouble with vision when moving, use of an antipsychotic drug, and feelings of anxiety, nervousness or fear. Exercise other than walking was associated with a reduced risk of injury-causing falls. Pragmatic intervention wasn’t effective in preventing falls, but it was effective in preserving balance performance. Among those with better functional abilities, intervention was effective in reducing the risk of the first four falls. Adherence to recommended interventions was relatively low.

In conclusion, the frequency of falls and fall-related fractures increases up to the highest ages. Anxiety-related disorders may be more important risk factors of falls than are drugs commonly used in treatment. Exercise related to everyday activities is safe among the most elderly. The effects of practical exercise intervention are promising, but attention needs to be paid to adherence to exercise in order to improve these effects.

Keywords: accidental fall, ageing, epidemiology of falls in elderly, exercise, fall, fall-induced injuries, home-dwelling old people, intervention, medications, physical activity, population studies, prevention, randomized, risk factors

Acknowledgement

I dedicate this thesis to my grandmother, Anna, who lost her balance, fell, and fractured her hip at the age of 89. She recovered from this devastating falling injury and continued home-dwelling life for five years until she passed away at the age of 94 in the autumn of 2008. I also dedicate this work to my grandmother-in-law, Hanna, who suffered a fall-related fracture of her proximal femur at the age of 88. She fell at night during a bathroom trip in a residential dwelling. She died three years later in the summer of 2007. I learned a lot about falling accidents from their cases, which both happened at the time of writing this thesis.

The Oulu 85plus -study was carried out in cooperation between elderly care in the city of Oulu and the Department of Health Sciences, public health and general practice, University of Oulu. I owe my sincerest gratitude to the geriatric teams and the participants for contribution and participation to this study.

Above all, I want to thank my supervisor, Professor Heikki Luukinen for giving me the opportunity to be part of this larger project, for encouragement and support to write and defend this thesis. I thank warmly the official referees, Professor Kaisu Pitkälä and Professor Elise Kosunen for the careful revisions, and a licensed translator Keith Kosola for language revision and Dosent Ilona Nurmi-Lüthje for a promise to opponent this thesis.

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Abbreviations

ADL	activities of daily living
ATC	anatomical therapeutic chemical
BMD	body mass density
BMI	body mass index
CES-D	Center for Epidemiologic Studies Depression Scale
CG	control group
CI	confidence interval
FICSIT	Frailty and Injuries: Cooperative Studies of Intervention Techniques, a set of 8 RCTs in the US, all aiming to reduce frailty and falls.
GDS-15	15-item Version of the Geriatric Depression Scale
HR	hazard ratio
hr	hour
ICD 9-10	International Classification of Diseases and Related Health Problems, Ninth, Tenth Revision
IG	intervention group
IR	incidence rate
IRR	incidence rate ratio
m	men
Md	median
MMSE	Mini-Mental State Examination
MSI	major soft tissue injury
N	study sample size
NS	not significant
OR	odds ratio
ProFANE	Prevention of Falls Network Europe
PROFET	The prevention of falls in the elderly trial
PY	person years
RCT	randomized controlled trial
RSG	risk factor study group
RR	relative risk
SD	standard deviation
sec	second
w	women
WHO	World Health Organisation
yr	year

List of original papers

This thesis is based on the following studies, which are referred to in the text by their Roman numerals:

I Lehtola S, Koistinen P & Luukinen H (2006) Falls and injurious falls late in home-dwelling life. Arch Gerontol Geriatr 42: 217–224.

II Iinattiniemi S, Jokelainen J & Luukinen H (2008) Falls risk among a very old home-dwelling population. Scand J Prim Health Care. In press.

III Iinattiniemi S, Jokelainen J & Luukinen H (2008) Exercise and risk of injurious fall late in home-dwelling life. Int J Circumpolar Health 67: 235–244.

IV Luukinen, H, Lehtola S, Jokelainen J, Väänänen-Sainio R, Lotvonen S & Koistinen P (2007) Pragmatic exercise-oriented prevention of falls among the elderly: a population-based, randomized, controlled trial. Prev Med 44: 265–271.

Contents

1 Introduction

Even in the twentieth centery, there is still a belief that falls are an unpreventable part of the aging process (Sheldon 1960a,b).

Falls are common among elderly persons (Jäntti *et al.* 1993, Luukinen *et al.* 1994) and they have a wide range of physical, psychological, and economic consequences (Ryynänen 1994), even when no serious injury has occurred (Tinetti & Williams 1997, Seematter-Bagnoud *et al.* 2006). Most important of all is the impact of a fall on an older individual, who may find him/herself trapped in a downward spiral of inactivity and loss of independence (Friedman *et al.* 2002). Fall accidents among old people are major issues for health care and social service providers because of the rapid aging of populations (Tinetti 2003), but also irrespective of this demographic change (Kannus *et al.* 1999, Luukinen *et al.* 2006a). However, during recent years, the age-adjusted incidence of hip fractures has declined (Kannus *et al.* 2006). Nurmi & Lüthje (2002) found that the direct health system cost per fall injury episode for people 65 year and older in Finland was 944 euros in 1999. Scuffham *et al.* (2003) found that costs rise after the age of 75.

Regular participation in moderate physical activity has been recommended in preventing fall accidents (Yoshida 2007, Lamb *et al.* 2005), because increased activity tends to improve balance and strength (Gregg *et al.* 2000, Skelton 2001, Latham *et al.* 2004, Howe *et al.* 2007, Orr *et al.* 2008), which are important risk factors of falls (Ganz *et al.* 2007). In fact, despite many of the recent developments in medical care through advanced technology (Bean *et al.* 2004, Paterson *et al.* 2007), active participation in physical exercise may well be the most universal and effective means of improving physical functioning, reducing morbidity and mortality in old age (Goetzel *et al.* 2007) and promoting healthy aging (Peel *et al.* 2004). A novel falls prevention policy (Campbell & Robertson 2007) concludes that, for populations at risk at the community level, targeted single interventions are as effective as multifactorial interventions, and may be more acceptable and cost-effective (Beard *et al.* 2006).

2 Literature review

2.1 Terminology

Old people are internationally (WHO 2008) defined as people aged 60 years or older, and the very old as those aged 80 years or older. People aged 80 years or older were earlier called the oldest old, but the WHO recently changed the nomenclature to the very old. Retirement age in Finland is 65 years, and aged people are defined as aged 65 years or older, while the very old are defined as being at the chronological age of 85 years or older (Iinattiniemi & Tervaskanto-Mäentausta 2008).

The literature contains several definitions of fall accidents (Hauer *et al.* 2006). The Kellogg International Group on the Prevention of Falls (1987) originally defined a fall as ”an event which results in a person coming to rest inadvertently on the ground or floor or other lower level and other than as a consequence of the following: sustaining a violent blow; loss of consciousness; sudden onset of paralysis, as in stroke; or an epileptic seizure”. A fall according to Luukinen *et al.* (1994) is defined as an unexpected event where a person falls to the ground from an upper level or at the same level, including falls on stairs and onto a piece of furniture. If a person is found lying on the floor and unable to explain why, it is also accepted as a fall. This is in accordance with the high-quality standardized definition set forth by the ProFaNE consensus statement of outcome definitions (Lamb *et al.* 2005) and the WHO definition of falls (Yoshida 2007).

Falls occurring due to loss of consciousness (syncope or seizure) or sudden paralysis were defined as ‘syncopal falls’ by Nevitt *et al.* (1989). Authors have often failed to report whether syncopal falls have been included or excluded in their research. Some studies have included syncopal falls (Luukinen *et al.* 1994, Jensen *et al.* 2002), while others have excluded them (e.g. Tinetti *et al.* 1988, Nevitt *et al.* 1989, Buchner *et al.* 1993, Hauer *et al.* 2001, Lord *et al.* 2003).

A faller is usually defined as someone who has fallen at least once over a set period of time, usually six months or one year, whereas a recurrent faller has fallen twice or more during the follow-up period (Nevitt *et al.* 1989, Lord *et al.* 1991).

Injuries resulting from falls have been classified as major injuries, such as wounds needing suturing, dislocations, or fracture (Nevitt *et al.* 1991, Luukinen *et al.* 1995a).

A risk factor has been defined in epidemiology literature by Last (1988) as "an aspect of personal behavior or lifestyle, an environmental exposure or an inborn or inherited characteristic which, on the basis of epidemiologic evidence, is known to be associated with a health-related condition(s) considered important to prevent".

Haddon (1968) described a countermeasure that addresses a specific risk factor. The literature describes three general approaches: primary prevention, defined as avoiding the onset of pathological processes that may eventually lead to disability; secondary prevention, defined as slowing the progression (and thereby postponing debilitating effects) of a disease; and tertiary prevention, defined as strategies to restore function and increase autonomy in people with reduced functional capacity (Pope & Tarlov 1991). Such strategies may be targeted at an individual, family, group or population level. Community-based prevention programs enable achievement of population-level changes (Coggan & Bennett 2004). Public Health terminology defines an intervention as a set of one or more actions "with a coherent objective of bringing about change or producing identifiable outcomes" (Rychetnik *et al.* 2001).

Physical activity is defined as "any bodily movement produced by skeletal muscles that result in energy expenditure" (Caspersen *et al.* 1985). Physical activity has occupational, transportational and recreational components and includes pursuits like golf, tennis, and swimming. It also includes other active pastimes like gardening, cutting wood, and carpentry. Household physical activities are everyday lifestyle habits that comprise a portion of nonexercise activity (Matthews *et al.* 2007, Sesso 2007). The term exercise is used to describe planned and structured activities, for example those designed for fallers in order to improve balance (e.g. group exercise programs like Tai Chi and individually prescribed programs) (McDermott & Mernitz 2006).

2.2 Incidence and circumstances of falls and fall-related injuries

Prospective studies on the epidemiology of falls and fall-related injuries have been presented since the late 1980s (Table 1 & 2). Incidence of falls varies greatly depending on the age and gender of the populations. The means of recording of falls may also explain some of the differences in incidence rates.

Table 1. Frequency of falls in prospective studies of home-dwelling older people.

Study	N	Age	Follow-up for falls	Percentage (%)		Incidence /1000 PY
				Total	Multiple	
Fleming *et al.* 2008	62	≥ 90	1 yr. Weekly fall calendars. Regular phone calls.	57	40	2500
Chu *et al.* 2005	1517	≥ 65	1 yr. Bimonthly phone calls.	19	5	270
	771 m					220
	746 w					324
Salvà *et al.* 2004	448	≥ 65	1 yr. Monthly phone calls.	32	8	460
	183 m			25	4	309
	265 w			37	11	565
Bergland *et al.* 2003	307 w	≥ 75	1 yr. Fall calendars every 3 months. Reminder phone calls.	51	22	1003
Schwartz *et al.* 1999	152 w	≥ 59	2.7 yr. Monthly phone calls.	41		508
Vellas *et al.* 1998	482	≥ 60	2 yr. Phone calls.	61		642
	193 m		Bimonthly postcard.	54	43	551
	289 w			66	49	704
Davis *et al.* 1997	1073	≥ 70	1 yr. Letter every 4 months.			
	436 m			9		139
	637 w			16		276
Berg *et al.* 1997	96	60–88	1 yr. A report card every 2	52		948
	38 m		weeks. Phone call	53		
	58 w		reminders.	52		
Graafmans *et al.* 1996	354	≥ 70	28 weeks. A diary mailed every two months.	36	16	
Luukinen *et al.* 1994	979	≥ 70	1 yr. 3-month phone calls.	30	11	518
	377 m		Falls diaries. Examination	26	6	368
	602 w		of the medical records.	34	14	611
Lord *et al.* 1994	341 w	≥ 65	1 yr. Bimonthly mail or phone contact.	39	21	842
Tinetti *et al.* 1993	1103	≥ 72	2.6 yr. Monthly mail or phone contact.	34		452
O'Loughlin *et al.* 1993	409	≥ 65	1 yr. Monthly phone calls.	29	11	482
	152 m		Memory calendar.	22	12	428
	257 w			34	11	536
Lach *et al.* 1991	1358	≥ 65	1 yr. Monthly postcard. Phone call after each fall. Reminder phone calls	30		
Campbell *et al.* 1990	761	≥ 70	1 yr. Monthly phone calls.	35	16	683
	296 m		Recording on forms.	28	15	644
	465 w			40	16	707
Nevitt *et al.* 1989	325	≥ 60 with	1 yr. Weekly postcard.	57	31	1658
	59 m	previous	Nonsyncopal falls.			
	266 w	falls				
Tinetti *et al.* 1988	336	≥ 75	1 yr. Bimonthly phone calls and a diary.	32	17	809

yr = year, PY = person year, m = men, w = women

Table 2. Frequency of injury-causing falls in prospective studies of home-dwelling older people.

Study	N	Age	Follow-up for falls	Percentage (%)		Incidence
				Fracture	MSI	/1000 PY
Chu *et al*. 2005	1517 771 m 746 w	≥ 65	1 yr. Bimonthly phone calls.	7 (MSI or fracture)		
Salvà *et al*. 2004	448 183 m 265 w	≥ 65	1 yr. Monthly phone calls. A diary.	8		
Schwartz *et al*. 1999	152 w	≥ 59	2.7 yr. Monthly phone calls.	3	13	79
Vellas *et al.* 1998	482	≥ 60	2 yr. Telephone. Bimonthly postcard.			
	193 m			3	13	
	289 w			6	13	
Berg *et al.* 1997	96 38 m 58 w	60-88	1 yr. A report card every 2 wk. Phone call reminders. A questionnaire mailed to fallers.	5	9	
Davis *et al.* 1997	1073	≥ 70	1 yr. Letter every 4 months. Injury needing medical attention.			
	436 m			0	9	
	637 w			12	6	
Luukinen *et al.* 1995a	1016	≥ 70	2 yr. 3-month phone calls and fall diaries. Examination of the medical records.			
	377 m			3	12	54
	602 w			6	11	98
Tinetti *et al.* 1995a	1103	≥ 72	1 yr. Fall calendar each month and phone calls.	6	24	65
O'Loughlin *et al.* 1993	409 152 m 257 w	≥ 65	1 yr. Monthly phone calls. Memory calendar. Self-report of fall-related injury.	3 (MSI or fracture)		
Campbell *et al.* 1990	761	≥ 70	1 yr. Monthly phone calls. Written forms. Medical records.			
	296 m			3		
	465 w			4		

m = men, w = women, yr = year, MSI = major soft tissue injury, wk = week, PY = person year

The incidence of falls (Luukinen *et al.* 1994, Tinetti *et al.* 1988, Campbell *et al.* 1990) and fall-related major soft tissue injuries and fractures tends to increase with age, being highest among persons aged 80 years or older (Luukinen *et al.* 1995a). Based on calculations made in several prospective studies of community-dwelling old people (Rubenstein & Josephson 2002), the mean incidence of any falls, severe falls, fractures and hip fractures are 650, 65, 30 and 5/1000 person years (PY). Every seventh faller is a recurrent faller. Women, especially those younger than 80 years, are more prone to sustain recurrent falls than are men of corresponding ages (Luukinen *et al*. 1994). Population studies of falls are based on observations made in generally healthy populations aged 65-75 years or older, including a minority of subjects aged 85 years or older. These incidence rates are mostly based on retrospective, self-reported data that probably underestimate the true incidence of falls.

Among persons who are 70 years and older, the incidence of minor injuries caused by falls has been 136 per 1000 person years (PY), of major injuries, 57 per 1000 PY and of fractures, 25 per 1000 PY (Luukinen *et al.* 1995a). In 1997, the age-adjusted incidence of hip fractures was 437 per 100,000 persons among women and 233 per 100,000 persons among men (Kannus *et al*. 1999). However, during recent years (1997–2004), the incidence of hip fractures has decreased, and the age-adjusted incidence of hip fractures has declined among both men and women (Kannus *et al*. 2006). There is no clear gender difference in the rate of major soft tissue injuries, but fracture rates tend to be more common in women than in men (Luukinen *et al.* 1995a, Davis *et al.* 1997, Vellas *et al.* 1998).

Most falls occur during the active hours of the day (Campbell *et al.* 1990, Luukinen *et al.* 1994) when elderly persons are involved in their basic daily activities of living (Berg *et al.* 1997, Luukinen *et al.* 1994, Bergland *et al.* 2003) inside the home (Luukinen *et al*. 1994). Most falls occur while walking (42-54%), during risk-taking behavior like running or jumping (4-12%), when rising to stand up (3-5%), when sitting down (7%) or on stairs (3-14%) (Berg *et al.* 1997, Luukinen *et al.* 1994, Bergland *et al.* 2003, Nachreiner *et al*. 2007). Luukinen *et al.* (1996) reported a higher incidence rate of falls during the period when the temperature was below -20◦ C than at temperatures above +9◦ C.

Luukinen *et al.* (1995a) found the distribution of injurious falls by time of day to be as follows: 7% at night, 26% in the morning, 48% in the afternoon and 20% in the evening. Most injury-causing falls occur when standing or walking (63%), sitting or sitting down (9%), standing up (7%), performing a risky task (4%), doing a known ongoing activity (15%), and doing an unknown activity (2%).

2.3 General risk factors of falls

A broad classification (modified from Scott *et al.* 2004, Yoshida 2007) divides risk factors into four categories reflecting the broad determinants of health: clinical (e.g., age or disease-related impairments in body structure and body functions), behavioral (e.g., choices that individuals make and how they interact with their environment), environmental (e.g., presence of environmental hazards and obstacles and the absence of supportive features) and socioeconomic risk factors.

Most falls have a multifactorial etiology, and are thus rarely caused by a single factor. They usually result from interactions between long-term predisposing factors (e.g. medical, behavioral, psychological, environmental or socioeconomic) and short-term precipitating factors (trips, slips, drop attack, syncope, dizziness) (AGS/BGS 2001, Moreland *et al.* 2003, Tinetti 2003, Skelton & Todd 2004). The risk of falling increases dramatically as the number of risk factors increases in community-dwelling older persons: fall risk increases from 27% in the presence of one risk factor to 78% in the presence of four or more risk factors (Tinetti *et al.* 1988).

Prospective studies that have used multivariate analyses on risk factors of falls are shown in Table 3 & 4.

2.3.1 Clinical risk factors

Ganz *et al.* (2007) recently reviewed prospective studies and found that people who have fallen in the past year are more likely than those without a fall history to fall again. A summary of 16 studies assessing fall risk factors per se using multivariate analyses (Rubenstein & Josephson 2002) ranked a series of the following risk factors: weakness (positive association in 11 out of 11 studies), balance deficit (9/9), mobility limitation (9/9), gait deficit (8/9), visual deficit (5/9), cognitive impairment (4/8), impaired ADL (5/9) and postural hypotension (2/7). These studies consisted of personal assessments by professionals and frequent (weekly to monthly) follow-ups for falls lasting up to one year. There is limited comparability between the studies due to their focus on different risk factors and a different classification of risk factors being investigated in each of these studies.

Aging exposes to the risk of falls (Campbell *et al.* 1989, Vellas *et al.* 1998, Schwartz *et al.* 1999). Several diseases, e.g. Parkinson´s disease (Chu *et al.* 2005), arthritis (Nevitt *et al.* 1989), stroke (Campbell *et al.* 1989), dementia, acute serious illness (Tinetti *et al.* 1988), cataracts, peripheral neuropathy, and depression (Campbell *et al.* 1989, Vellas *et al.* 1998, Bergland *et al.* 2003, Chu *et al.* 2005), increase the risk of falls.

Meta-analyses (Leipzig *et al.* 1999b) and reviews (Kannus *et al.* 2005, Hartikainen *et al.* 2007) have found that a higher number of medications increases fall risk significantly. Use of multiple medications may lead to falls as a result of adverse reactions to one or more of the medications, detrimental drug interactions, or incorrect use. Even taking into account the underlying disease, specific psychotropic medication (e.g. neuroleptics, benzodiazepines, sedatives/hypnotics, and antidepressants) (Leipzig *et al.* 1999a) and cardiovascular and analgesic medication (Leipzig *et al.* 1999b) are predictors of falls. Ensrud *et al.* (2002) found that using benzodiazepines, antidepressants and anticonvulsants increases the risk of falling. A study by Nurmi-Lüthje *et al.* (2006) has shown that half of patients with an acute hip fracture use benzodiazepines or benzodiazepine-related drugs. Every third of them was home-dwelling people.

Many medical conditions increase the risk of falling by impacting directly on physiological mechanisms that affect maintenance of an upright posture (Lord *et al.* 2007). Sensory or neuromuscular impairments that are risk factors of falls include deficits in vision (Campbell *et al.* 1989, Nevitt *et al.* 1989, Bergland *et al.* 2003, Lord *et al.* 2006), proprioception, vestibular function, reaction time (Lord *et al.* 2007) and impaired cognition (Tinetti *et al.* 1988, Graafmans *et al.* 1996, Bergland *et al.* 2003) and muscle weakness (Graafmans *et al.* 1996, Vellas *et al.* 1998, Bergland *et al.* 2003, Chu *et al.* 2005). Age-associated hearing impairments tend to increase the number of trips and stumbles (Rubenstein 2006). Evidence from Moreland *et al.* (2003) is contradictory in this regard.

The disablement process increases with age (Verbrugge & Jette 1994). Clinically detected abnormalities in gait and balance are the other most consistent predictors of subsequent falls (Ganz *et al.* 2007). Abnormalities in balance and gait stem from impairments in sensory, central and musculosceletal functions that affect gait and posture (Trueblood & Rubenstein 1991). Problems with balance can also be experienced due to disorders that impair central processing of sensory information and motor responses, such as cognitive impairment and impaired alertness (Carter *et al.* 2001). Following central processing, anything that affects a person’s ability to respond to a sensory input can contribute to the risk of falling, such as disorders of the spinal cord, nerves, bones, muscles and joints. Such conditions include arthritis in weight-bearing joints resulting from structural deformity, decreased range of motion and pain, foot problems, and muscle disuse following fracture, injury or prolonged immobility (Lord *et al.* 2007).

2.3.2 Behavioral risk factors

Studies show a U-shaped association, i.e. the most inactive and active old people are at increased risk of falls (Tinetti *et al.* 1988, O'Loughlin *et al.* 1993). However, most findings indicate that restricted behavior is a risk factor of falls (Vellas *et al.* 1998, Schwartz *et al.* 1999, Heech *et al.* 2008). A recent cross-sectional study has shown an association between low physical activity and falls among 85-year-old subjects (Ruthig *et al.* 2007). It is suggested in the literature that excess activity increases fall risk, presumably because engagement in frequent physical activities, including household activities, increases exposure to falls (O'Loughlin *et al.* 1993, Chan *et al.* 2007, Wijlhuizen *et al.* 2008). Studies by Bergland *et al.* (2003) and Wijlhuizen *et al.* (2007) have shown that a higher risk of falling is associated with increased walking activity.

Tinetti *et al.* (1995a) found that a high level of physical activity is associated with a decreased risk of falls but tends to be associated with an increased risk of serious injury. A study by Gill *et al.* (2008) has suggested that a low level of recreational physical activity is more likely to be associated with injury-causing falls than is corresponding household activity. Herala *et al.* (2002) found an association between a recent decline in heavy outdoor work activity and the occurrence of fall-related fractures but not of major soft tissue injuries. Frequent engagement in physical activity, particularly in rapid or forceful activity, is associated with subsequent fall-related injury (Speechley & Tinetti 1991, O'Loughlin *et al.* 1993, Koski *et al.* 1998).

Psychological factors such as fear of falling (Luukinen *et al.* 1996) are associated with increased fall risk. Avoidance of activities due to fear of falling (Zijlstra *et al.* 2007) are strongly correlated with multiple falls. The relationship between falls and fear of falling is complex, because falls are an independent predictor of developing fear of falling and fear of falling is a predictor of subsequent falls (Friedman *et al.* 2002).

A study from Latimer *et al.* (2007) has shown that sleep disturbances increase the risk of falls. There are suggestions that psychological disturbance, particularly depression, may be an intermediary factor in the association between poor sleep quality and falls (Kaushik *et al.* 2007).

A U-shaped relationship between alcohol and hip fracture has been considered (Mukamal *et al.* 2007). A study by Kaukonen *et al.* (2006) has shown that alcohol consumption is common (28%, N = 103) among patients with an acute hip fracture (mean age 73 years among men and 81 years among women).

High consumption of alcohol is a risk factor of injurious falls (Stenbacka *et al.* 2002), and alcohol intake is associated with a significant increase in osteoporotic and hip fracture risk (Kanis *et al.* 2005). Some studies have not found an association (Nelson *et al.* 1992, Tinetti *et al.* 1995a), while O'Loughlin *et al.* (1993) have shown that alcohol consumption even protects community-living older adults from falling. For example, moderate alcohol consumption is negatively associated with stroke and may thus reduce the risk of falling (Reynolds *et al.* 2003). Other explanations may be that older adults with a high fall risk refrain from alcohol, or that heavy drinkers are not willing to participate in studies or may have died at an earlier age. These selections may underestimate the effect of heavy alcohol consumption on fall risk.

The association between poor nutritional status and falls among the elderly has not been studied extensively (Vellas *et al.* 1992). Limited evidence supports the hypothesis that malnutrition increases the propensity to fall (Vellas *et al.* 1990). A low body mass index (BMI) contributes to frailty (Fried *et al.* 2001). Frailty results from a 'vicious loop' that includes sarcopenia (loss of muscle mass and strength), neuromuscular impairment, falls and fractures, immobilisation, malnutrition and impaired protein synthesis (Muhlberg & Sieber 2004). Low levels of vitamin D are associated with an increased incidence of falling among older people (Mosekilde 2005, Venning 2005). A meta-analysis by Bischoff-Ferrari *et al.* 2004 clearly suggests a benefit of reduced fall risk from the use of vitamin D supplementation among community-dwelling old people.

2.3.3 Environmental and socioeconomic risk factors

Falls result from an interaction between physical abilities, behavior and environmental hazards (Lord *et al.* 2006). None of the prospective cohort studies (Tinetti *et al.* 1988, Campbell *et al.* 1989, Nevitt *et al.* 1989, Gill *et al.* 2000) have found household hazards to be associated with falls in primary analyses. However, because of greater exposure, older adults with fair balance are at a greater risk of environmental hazards than those with poor balance. On the other hand, those with excellent balance tolerate the exposure caused by household environmental hazards better than those with fair balance (Lord *et al.* 2006). Northridge *et al.* (1995) found that vigorous people living in hazardous environments are more likely to fall compared with frail people. Studies by Tinetti *et al.* (1995b) and Nevitt *et al.* (1991) found unsafe stairs to predispose to fall injuries.

Surprisingly, the association between falls and socioeconomic status remains poorly investigated. The Women's Heart and Health study (Lawlor *et al.* 2003) found that socioeconomic differences in fallers were modest. In general, people with low income, low education, inadequate housing, a lack of support networks, loneliness or lack of access to appropriate health or social services are at a greater risk of chronic health conditions (Mackenbach *et al.* 1997, Kunst *et al.* 1998) that are well-established risk factors of falls (Campbell *et al.* 1989, Nevitt *et al.* 1989). Gill *et al.* (2005) found more education to be protective and lower income to be associated with increased risk, but others (Yasamura *et al.* 1994, Reyes *et al.* 2004) report no relationship between years of education and fall risk. Ho *et al.* (1996) reported in a cross-sectional study that a blue collar occupation is protective against falls, while in their prospective longitudinal study Chu *et al.* (2005) reported no effect of previous occupation on fall risk. Data by West *et al.* (2004) were collected from hospital databases following admission for fracture or other injury. Based on these data, higher admission rates to health services due to falls have been found among the most deprived. This is presumably because falls have bigger effects among individuals with multiple comorbidities and poor living environments compared with those with better health, social and financial resources.

2.3.4 Randomized controlled trials aimed at preventing falls by affecting risk factors

A Yale FICSIT (Frailty and Injuries: Cooperative Studies of Intervention Techniques) study (Tinetti *et al.* 1994) used a tailored combination of intervention strategies based on an assessment of each participant's fall risk factors. Participants were about 30 percent less likely to fall compared with people who did not receive the intervention. A study by Wagner *et al.* (1994) tested a moderate-intensity intervention with tailored strategies based on assessments of each participant's risk factors. After one year, participants were 10 percent less likely to fall and 5 percent less likely to have an injurious fall compared with people who received usual medical care. The fall rate among male participants was reduced by almost two-thirds. In a Study of Accidental Falls in the Elderly (SAFE) by Hornbrook *et al.* (1994), health behavior intervention was comprised of a program of four group classes to prevent falls. The classes addressed environmental, behavioral, and physical risk factors and included exercise with instructions and supervised practice. The home safety portion included a home inspection with guidance and assistance in reducing fall hazards. Overall, participants were 15 percent less likely to fall compared with those who had not received the intervention. Male participants showed the greatest benefit.

A PROFET (Prevention of Falls in the Elderly Trial) conducted by Close *et al.* (1999) provided medical assessments of fall risk factors with referrals to relevant services and an occupational therapy home hazard assessment with recommendations for home modifications. After 12 months, those in the intervention group were 60 percent less likely to fall once and 67 percent less likely to fall repeatedly compared with those who had not received the intervention. A study by Day *et al.* (2002) looked at the effectiveness of group-based exercise in preventing falls when used alone or in combination with vision improvement and/or home hazard reduction. The intervention components were focused on increasing strength and balance, improving poor vision, and reducing home hazards. The group-based exercise was the most potent single intervention; when used alone, it reduced the fall rate by 20 percent. Falls were reduced further when vision improvement or home hazard reduction was combined with exercise. The most effective combination was group-based exercise with both vision improvement and home hazard reduction. Participants who received all three components were one-third less likely to fall. A study by Clemson *et al.* (2004) used a series of small group sessions to teach fall prevention strategies to community-dwelling older people. The fall rate among participants was reduced about 30 percent compared with those who had not received the intervention. The intervention was especially effective for men.

Home hazard reductions are most effective when targeted at subjects with a history of falls and those with limited mobility (Lord *et al.* 2006). The intervention implemented by Cumming *et al.* (1999) employed an occupational therapist who visited participants in their homes, identified environmental hazards and unsafe behavior, and recommended home modifications and behavior changes. In this way fall rates were reduced by one-third, but only among men and women who had experienced one or more falls in the year before the study. In a Falls-HIT (Home Intervention Team) Program by Nikolaus & Bach (2003), intervention was provided on home visits to identify environmental hazards that could increase the risk of falling. The intervention consisted of providing advice about possible changes, offering assistance with home modifications, and providing training in using safety devices and mobility aids. These interventions reduced the fall rate by 31 percent. The intervention was most effective among those with recurrent falls in the previous year.

Reviews by Clemson *et al.* (2008) and Gillespie *et al.* (2003) confirmed home assessment interventions that are comprehensive, well focused, and incorporate an environmentally fit perspective. On the contrary, a review by Chang *et al.* (2004) found no benefit from environmental risk modifications in reducing fall risk.

Table 3. Clinical risk factors for falls in prospective studies which have used multivariate analyses among home-dwelling older people.

Study	N	Age	Balance deficit	Gait deficit	Lower extremity weakness	Vision deficit	Impaired hearing	Dizzin-ess	Orthostatic hypo-tension	ADL deficit	Assistive device	Sensory problems	Parkin-son's disease	Arthritis	Stroke	Cognitive deficit	De-pression	Poly-phar-macy	Psycho-tropic drug	Antihy-perten-sives
Tinetti *et al.* 1988	336	≥ 75	↑*	↑*	↑*	↑	-	-	-	↑*	↑	↑*		↑		↑*	↑	↑	↑	↑
Campbell *et al.* 1989	761	≥ 70	↑*	↑	↑*	↑			↑*w		↑			↑*m	↑*			↑*w	↑*w	w↑
O'Loughlin *et al.* 1993	409	≥ 65	↑*	↑	↑*		-	↑*							↑*			↑		
Vellas *et al.* 1998	482	≥ 60	↑*W	↑	↑*M					↑								↑	-	-
Davis *et al.* 1999	1073	≥ 70 w			↑					↑*					-			↑		
Schwartz *et al.* 1999	1517	≥ 65			↑*				↑*	↑				↑*			↑	↑	↑*	
Bergland *et al.* 2003	307	≥ 75 w	↑*	↑*	↑*	↑*			↑*	↑						↑*	↑*		-	-
Chu *et al.* 2005	152	≥ 59 w	↑*	↑*	↑*	-			↑	↑	↑	↑	↑*	↑*	↑	↑	-	↑	-	↑
Nevitt *et al.* 1989	325	≥ 60 #	↑	↑*	↑*	↑*						↑	↑*	↑*			-			
Luukinen *et al.* 1995b	1016	≥ 70 #	↑	↑*	↑							↑*							↑*	
Graafmans *et al.* 1996	354	≥ 70 #	↑*	↑*	↑*	-		↑*	-	↑	↑			-	↑	↑*	↑			
Luukinen *et al.* 1996	1016	≥ 70 #		↑				↑*	↑	↑	↑	-			↑	-	↑			

↑ = positive association in bivariate analysis, $p < 0.05$ or 95% CI for RR not crossing 1, * = positive association verified in multivariate analysis, - = no association, # = recurrent falls, w = women, m = men.

Table 4. Sociodemographic, behavioral and environmental risk factors for falls in prospective studies which have used multivariate analyses among home-dwelling older people.

Study	N	Age	Previous fall	Age ≥ 80	Female	Low education	White collar work	Low physical activity	High physical activity	Alcohol consumption	Poor nutrition	Loneliness	Fear of falling	Environmental hazard
Tinetti *et al.* 1988	336	≥ 75	↑	↑	-			-	↑	-	-			-
Campbell *et al.* 1989	761	≥ 70	↑	↑*	-			↑*w	↑					-
O'Loughlin *et al.* 1993	409	≥ 65	↑	↑	↑			↑*	↑*	↓	-			
Vellas *et al.* 1998	482	≥ 60	↑*	↑*	↑*			-	-		-			
Davis *et al.* 1999	1073	≥ 70 w	↑*					-	↓	-	↑			
Schwartz *et al.* 1999	152	≥ 59 w	↑	↑*				↑*	↓		-			
Gill *et al.* 2000	1088	≥ 72												-
Bergland *et al.* 2003	307	≥ 75 w	↑*						↑					
Chu *et al.* 2005	1517	≥ 65	↑*	↑*	↑	-	-							
Nevitt *et al.* 1989	325	≥ 60 #	↑*	↑				↑		-	-	↑*		-
Luukinen *et al.* 1995b	1016	≥ 70 #	↑*	-	↑									
Luukinen *et al.* 1996	1016	≥ 70 #	↑*	↑	↑*			-	-	-			↑*	
Graafmans *et al.* 1996	354	≥ 70 #	↑	-	-			-			-			

↑ = positive association in bivariate analysis, $p < 0.05$ or 95% CI for RR not crossing 1, ↓ = negative association in bivariate analysis, * = positive association verified in multivariate analysis, - = no association, # = recurrent falls, w = women.

2.4 Exercise interventions in fall prevention

Accumulating evidence suggests that physical activity helps maintain mobility, muscle strength, reaction time, balance, and bone mineral density, thereby reducing the risk of falls and osteoporotic fractures (Gregg *et al.* 2000, Latham *et al.* 2004, Howe *et al.* 2007, Orr *et al.* 2008). There are at least 44 randomized controlled trials that evaluate the effect of exercise on falls. The program characteristics and results are shown in Table 5.

A recent meta-analysis (Sherrington *et al.* 2008) has shown that exercise reduces the rate of falls by around 17% (RR 0.83 95% CI 0.75–0.91). There are bigger effects from programs that include more challenging balance training, a higher dose of exercise (more than 2 hours per week over a 6-month period) and do not include a walking program. Programs with all of these features reduce fall risk by 42% (RR 0.58 95% CI 0.48–0.69). An earlier meta-analysis by Chang *et al.* (2004) has shown that exercise trials reduce fall risk among subjects with a high risk of falling, i.e. those with a history of falling or who were selected because of other risk factors (1176 participants; RR 0.86 95% CI 0.76–0.98). According to Cochrane's review, fall risk is reduced by Otago home-based balance and strength training (3 RCTs) and a Tai Chi program (1 RCT) (Gillespie *et al.* 2003). However, group exercise (9 RCTs) and strength training (1 RCT) did not reduce fall risk, and walking exercise (1 RCT) was not effective in reducing fall risk in populations not selected according to risk factors of falling.

The Otago home exercise program (Campbell *et al.* 1997, Robertson *et al.* 2001a,b) aims to incorporate exercises into daily routines, supplementing effects with education, peer support and individual attention by a physiotherapist. The exercise program aims to improve balance by means of home exercise, and walking is also included in the training if it is found to be safe. The trial has been processed into practice and favorable pragmatic results are reported conclusively in papers by Gardner *et al.* (2001, 2002). The Otago exercise program seems not to work well with people younger than 80 years, those with visual impairment or those who take psychoactive drugs, unless fully compliant (Campbell *et al.* 2005).

Exercise programs that are not targeted at high risk populations have shown positive effects in fall prevention (Wolf *et al.* 1996, Lehtola *et al.* 2000, Li *et al.* 2005, Madureira *et al.* 2007, Voukelatos *et al.* 2007). Tai Chi classes have been shown to be effective in fall prevention (Harling & Janet 2008). They involve controlled movements of the center of mass and narrowing of the base of support and can be modified to include hand support. However, Tai Chi conducted twice a week for 48 weeks has not reduced fall risk in frail older people aged 70–97 years (Wolf *et al.* 2003). In addition to Tai Chi, also other forms of group exercise have reduced fall risk (Day *et al.* 2002, Barnett *et al.* 2003, Lord *et al.* 2003, Skelton *et al.* 2005, Madureira *et al.* 2007). An exercise program implemented by Skelton *et al.* (2005) includes floor coping skills such as crawling and rolling to ensure avoidance of a long lie after a fall.

In general, exercise has been shown to exert a strong effect on functional level and modifiable fall risk factors, and accordingly, to reduce fall risk. High-level functional balance training in a group or a home setting, delivered by a specialist, is crucial in order to lower fall risk significantly (King 1998, Sherrington *et al.* 2008). To be effective, the exercise must be highly challenging balance exercise, regular (2–3 times a week), progressive for more than six months, and supervised until the older adult can exercise independently. The program uptake (Campbell *et al.* 2005) and continuation after intervention is also crucial: a 12-week strength and balance program will only be effective if maximal input is expended and all exercise sessions are attended, the exercise is undertaken as prescribed, it progresses and then continues after completion of the course (Rubenstein *et al.* 2000).

Table 5. Exercise-based intervention matrix – Randomized controlled trials examining the effect of exercise on falls among community-living older people. Results summarized by the nature of the exercise program.

Study	N	Mean age	Follow-up for falls	Home-based	Group-based	Dose	Effect [a]
Barnett *et al.* 2003	163 at risk	75	1 yr. Fall calendar each month and phone calls.	A, B, C, D, E, F	A, B, C, D, E, F	37 wk, 1-hour class 1×/wk Additional home exercises	RR 0.60 (0.36–0.99)
Buchner *et al.* 1997	105 at risk	75	25 months. Monthly postcard and phone call		A, E	24–26 wk, 1-hour class, 3×/wk	RR 0.53 (0.30–0.91)
Campbell *et al.* 1997	233 w	84	1 yr. Monthly postcard calendars.	A, B, D, F		1 yr, 30 min 3×/wk, 5 min walking per day	RR 0.68 (0.52–0.90)
Campbell *et al.* 1999	103 w	75	1 yr. Monthly postcard calendars.	A, B, D, F		2 yr, 30 min 3×/wk, 5 min walking per day	RR 0.69 (0.49–0.97)
Campbell *et al.* 2005	97	83	1 yr. Monthly postcard calendars.	A, B, D, F		1 yr, 30 min 3×/wk, 5 min walking per day	RR 0.72; $p < 0.001$, fully compliant subjects
Day *et al.* 2002	1090 at risk	76	18 months. Monthly postcard calendars and phone calls.	A, B, F	A, B, F	15 wk, 1-hour class. 1×/wk Daily home exercises	RR 0.82 (0.70–0.97)
Hauer *et al.* 2001	57 at risk	82	6 months. 2×/month postcard calendars and phone calls.		A, B, F	3 monhts, 3×/wk, 45-min class	RR 0.75 (0.46–1.25)
Helbostad *et al.* 2004	77	81	1 yr. Monthly postcard and an interview.	A, B	A, B, F	12 wk, 4 execises, 10 repetition, 2×/day	Home/group NS (RR not reported)

Study	N	Mean age	Follow-up for falls	Home-based	Group-based	Dose	Effect [a]
Latham *et al.* 2003	243	79	6 months. A fall diary and 2 home visits.	A		10 wk, 3×/wk, 60–80% of 1RM	RR 0.96 (0.67–1.36)
Lehtola *et al.* 2000	131	72	10 months. Phone call every month.	D	A, B, F	20 wk, 1-hour class, home exercises 3×/wk, walk 20 min	RR 0.60 (0.43–0.84)
Li *et al.* 2005	256 at risk	77	1 yr. Daily fall calendar.		B, C, F	26 wk, 1-hour sessions 3×/wk, totally 78 hours	RR 0.45 (0.33–0.62)
Liu-Abrose *et al.* 2004	104 w	79	25 wk. A fall diary.		A, B, F	25 wk, 50 min class 2×/wk	RR 1.8 (0.67–4.85)
Lord *et al.* 2003	551 retirement village	80	1 yr. Monthly questinairre, a phone call or home visit.		B, D	1 yr, 1-hour class 2×/wk, totally 96 hours	RR 0.78 (0.62–0.99)
Madureira *et al.* 2007	66 w at risk	74	1 yr. a fall diary.		B, D	1 yr, 1-hour 1×/wk	RR 0.48 (0.25–0.93)
Means *et al.* 2005	205	74	6 months. Monthly post cards and phone calls.		B, D, E, F	6 wk, 90 min 3×/wk	RR 0.41 (0.21–0.77)
Morgan *et al.* 2004	294 at risk	81	1 yr. Postcard diary 2×/month		B	8 wk, 45 min 3×/wk, totally 24 sessions	RR 1.05 (0.66–1.68)
Robertson *et al.* 2001a	240	81	1 yr. Monthly post cards and phone calls.	A, B, D		1 yr, 3×/week, walk 2×/wk	RR 0.54 (0.32–0.90)

Study	N	Mean age	Follow-up for falls	Home-based	Group-based	Dose	Effect [a]
Robertson *et al.* 2001b	N = 450	83	1 yr. Monthly post cards and phone calls.	A, B, D		1 yr, 3×/wk, walk 2×/wk	RR 0.70 (0.59–0.84)
Rubenstein *et al.* 2000	N = 59 m	74	3 months. An interview 2×/month or phone calls.		A, B, D, E, F	12 wk, 90 min class 3×/wk, totally 54 hours	RR 0.90 (0.42–1.90)
Skelton *et al.* 2005	N = 100 w recurrent fallers	72	20 months. A fall diary 2×/month.	A, B, F	B (hip protectors)	9 months, 1-hour class 1×/wk, home exercises ½-hour 2×/wk	RR 0.69 (0.50–0.96)
Suzuki *et al.* 2004	N = 110 w	78	20 months. Two inter-views (8 and 20 month)	A	A, B,C, D	6 months, 1-hour class/2wk, 30 min home exercises 3×/wk	RR 0.35 (0.14–0.90)
Timonen *et al.* 2008	N = 68 discharged from hospital	83	10 wk. A questionairre and medical records.	A, B, F	A, B, F	10 wk, 90 min class, totally 20.	Group/ home NS (RR not reported)
Voukelatos *et al.* 2007	N = 702	69	24 wk. Monthly post cards and phone calls.	B, C	C	16 wk, 1-hour class 1×/wk, 10 min walk/day	RR 0.67 (0.49–0.93)
Wolf *et al.* 1996	N = 200	76	20 months. Monthly fall reports and phone calls.	A, B, C, D, F	A, B, C, D, F	15 wk, 25 min class 2×/wk, 15 min practice at home 2 times a week	RR 0.53 (0.32–0.86)
Wolf *et al.* 2003	N = 291 w	81	6 months. Monthly fall reports and phone calls.		C	48 wk, 60–90 min, 2×/wk	RR 0.75 (0.52–1.08)

[a] RR = relative risk from the original study or a meta-analysis by Sherrington *et al.* 2008. A = resistance training, B = static and dynamic balance training, C = Tai Chi, D = gait training, E = aerobic/cardiovascular training, F = flexibility training, ×/wk = times a week, min = minutes, NS = not significant, yr = year, m = men, w = women

2.5 Exercise interventions in fall injury prevention

Education that aims to adopt effective risk assessments and strategies for prevention of falls (e.g., medication reduction and balance and gait training) reduces the rate of fall-related injuries in elderly populations (Tinetti *et al.* 2008).

Most studies of fall prevention interventions are not large enough or adequately powered to detect any effect on injuries, but post-hoc analyses of four randomized fall prevention interventions (N = 1016 aged 65–97) have shown that strength and balance exercise delivered by a physiotherapist and trained nurses may reduce the risk of injurious falling by 35%, most effectively among those aged 80 or older and having reported previous falls (Robertson *et al.* 2002). According to a Cochrane review on rehabilitation interventions after hip fracture, the results from 13 exercise trials were inconclusive (Handoll & Sherrington 2007). However, the effects of interventions seem to be the best in trials that have used the most intensive interventions (Hauer *et al.* 2002, Binder *et al.* 2004). A study by Korpelainen *et al.* (2006) showed that impact exercise composed of jumping and balance training for 30 months reduces fracture risk in 72–74-year-old women by over 60%. Skelton *et al.* (2008) have shown that exercise intervention increases BMD among fallers.

Evidence from quasi-controlled studies (McClure *et al.* 2005) indicates that a "population approach" can reduce the rate of injury-causing falls by 6–33% in elderly people. Significant decreases or downward trends in the rate of fall-related injuries have been reported in five large studies (Svanstrom *et al.* 1996, Ytterstad *et al.* 1996, Kempton *et al.* 2000, Poulstrup & Jeune 2000, Lindqvist *et al.* 2001). All the interventions included promotion of physical activity. In a large 10-year study, Grahn *et al.* (2005) showed a reduction in the forearm fracture rate by advocating increased physical activity and other lifestyle changes. Lin *et al.* (2006) did not show a reduction in the rate of injurious falls among Tai Chi villagers compared with control villagers.

2.6 Evaluation of literature

The frequency of falls increases with advancing age (Tinetti *et al.* 1988, Campbell *et al.* 1990, Luukinen *et al.* 1994). The impact of falling on the risk of hip fracture also increases with advancing age, whereas that of bone density tends to decrease (Cummings & Black 1995). The focus in fracture prevention is suggested to shift from osteoporosis to falls (Järvinen *et al.* 2008). Although high age is a distinguished risk factor of falling (Campbell *et al.* 1989, Vellas *et al.* 1998, Schwartz *et al.* 1999), gaps remain in epidemiological data among very old people. Generally, data on the risk factors of falling are based on observations made in populations aged 65–75 years or older, including a minority of subjects aged 85 years or older.

Although exercise has proven advantageous for old people (Campbell *et al.* 1997, Robertson *et al.* 2001 a,b), it's not known which kind of habitual and novel physical activity might reduce the risk of falls. It is not known if habitual and novel exercise is safe in the most elderly home-dwelling populations. It seems that a walking program alone is not effective in preventing falls (Ebrahim *et al.* 1997, Sherrington *et al.* 2008). Safety is of paramount importance when very old people are undertaking exercise programs.

Meta-analyses have shown the effectiveness of exercise in fall prevention in selected elderly populations (Chang *et al.* 2004, Sherrington *et al.* 2008). However, the effect of exercise programs planned and implemented by geriatric teams remains to be shown in very old home-dwelling populations.

The Cochrane review (Gillespie *et al.* 2003) reports an 18% average dropout rate in exercise programs. Exercise compliance among 73–94-year-old volunteers has been shown to be 87% (Brill *et al.* 1999). Exercise compliance in a random elderly population is not known, however. Sjösten *et al.* (2007) have concluded that subjects with the poorest physical and mental abilities are poorly adherent in multifactorial fall intervention.

3 Aims

This prospective cohort study on a home-dwelling population aged 85 and older aims to describe the incidence and risk factors of falls and the risk of fall-related injuries associated with everyday physical activities, and finally, to investigate the effect of pragmatic exercise-oriented intervention on fall risk.

The specific aims are:

1. to describe the incidence of falls and injury-causing falls and their circumstances among the home-dwelling elderly aged 85 years or older.
2. to examine risk factors of falling in this population.
3. to investigate the relationship between different types of physical exercise and subsequent injurious falling.
4. to evaluate the effectiveness of a randomized trial planned and implemented by geriatric teams to prevent falls among a home-dwelling population aged 85 years or older.

4 Methods

4.1 Settings and subjects

The target population consisted of all 827 home-dwelling people aged 85 years or older living in the city of Oulu on August 30, 2000 according the official population register in Finland and the geriatric registers of the city of Oulu. Studies I and II comprised 555 persons, who participated in the baseline examinations and follow-up for falls. Five hundred and twelve persons participated in the recordings of physical exercise and falls from the first phone call round onwards (study III). Based on the baseline examinations, 486 subjects were at high fall risk. Eleven months later, at the intervention baseline, 217 intervention subjects and 220 control subjects to be followed up during the intervention period were still living at home (study IV). Studies I–III were prospective observational cohort studies (Figure 1) and study IV was a population-based, randomized, controlled trial (Figure 2). An overview of the outcomes and interventions in the studies is presented in Table 6.

Table 6. Overview of the outcomes/interventions in studies I–IV.

Parametres	I	II	III	IV
Fall rate [a]	x	x		X
Fall injury rate	x		x	X
Activities related to falls	x			
Types of falls	x			
Risk factors of falls		x		
Walking exercise and other types of exercise [b]			x	
Exercise intervention [c]				X

[a] incidence, time to the first four falls and all falls, proportions of fallers and recurrent fallers.

[b] home exercise, gardening, group exercise, cross-country skiing, dancing, swimming, bicycling.

[c] home, walking, group and self-care exercises.

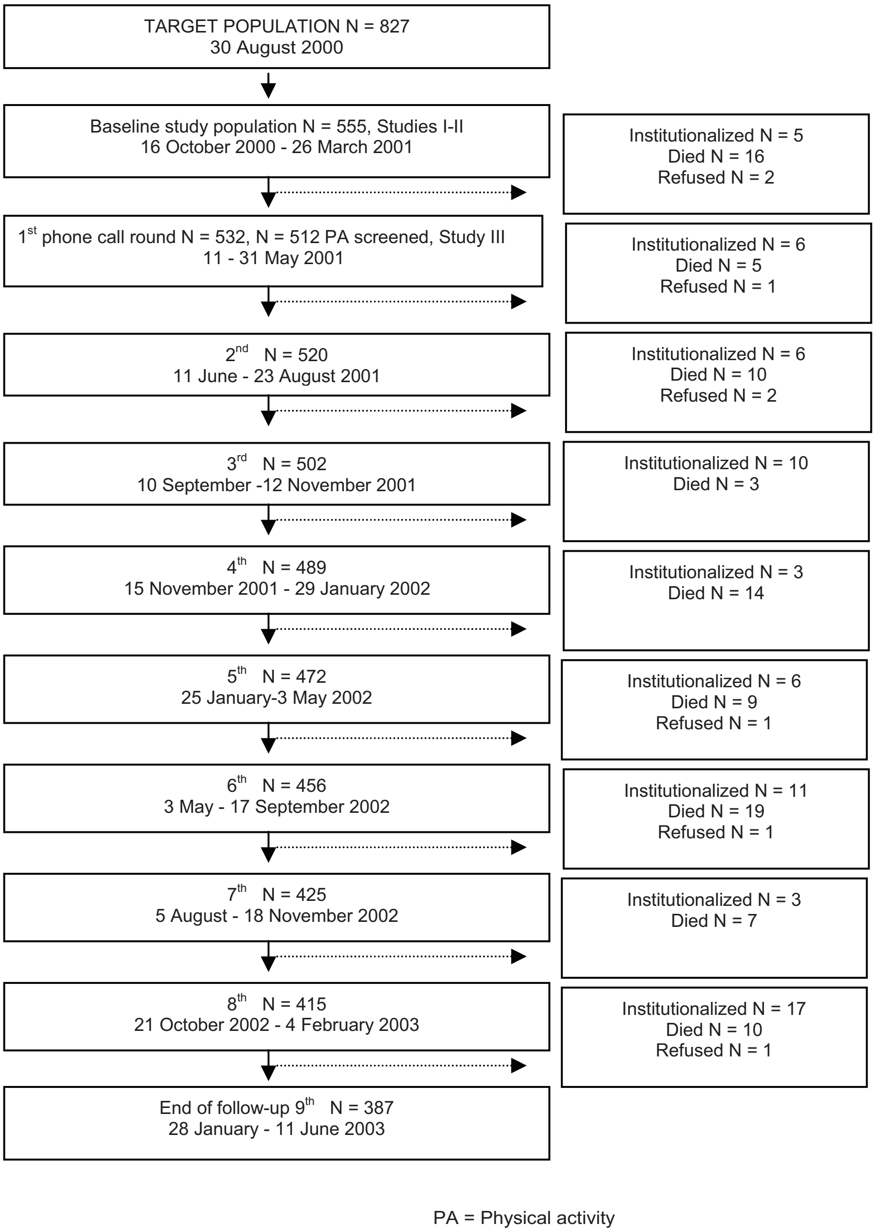

Fig. 1. Flow of subjects through studies I–III.

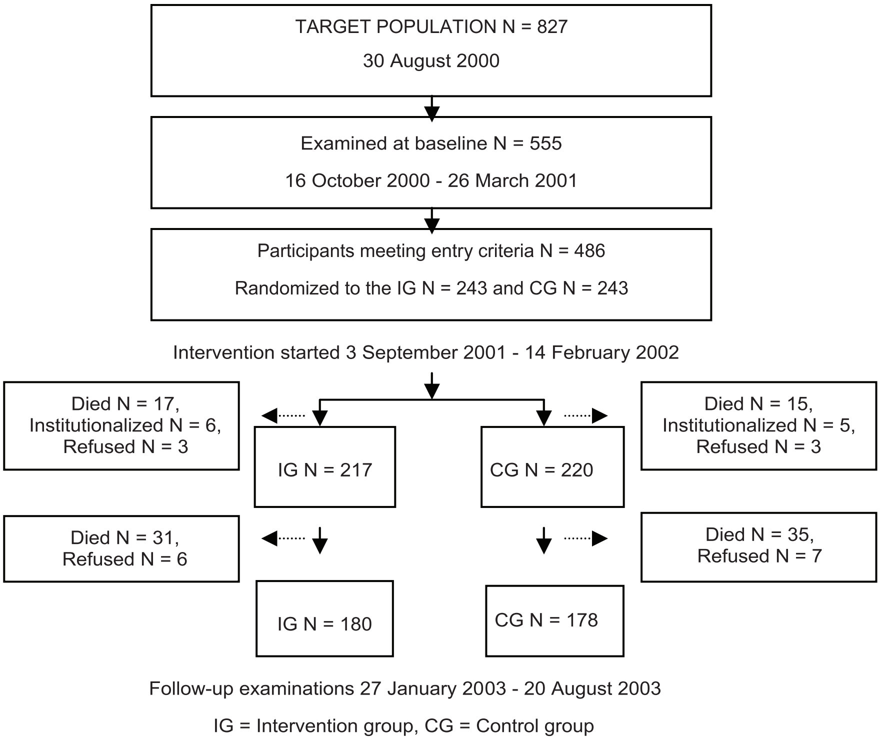

Fig. 2. Flow of subjects through study IV.

4.2 Procedures

4.2.1 Baseline examinations

The study protocol was approved by the institutional ethics committee of the Oulu University Hospital. As the first step, eight hundred twenty-seven home-dwelling subjects aged 85 years or older living in Oulu were sent a letter containing information about the study and the home visit procedure by elderly care in the city of Oulu. Informed consent was obtained from the 555 subjects.

Baseline measurements were conducted through a postal questionnaire (Leinonen *et al.* 1996), with assistance provided by home-nursing staff and close relatives. Demographic variables included age, gender, education, and living arrangements. Clinical variables included problems with vision, assessed with the question "do you have trouble with vision while moving and trouble with near vision (e.g. while reading or knitting)", and hearing difficulties, assessed with a question concerning ability to discriminate between the speech of three individuals. The participants were asked about the number of falls in the previous 12 months and lifetime history of fractures, disease history, use of drugs, self-rated health, change in mental agility during the past year and physical activity. Questions related to physical and psychological symptoms during the previous two weeks were difficulty in urination, feelings of anxiety, nervousness or fear, sleeping problems, and breathlessness. Mobility was characterized by a question concerning ability to move outdoors. The categorizations and cut points of the variables are described in Table 7.

Table 7. Study variables in the postal questionnaire.

Variable	Alternatives of responses	Categories in analysis
Baseline age	years	
Gender	female male	–
Education	1 no school 2 some school 3 primary school 4 secondary school 5 graduate school	1–2 vs. 3–5
Living arrangements	1 alone 2 with a spouse 3 with a spouse and children 4 with children/no spouse 5 with someone else	1 vs. 2–5
Home-nursing care	yes no	–
Self-rated health*	1 very good 2 rather good 3 average 4 rather poor 5 very poor	4–5 vs. 1–3
Physical activity in the previous year (modified by Grimby 1986)	1 mainly resting or only minimal physical activity, most activities performed sitting down 2 light physical activity 3 moderate physical activity about 3 hr a week 4 moderate physical activity at least 4 hr a week or heavy physical activity > 4 hr a week 5 physical exercise several times a week or heavy leisure-time work at least 3 hr a week 6 competitive sports several times a week	1 vs. 2–6
Use of mobility device	yes no	–
Feelings of loneliness*	1 frequently 2 often 3 moderately often 4 seldom 5 never	1–3 vs. 4–5
Recurrent falling during the previous year	times	≥ 2 vs. 0–1

Variable	Alternatives of responses	Categories in analysis
Lifetime history of fractures	yes no	–
Change of mental agility during the past year	1 clearly better 2 somewhat better 3 no change 4 somewhat worse 5 clearly worse	3–5 vs. 1–2
Trouble with vision when moving*	yes no	–
Trouble with near vision	yes no	–
Symptoms disturbing life during the previous two weeks anxiety, nervousness, or fear sleeping problem urination problem breathlessness	1 no 2 yes, but not disturbed 3 disturbed a little 4 disturbed a lot	4 vs. 1–3
Problems moving outdoors	1 fully unable 2 unable without personal assistance 3 with great difficulty 4 with some difficulty 5 without difficulty	1–3 vs. 4–5
Hearing in general talk*	1 no problems 2 some problems 3 many problems 4 no hearing	3–4 vs. 1–2
Use of medication	ATC group NO5 and N06 psychotropic drug, N05A antipsychotic, N05B anxiolytic, N05C hypnotic, N06A antidepressant, C03 diuretic, C01A digitalis, C07 beta blocker, C08 calcium channel blocker, C09 drug affecting rennin-angiotensin system	
Disease history	Tablet or insulin-treated diabetes mellitus (ATC code A10)	

Table 8. Sudy variables in the clinical assessments.

Variable	Method of measurement	Cut point
Nutrional status	Body mass index (BMI) (kg/m2)	BMI < 18.5, 18.5–24, 25–29, > 30 (WHO NHLBI 1998)
Blood pressure	mmHg; two measurements with a 10-minute interval in a sitting position with a mercury manometer	low BP < 120mmHg (Stroup-Benham *et al.* 2000)
Cognition*	MiniMental State Examination test (Fostein *et al.* 1975)	range 0–30 points poor cognitive status < 21 points (Siu 1991)
Depression*	Short version of the Geriatric Depression scale	≥ 7 points (Yeasavage *et al.* 1982)
Sum score of lower extremity function	Ability to rise from a chair*, including five iterations without using one's arms; the time required to do this was recorded. (0–4) Walking speed* was based on the number of seconds needed to cover a 2.4-meter distance, irrespective of whether or not a walking device was being used. (0–4) Standing balance* was assessed with the feet in tandem (e.g., the heel of one foot directly in front of and touching the toes), semi-tandem and side-by-side positions. Those unable to hold a semi-tandem position for 10 seconds were evaluated with the feet in a side-by-side position. Those able to hold the semi-tandem position were further assessed with the feet in a tandem position, and the time up to 10 seconds maintained in this position was recorded. (0–4)	Guralnik *et al.* 1994
Grip strength (kg)	Jamar Hydraulic Hand Dynamometer	

The clinical assessments (Table 8) were made during home visits by district nurses trained to do the examinations (N = 40) between 16 October 2000 – 26 March 2001. Medication was recorded from all available data present at home (drug packages, drug prescriptions). Diabetes requiring medication was recorded from the subject's personal health insurance card. Body mass index was calculated as weight divided by height squared, measured in light clothing

(kg/m^2). Systolic blood pressure (mm Hg) was measured twice, with a 10-minute interval, using a mercury manometer with the subject in a sitting position. Blood pressure was defined as the mean value of the two measurements. Home-nursing staff measured cognition according to the Mini Mental State Examination test (MMSE, 0–30) (Folstein *et al.* 1975). Standing balance was assessed with the feet in tandem, semi-tandem and side-by-side positions. Those unable to hold a semi-tandem position for 10 seconds were evaluated with the feet in a side-by-side position. Those able to hold the semi-tandem position were further assessed with the feet in a tandem position, and the time up to 10 seconds maintained in this position was recorded. Walking speed was based on the number of seconds needed to cover a 2.4-meter distance, irrespective of whether or not a walking device was being used. Ability to rise from a chair included five iterations without using one's arms, and the time required to do this was recorded. Categories of performance were set up for each of the three performance measures, and finally, a sum score of all three performances (0–12) was calculated according to Guralnik *et al.* (1994). Grip strength was measured with a Jamar Hydraulic Hand Dynamometer (Trent Building, South Buckout St., Irvington, NY 10533 USA). Depression was assessed according the short version of the Geriatric Depression Scale (Yesavage *et al.* 1982).

The baseline characteristics of the study populations are shown in Table 9, 10 and 11. In studies I, II and III, the average age of both men (126, 23%) and women (429, 77%) at the baseline was 88 (SD 2.6) years. Among the representative population sample of the target population (N = 827), of the 272 (33%) who did not participate, 67 (25%) were men and 205 (75%) were women, and the median age for men (87, SD 2.7) and women (88, SD 3.2) did not differ from those of the participants. No other drop-out analyses were available.

Table 9. Characteristics of the populations of study I and II by gender.

Variable	Men N = 126	Women N = 429	Total N = 555	p [a]
Age, years, mean (SD)	88 (2.6)	88 (2.6)	88 (2.6)	0.564
Less than primary school education, N (%)	10 (8)	47 (11)	57 (10)	0.324
Poor or very poor self-rated health, N (%)	15 (12)	74 (17)	89 (16)	0.161
Falls in the last 12 months, mean (SD)	1.0 (1.6)	1.5 (2.3)	1.1 (2.2)	0.032
Lifetime history of fracture, N (%)				
hip	7 (6)	33 (8)	40 (8)	0.407
wrist	8 (7)	86 (21)	94 (18)	< 0.001
rib	16 (14)	15 (4)	31 (6)	< 0.001
Sedentary physical activity [b] in the previous year, N (%)	31 (25)	113 (27)	144 (26)	0.717
Number of medications, mean (SD)	5 (3)	7 (4)	5 (4)	< 0.001
Short Geriatric Depression rating scale > 7 pts [c], N (%)	21 (17)	91 (22)	112 (21)	0.262
MMSE score [d], mean (SD)	24 (4)	23 (4)	24 (4)	0.021

[a] P value is from Student´s t test (variables with normal distribution), Mann Whitney U test (variables with skewed distribution) or Chi^2 test. [b] mainly resting or only minimal physical activity, most activities performed sitting down. [c] Yesavage *et al.* 1982. [d] MiniMental State Examination test (Fostein *et al.* 1975) result (0–30).

Table 10. Characteristics of the population of study III according to incident fall-related injury during the 27 month follow-up.

Risk factor	Injury N = 113	No injury N = 399	p[a]
Age, years, mean (SD)	88 (2.5)	88 (2.6)	0.06
Female, N (%)	98 (87)	297 (74)	< 0.01
Great difficulty walking outdoors or unable to walk, N (%)	26 (23)	74 (19)	< 0.01
Systolic blood pressure < 120 mmHg, N (%)	11 (10)	29 (8)	0.04
Mini Mental State Examination test [b] ≤ 20 points [c], or use of Alzheimer's disease drugs N06DA, N (%)	24 (22)	79 (20)	0.01
Trouble with vision when moving, N (%)	26 (23)	76 (19)	0.35
Trouble with near vision, N (%)	59 (54)	157 (40)	0.01
Short Geriatric Depression scale [d] ≥ 7 points, N (%)	24 (22)	79 (20)	0.02
Body mass index, kg/m^2, N (%)			
< 18.5	18 (16)	39 (10)	
18.5–24	61 (54)	178 (45)	< 0.01
25–29	24 (21)	145 (36)	
≥ 30	10 (9)	37 (9)	
Medically treated diabetes mellitus (DM) [e], N (%)	13 (12)	34 (9)	0.04
Use of hypnotic medicine N05C, N (%)	35 (31)	116 (29)	0.26
Use of anxiolytic medicine N05B, N (%)	7 (6)	40 (10)	0.63
Lower extremity performance score [f], mean (SD)	5.2 (3.3)	5.7 (3.3)	< 0.01
Grip strength, kg, mean (SD)	18 (9.1)	22 (13)	< 0.01
Number of medications, mean (SD)	6.7 (4.4)	5.5 (3.6)	< 0.01

[a] p is from Cox regression, for yes/no (dichotomized) and for one unit change (ordinal or continuous) variables. [b] Fostein *et al.* 1975, [c] Siu 1991. [d] Yesavage *et al.* 1982. [e] tablet or insulin-treated DM. [f] sum score (0–12) calculated from balance, walking speed and chair stand scores. (Guralnik *et al.* 1994)

The participants in the randomized and controlled trial had a history of recurrent falls or baseline risk factors of disability (modified by Femia *et al.* 2001) (Table 11). The risk factors of disability are marked with an asterisk * in Tables 7 and 8.

Table 11. Characteristics of intervention and control groups (study IV).

Characteristic	Intervention N = 217	Control N = 220
Age, years, mean (SD)	88 (3)	88 (3)
Male, N (%)	47 (22)	44 (20)
Body mass index, kg/m^2; mean (SD)	25 (4)	25 (4)
Systolic blood pressure, mm Hg, mean (SD)	151 (25)	152 (25)
Grip strength, kg, mean (SD)	19 (12)	20 (12)
Number of medications, mean (SD)	6 (4)	6 (3)
MiniMental State Exam (30–0), points, mean (SD)	23 (4)	24 (4)
Trouble with vision [a]; N (%)	45 (21)	55 (26)
Impaired balance with feet in tandem position [b], N (%)	101 (47)	106 (50)
Impaired chair stand [c], N (%)	74 (35)	81 (38)
Slow walking speed [d], N (%)	56 (27)	40 (20)
Recurrent [e] falling during the previous year, N (%)	57 (27)	58 (27)

[a] Subjective trouble with vision while moving. [b] Unable to stand 10 s with feet in tandem position. [c] Unable to rise from chair (5 iterations) without using one's arms. [d] ≤ 0.34 m/s. [e] ≥ 2 falls.

4.2.2 Follow-up of falls, fall-related injuries and physical activity

Data on fall accidents and the circumstances and consequences of any fall were recorded in telephone interviews conducted by a nurse examiner every other month during a follow-up constituting a total of 1114 person years (PY). The recorder was blinded and unaware of the intervention status. The occurrence of falls was monitored from the day of baseline examinations until the end of the follow-up, death, a move to institutional care, or refusal to participate. In the intervention study, recordings of falls during the time lived in long-term institutionalized care were also included in the analyses. The recordings were done by the nursing staff in the institutions. According to the structured form, a fall was defined as an unexpected event where a person fell to the ground from an upper level or at the same level, including falls on stairs and onto a piece of furniture. If a person was found lying on the floor unable to explain why, it was also accepted as a fall (Luukinen *et al.* 1994). The types of falls were classified according to the International Classification of Diseases, 9th revision, modified as follows: slips, trips, other extrinsic falls on the same level, intrinsic falls without any extrinsic contributions on the same level, falls on stairs, falls from an upper level (lower than 1 m, higher than 1 m) and non-defined falls (Luukinen *et al.* 2000). The time of falling was categorized as 23:00–04:59, 05:00–10:59, 11:00–16:59, and 17:00–22:59. Activities associated with falling were characterized as follows: standing up, standing, walking, undertaking a risky task, sitting down, something else defined and non-defined (Luukinen *et al.* 1995a).

Injuries were classified according to Nevitt *et al.* (1991) and Luukinen *et al.* (1995a), where major injuries included soft tissue injuries needing suturing, dislocations, or even more serious soft tissue injuries, and fractures. The occurrence of major soft tissue injuries and fractures was checked yearly by the nurse examiner from the subjects' medical records in the health center of Oulu and the local hospital.

Physical exercise done by the subject during the preceding two weeks and self-rated health (good, average [reference] and poor) were asked in connection with the first eight phone call rounds made by the nurse examiner working at the university. Subjects who were engaged in physical exercise were those who answered "yes" to the following question, "Did you do walking exercise (ordinary walking during daily activities, including shopping) and other exercise (home exercise, outdoor activity, cross-country skiing, dancing, swimming, bicycling, group exercise) during the last two weeks?" If so, the frequency (times) and approximate duration (minutes) were asked (Leinonen *et al.* 1996).

4.2.3 Exercise intervention

Intervention was implemented during 3 September 2001 – 4 February 2002. The five-month exercise intervention included home, walking, group and self-care exercises. A prescription of exercise was made during home visits by a physiotherapist and an occupational therapist according to the risk factors of the subjects. A pre-exercise assessment provided individualized recommendations. However, home exercise was prioritized over the other types of exercise, and it was the main or only new intervention for 48 (22%). The exercise recommendations are shown in Table 12. The intervention subjects had a visit with their own doctor to assess the feasibility of the exercise. The control subjects had usual care. No data were gathered during these physician visits.

The home exercise interventions included exercises performed in a standing position for those who could manage that: marching in place, rising and standing on toes, ankle extension and flexion, hip abduction, hip extension and transition of weight from one foot to the other. Exercises in a sitting position were suggested for those unable to exercise standing: chair stands, marching in a sitting position, knee extension, hip abduction, ankle flexion and extension and rotation with extended knees. Exercises in a lying position were suggested if the subject was unable to exercise in a standing or sitting position. The suggested exercises were: raising the pelvis, lifting an extended lower extremity, flexion and extension of the foot without lifting it from the ground, abduction and rotation of the hip, flexion and extension of the ankles. These exercises were recommended to be done three times daily with 5–15 repetitions.

Walking outside the home at least two times a week was recommended if it was found safe for the subject. Group exercise was arranged at five areas as a part of routine elderly care in the city of Oulu. A physical or occupational therapist supervised all exercise sessions. Group exercises consisted of physical exercises that challenged balance and strength, done in small groups less than 10 participants, and rehabilitation for war veterans 60 minutes once a week. There was a four-week Christmas break. A set of daily in-home self-care exercises (selected at appropriate and increasing levels of difficulty) was recommended to improve the functional level of the whole body.

Table 12. Frequency of exercise recommendations by type, quality and number of recommendations in the intervention group (N = 217).

Intervention	Novel [a]	Established [b]	Total
Home exercise	121	25	146
Walking	56	86	142
Group excercise	46	49	95
Self-care excercise	21	121	142
One recommendation	61		
Combination of 2 recommendations	45		
Combination of 3 recommendations	27		
Combination of 4 recommendations	3		

[a] New exercise of a kind not practiced by the subject prior to the intervention period.

[b] Exercise practiced by the subject prior to the intervention period.

4.3 Statistical analyses

The incidence rates of falls and injuries were calculated as numbers divided by person time. Comparisons between fallers and non-fallers regarding categorical background variables were made using the chi-square test. Student's t-test (data with normal distributions) and the Mann-Whitney U test (ordinal or skewed data) were used to compare continuous background data. Negative binomial regression was used to analyze fall risk data. Pooled logistic regression analysis was used to analyze the relationship between habitual physical exercise and injury-causing falls. In the intervention study, outcomes were analyzed on an intention-to-treat basis using the Andersen-Gill extension of the Cox regression for repeated events; first four falls (Campbell *et al.* 1997) and all falls (Province *et al.* 1995). The first four falls were chosen to avoid overweighting by subjects who fell more than four times. Relative risks were expressed as the incidence rate ratio (IRR), odds ratio (OR) or hazard ratio (HR), with 95% confidence intervals. Two-tailed p values < 0.05 were regarded as statistically significant.

5 Results

The detailed results are presented in the original publications I–IV.

5.1 Incidence and circumstances of fall accidents (study I&IV)

The incidence rates of falls and fall-related injuries are presented in Table 13. A total of 409 persons (74%) fell at least once during the 27-month follow-up, including 86 (21%) men and 323 (79%) women. Altogether 263 (64%) persons were defined as recurrent fallers; 51 men (19%) and 212 women (81%). A total of 181 (16%) subjects sustained an injury-causing fall. Eighty-two falls (7%) out of 1158 falls caused a major soft tissue injury and 99 (9%) resulted in a fracture.

The probability of getting injured in a fall was higher in the morning ($p = 0.010$) and evening ($p = 0.007$) than in the daytime. More injury-causing falls than falls without injury were non-defined, as regards ongoing activity at the time of the fall ($p < 0.001$) and the type of falling ($p < 0.001$). Ongoing activity and type of falling did not discriminate injury-causing falls from other falls after exclusion of the non-defined falls.

Table 13. Incidence of falls and fall-related injuries in the total population, women, men, and among those with recommendations of exercise-based intervention and controls, all subjects and those able to move outdoors.

				During the intervention period			
				Total		Able to move outdoors	
	Total	Women	Men	IG	CG	IG	CG
	N = 555*	N = 429	N = 126	N = 217	N = 220	N = 168	N = 178
Number of falls	1158	961	197				
Person Year, PY	1114	853	261				
Falls per PY	1.04	1.13	0.76	1.15	1.23	1.02	1.15
Injuries per PY	0.16	0.18	0.10	0.18	0.19	0.16	0.16
Major soft tissue injuries per PY	0.07	0.08	0.05				
Fractures per PY	0.09	0.10	0.05				

* = Total population, pre-intervention and during the intervention. Pre-intervention = last phone interview before the intervention baseline. Early intervention = first phone interview during the intervention (min 14–max 96 days from intervention baseline). Late intervention = last phone interview during the intervention (min 371–max 610 days from intervention baseline). IG = intervention group, CG = control group.

5.2 Risk factors of falls (study II)

In the univariate negative binomial regression analyses, recurrent falls during the past year, 2.15 (1.68–2.76); lower body mass index, 1.44 (1.02–2.02); poor self-rated health, 1.55 (1.15–2.09); decline of mental agility in the past year, 1.53 (1.20–1.96); sedentary physical activity in the past year, 1.51 (1.17–1.95); feeling of anxiety, nervousness or fear in the past two weeks, 1.73 (1.31–2.28); difficulty in urination, 1.79 (1.22–2.64); depression, 1.59 (1.21–2.08); trouble with vision when moving, 1.69 (1.28–2.22); use of an antipsychotic drug, 2.15 (1.36–3.40); use of a hypnotic drug, 1.40 (1.10–1.79); use of an antidepressant drug, 1.82 (1.32–2.50); and use of a higher number of drugs, 1.06 (1.03–1.10) were associated with subsequent falls.

In the multivariate analysis, after stepwise backward elimination of non-significant variables, recurrent falling during the past year, 1.91 (1.49–2.44); trouble with vision when moving, 1.46 (1.13–1.90); feelings of anxiety, nervousness or fear during the past two weeks, 1.56 (1.19–2.03); and use of an antipsychotic drug, 1.66 (1.07–2.58) predicted falls. After adjusting for age and sex, these associations still remained statistically significant and it could be shown that each of the contributing factors had an independent significant association with subsequent falls.

5.3 Exercise and risk of injurious falls (study III)

Using pooled results on quantities of walking exercise, recorded from phone call rounds 1–8, walking exercise was stratified into quartiles of the population; none, < 60 minutes, 60 < 140 minutes, and ≥ 140 minutes during a week. Other exercises were categorized into none, < 60 minutes and ≥ 60 minutes during a week.

The overall IR of injury-causing falls was 0.15 per PY. Within each exercise group, IR tended to decrease as exercise activity increased; walking exercise 0.17, 0.14, 0.14, 0.13, and other exercise 0.17, 0.10 and 0.09, respectively.

The risk of injury-causing falls was not reduced as regards walking exercise taken ≥ 140 minutes; adjusted OR 0.83 (95% CI 0.46–1.48), 60–140 minutes; 0.94 (0.56–1.58), and < 60 minutes; 0.87 (0.50–1.50), as compared with no exercising. The risk of injury-causing falls was reduced as regards other exercise taken ≥ 60 minutes a week as compared with no exercising; 0.37 (0.19–0.72).

Correspondingly, other exercise taken < 60 minutes tended to be associated with a reduced risk of injury-causing falls; 0.56 (0.30–1.04).

5.4 Prevention of falls by exercise (study IV)

In addition to a history of recurrent falls during the previous year, the following risk factors of disability (modified from Femia *et al.* 2001) were used to recruit the study population for randomization: frequent feelings of loneliness, poor self-rated health, trouble with vision when moving, poor hearing, depression, poor cognition, impaired balance, impaired chair stand and slow walking speed.

The time to the first four falls and all falls did not differ significantly in the targeted intervention group (N = 217) compared with the controls (N = 220); HR 0.88 (95% CI 0.74 to 1.04) and 0.93 (0.80–1.09), respectively. Among those able to move outdoors, the corresponding HRs in the intervention group (N = 168) compared with the controls (N = 178) were 0.78 (0.64–0.94) and 0.88 (0.74–1.05).

After the intervention period, impaired balance was less common in the intervention group than in the control subjects; 64 (45%) and 89 (59%) ($p < 0.05$). Impaired chair stand tended to be less frequent in the intervention subjects ($p = 0.06$), but the other follow-up characteristics did not differ between the intervention and control groups ($p > 0.1$).

Positive changes were found between the early intervention and pre-intervention periods in the intervention group compared with the controls as regards the duration of walking exercise ($p = 0.032$), home exercise ($p = 0.003$) and group exercise ($p = 0.015$). A corresponding positive change during the late intervention period compared with the pre-intervention period was apparent only as regards the frequency of walking exercise ($p = 0.023$).

Compliance with exercise intervention was low, and there was no increase in the frequency of home exercisers or those engaged in walking and other exercise. Although there was an increase in the duration of all these types of exercise, the difference compared with the control group was short-lasting and vanished towards the end of the intervention period. The intervention had no statistically significant effects on the risk of fall-related injuries.

6 Discussion

6.1 Methodology

A novel aspect in the study was the very old target population and evaluation of the work of regional geriatric care teams, producing a practical approach to fall prevention among those with the highest risk of falls and fall-related injuries. The study was also the first to examine fall prevention with a population-based randomized design among very old home-dwelling people.

The results were summarized as the number of falls, fallers, frequent fallers, fall rate per person year, as suggested according to a consensus of Profane (Lamb *et al.* 2005).

The target population represents very old home-dwelling citizens of Oulu, but only some two-thirds of the age cohort participated. Those who did not participate did not differ from the participants as regards age and gender. No other data from the non-participants are available, and we do not know whether those who withdrew were at a higher risk of falling. Cognitive impairment (Luukinen *et al.* 2008) and dementia (Aevarsson & Skoog 1997) may have been overrepresented among the non-participants. This may limit the external validity of the results.

The definition of falls was similar to the well-established definition that includes falls resulting from loss of consciousness or an overwhelming hazard (Luukinen *et al.* 1994, Lamb *et al.* 2005). Hauer *et al.* (2006) recently reviewed over 90 fall publications. Of these, 44 provided no definition of the term fall, and others included various definitions of falls. Variations in definitions may affect the results and complicate evaluation of the results between different studies. Surprisingly, even in the FICSIT studies (Frailty and Injuries: Cooperative Studies of Intervention Techniques), two kinds of fall definitions were used (Wolf *et al.* 1996).

An acknowledged method of recording falls is monthly phone calls in association with the use of fall diaries (Lamb *et al.* 2005). In the present study, falls were recorded without diary reporting, which causes a retrospective feature in the recordings. Accordingly, deaths, moves to long-term institutional care, refusals, and hospital admissions obviously led to some underreporting of falls. The lack of use of diaries may decrease the internal validity of the fall recordings. This does not distort results of the intervention study, however, because withdrewers were similar in numbers in the intervention and control groups.

A nurse recorder working at the university was not part of the duty personnel and was blinded to the intervention status of the participants. Therefore, information bias did not affect the fall results. The occurrence of injury-causing falls was ascertained from the hospital and health center records reviewed by the nurse recorder, and accordingly the validity of the recordings of falls resulting in major injuries was obviously high. The definition of injurious falls described by Nevitt *et al.* (1991) and Luukinen *et al.* (1995a) was used. There are substantial differences in the definition of major injuries between different studies: a major injury has been reported as a fracture or dislocation (Close *et al.* 1999), a fractured neck of femur, or other fracture, (Davison *et al.* 2005), fall-related fractures of the hand, hip, coccyx, and shoulder (Gill *et al.* 2002), or a fracture, a head injury requiring hospitalization, a joint dislocation and a severe sprain or lacerations requiring suturing (Tinetti *et al.* 1994). Lord *et al.* (2005) used self-reporting of falls resulting in injury, and Shaw *et al.* (2003) used a major non-defined injury as a definition of injury.

Ongoing activity related to falls and types of falls were recorded using a method described by Luukinen *et al.* (1994, 1995a, 2000). It was found that non-defined falls were overrepresented among injury-causing falls compared with falls without injury. Therefore, recording of the circumstances of injury-causing falls needs development.

In connection with fall recording, physical exercises of different kinds were measured using a method described in the Evergreen study (Heikkinen 1998). The recall period was two weeks, which is somewhat longer than the seven-day recall period recently proposed by Jorstad-Stein *et al.* (2005) and Lamb *et al.* (2005) for use in large-scale fall injury interventions.

6.2 Findings of the study

Only one study has previously investigated falls in a population-based sample of very old home-dwelling people. Based on a retrospective fall inquiry among 85-year-olds in Leiden, the Netherlands, 42% reported having fallen during the previous year (Bootsma-van der Wiel *et al.* 2003). The present results on the frequency of falls are in accordance with subgroup analyses of the oldest subjects in earlier community studies (Campbell *et al.* 1990, O'Loughlin *et al.* 1993, Luukinen *et al.* 1994, Davis *et al.* 1997, Bergland *et al.* 2003). The study by O'Loughlin *et al.* (1993) reported identical rates for men and women aged 80 or older (659/1000 PY), notably lower than in studies by Campbell *et al.* (1990) and

Luukinen *et al.* (1994). Campbell *et al.* (1990) showed that the incidence of falls was 940 and 1520 per 1000 person years among subjects aged 80–84 and over 90 years, respectively. Luukinen *et al.* (1994) found fall incidence rates of 514 and 955 among 85–89-year-old men and women, respectively. Among those ninety years and older, the corresponding figures were 1500 and 1000. Based on the Cambridge City over-75s Cohort study (Fleming *et al.* 2008), the fall rate is even higher, 2500 among people aged 90 years or older.

The share of recurrent fallers ranges from 11–13% among men to 14–18% among women in studies that have reported these proportions among 80-year-old people (O'Loughlin *et al.* 1993, Luukinen *et al.* 1994). The figures in the present study were higher, as at the baseline one-fourth of the subjects reported having fallen at least twice during the past year. The present prospective fall data do not allow comparisons to be made due to a twice-as-long follow-up period.

Luukinen *et al.* (1995a) studied people aged 70 years and older, in different age groups, with a two-year follow-up using a similar definition of injurious falls as in the present study. Among home-dwelling men and women aged 80 years or older, the incidence rates of major soft tissue injuries were quite similar to those in the present study. Only female fracture rates seemed higher in the present study compared with the women aged 80 years or older in the study by Luukinen *et al.* (1995a). Major soft injuries among those aged 80 years or older living in long-term institutional care were higher (Luukinen *et al.* 1995a) compared with the present findings among very old home-dwellers. This is due to a high frequency of major head injuries in institutions. Although the present fracture rates do not differ greatly from those found in long-term care, the probability of sustaining fractures in falls is greater at home, probably because of more challenging situational and behavioral circumstances (Tinetti *et al.* 1995b).

Most falls and fall injuries occur while the elderly are involved in the basic activities of daily living. The distributions of ongoing activities related to falls in the present series are consistent with the findings of previous studies among the younger elderly (Luukinen *et al.* 1994, Bergland *et al.* 2003). However, the contribution of fall situations and behavior to injury risk seems to decrease with increasing age. Fall situations and behavior contribute to the risk of serious injury among the younger elderly (Tinetti *et al.* 1995b), and the types of falls with high kinetic energy also increase the risk of fractures (Luukinen *et al.* 2000). This differs from the present observations among very old home-dwellers in that ongoing activity and the type of falling do not discriminate between falls with and without injury. Also the fact that habitual walking exercise appeared to be safe suggests that injuries among very old individuals are not as clearly activity-related as those among the younger elderly. Despite these observations, the share of fractures compared with major soft tissue injuries was higher than that presented among younger home-dwelling populations (Luukinen *et al.* 1995a). This suggests that bone strength crucially contributes to the type of injury in falls among the most elderly.

Environmental factors may also have increased the risk of injury in falls, because injury-causing falls were overrepresented in the morning and evening. The fact that near visual acuity was a risk factor of injury-causing falls may reflect an interaction between poor lighting and compromised visual acuity, but this needs further evaluation.

Visual acuity has a central role in fall accidents among the elderly. Unlike the role of near visual acuity in injury-causing falls, movement vision seems to be crucial to falling in general. It may be that near vision is needed to see nearby obstacles that may be partly responsible for sustaining injuries. Movement vision may specifically affect balance performance (Lord & Dayhew 2001) and fall risk. The role of vision in balance performance increases while the role of vestibular and somatosensory input decreases with advancing age (Era & Heikkinen 1985). The possibilities of reducing fall risk by improving vision are good. There is evidence that cataract surgery can prevent falls (Foss *et al.* 2006, Harwood *et al.* 2005). On the other hand, improvement of vision by updating glasses has shown contradictory results (Cumming *et al.* 2007), because such an intervention has increased the risk of falling by approximately 50%.

A history of falls seems to be an important predictor of future falls (Luukinen *et al.* 1995b, Ganz *et al.* 2007). This prediction offers a simple and useful method for selecting subjects for secondary fall accident prevention measures. In the present fall analyses, past falls may have reduced the effect of other risk factors due to multivariate confounding. On the other hand, falls predict events that characterize disability (Tinetti *et al.* 1997), and thus may have reduced the effect of other risk factors presented here.

Interestingly, anxiety drugs were not associated with falling and hypnotics and antidepressants did not withstand multivariate adjustments. Somewhat surprisingly, a feeling of anxiety, nervousness or fear was an independent risk factor of falls. Others have shown similar results for the relationship between insomnia and use of hypnotic drugs (Avidan *et al.* 2005). The validity of the result regarding the risk of falls being related to the use of psychotropic drugs, presented in a meta-analysis (Leipzig *et al.* 1999b), may be distorted by possible confounding by disorders being treated with psychotropic drugs. On the other hand, fear of falling is a distinguished risk factor of falls (Luukinen *et al.* 1996, Scheffer *et al.* 2008), fall-related fractures (Luukinen *et al.* 1997), and low recreational physical activity and cessation of recreational physical activity (Bruce *et al.* 2002, Shimada *et al.* 2007). Accordingly, fear of falling may explain some of the effect underlying the feelings of anxiety, nervousness or fear in the present study. Campbell *et al.* (1999b) have shown earlier that cessation of psychotropic medication can prevent falls, but difficulties in the cessation of drugs remain a major practical issue. Use of antipsychotic drugs was an independent risk factor of falls. Extrapyramidal effects along with the anticholinergic effects and blockade of α-adrenergic receptors may affect fall risk (Hartikainen *et al.* 2007), particularly among the most elderly subjects.

This study showed that exercise other than walking taken as a part of everyday life was associated with a reduced risk of injury-causing falls when compared with non-exercising. Moreover, a dose-response effect has been suggested (Kesäniemi *et al.* 2001). It was also found that walking exercise is safe. One study has suggested that walking may increase fracture risk through increased exposure to fall events (Ebrahim *et al.* 1997). The present results suggest that behavioral factors play a minor causal role in fall injuries among the most elderly. On the contrary, habitual exercise tends to protect from injury-causing falls.

Pragmatic intervention slowed down the deterioration of balance performance. This was so despite the low adherence to the exercise program during the intervention. In agreement with the changes found in balance performance by us and others (Fiatarone *et al.* 1994), the present intervention was effective in preserving mobility in this population (Luukinen *et al.* 2006b). Among those with better functional abilities, the intervention was also effective in reducing the risk of the first four falls. However, intervention was not effective in reducing the risk of falls at the population level, and severe disabilities were not overcome (Luukinen *et al.* 2006b). This is in agreement with findings made by others (Gill *et al.* 2002). Earlier observations indicate that interventions that increase physical activity should be implemented in early phases of the disablement process (Rubenstein *et al.* 2001, Gill *et al.* 2002). However, the effects of exercise interventions are most prominent at the highest ages (Fiatarone *et al.* 1990). This calls for studies on adherence to exercise interventions in random most elderly populations. In selected elderly populations, exercise adherence is as high as 87% (Brill *et al.* 1999). Practical difficulties in managing interventions may crucially explain low adherence among those at a high risk of falling (Sjösten *et al.* 2007). In a nurse–led intervention aiming to prevent risk factors for falls and fractures it was found that, referrals to general practitioners may increase adherence to preventive measures (Elley *et al.* 2008). Health promotion programs with aims to enhance health and independence instead of traditional fall prevention (Yardley *et al.* 2006a,b, Hughes *et al.* 2008) might be useful among the most elderly disabled populations. Whitehead *et al.* (2006) showed that when offered a choice of intervention to prevent a future fall, 72% of the subjects were reluctant to take up an exercise program and 28% were reluctant to choose osteoporosis medication. But, when asked if they were likely to take up intervention to prevent a worsening state of health, 63% said they would take up exercise and 93% would take osteoporosis medication

This study showed that incidence of falls rises and the rate of fractures seems to increase at the expence of major soft tissue injuries with advancing age. Whatever the means of fracture prevention might be, obviously more investments are needed in public tailored strength and balance exercise programs (Robertson *et al.* 2002, Barnett *et al.* 2003). Most likely these kinds of interventions will reach more people cost-effectively (Beard *et al.* 2006) than more expensive and complex multidisciplinary, multi-professional, and multi-factorial interventions (Campbell & Robertson 2007) and falls clinics (Lamb *et al.* 2007). What's more, falls clinics have not been found to be effective in reducing the rate of falls and fall-related injuries (Gates *et al.* 2008).

At the population level, physical activity serves a primary role in preventing the onset of disability for those at low fall risk and a secondary role in slowing the progression of a disease/impairment. At the individual level, physical activity serves a tertiary role by preventing multiple falls and thus raising physical capacity to perform activities of daily living (Tinetti 2003, Campbell & Robertson 2007).

According to the present findings, exercise in connection with everyday life is recommended for older adults. To reach maximum effect, this kind of behavior should be targeted earlier in life. It remains to be studied and shown whether more intensive work by geriatric teams would enhance the effects of novel exercise programs at advanced ages. In general, the lower the baseline level of physical activity, the greater the health benefit gained with increased physical activity (Haskell 1994).

7 Conclusions

1. The frequency of falls, and especially the frequency of fall-related fractures, increases up to the highest ages among the home-dwelling elderly. The circumstances of falls affect injury risk less than among the younger elderly.
2. The risk factors of falls among the elderly individuals do not, in general, differ from those presented in younger elderly populations. Feelings of anxiety, nervousness or fear may be more significant risk factors than drugs used in their treatment.
3. Exercise related to everyday activities is safe among very old individuals. Habitual exercise other than walking is associated with a reduced risk of injury-causing falls.
4. Recommendations of exercise to be performed in connection with everyday living are effective in fall prevention only among those with relatively good functional abilities. There is an improvement in balance performance at the population level. Adherence with the recommended exercise needs to be improved.

8 Implications for the future

1. Factors affecting the practices of geriatric teams in the prevention of falls need further studies.
2. Factors affecting adherence to exercise interventions among elderly persons need further investigation.
3. The value of different types and amounts of exercise in the prevention of falls and fall-related injuries needs evaluation in further studies.

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Original papers

I Lehtola S, Koistinen P & Luukinen H (2006) Falls and injurious falls late in home-dwelling life. Arch Gerontol Geriatr 42: 217–224.

II Iinattiniemi S, Jokelainen J & Luukinen H (2008) Falls risk among a very old home-dwelling population. Scand J Prim Health Care. In Press.

III Iinattiniemi S, Jokelainen J & Luukinen H (2008) Exercise and risk of injurious fall late in home-dwelling life. Int J Circumpolar Health 67: 235–244.

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