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To my dearest Tapio, Teemu, Niko and Anna-Mari

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ABSTRACT

Falls present common serious clinical problems among older adults. To detect older adults with a high risk to fall, there is a need to develop clinically usable tools. For clinicians, balance is an important aspect of fall risk, but no proper, short, validated tool is available that measures balance reliably among community-dwelling older adults with quite good physical function. Therefore, a standardized tool that measures balance is needed. Orthostatic hypotension (OH) is a common, yet under diagnosed disorder. The association between falls and OH is unclear, particularly because of poor measurement methods of previous longitudinal studies.

The purpose of this thesis was to validate an easy-to-use tool to measure balance. The thesis aimed to create a shorter version of the original Berg Balance Scale (BBS) and to assess the adequacy and predicting value of the nine-item Berg Balance Scale (BBS-9) to predict fall risk among older adults. In addition, it aimed to assess the prevalence of OH and the association of OH with the risk of falls.

The subjects were participants in fall prevention conducted in Pori. Home-dwelling older adults ≥65 years, who had fallen during the previous year, were included in the study. Falls were recorded by fall diaries during 12-month. Falls requiring treatment were gathered from health center and hospital registers during 12 and 36 months. OH was defined according to the consensus by the Consensus Committee of the American Autonomic Society and the American Academy of Neurology and European Federation of Neurological Societies. The blood pressure (BP) was measured in supine position and at 30 seconds and 3 minutes after standing.

BBS-9 correlated significantly with the original BBS and had moderate correlations with static and dynamic aspects of balance. The cut-off score 32/33 of BBS-9 together with data of vision and the number of regularly used drugs predicted quite poorly the risk of falling among older adults. The prevalence of OH was 23.4% (30 seconds) and 7.3% (3 minutes). OH at 30 seconds or 3 minutes after standing is associated with a greater risk for falling within 12 months in older adults. 30 seconds BP measurement is more reliable to detect the risk than the 3 minutes measurement. Results showed BBS-9 alone is not specific and sensitive enough to be used as a screening tool. BBS-9 together with the data of vision and the number of regularly used drugs predicted falls rather poorly. The results support the usability of 30 seconds measurement in determining OH and the risk for falling among older adults.

KEYWORDS: fall, balance, OH, older adults, risk factors, BBS-9

TURUN YLIOPISTO
Lääketieteellinen tiedekunta
Yleislääketiede
ULLA HOHTARI-KIVIMÄKI: Tasapainohäiriö ja ortostaattinen hypotonia kaatumisten riskitekijöinä iäkkäillä
Väitöskirja, 116 s.
Turun kliininen tohtoriohjelma
Tammikuu 2022

TIIVISTELMÄ

Kaatumiset ja niistä aiheutuvat vammat ovat yleisiä iäkkäillä. Kaatumisten ehkäisemiseksi kaatumisvaarassa olevien iäkkäiden tunnistaminen on tärkeää. Tasapainohäiriö on keskeisiä kaatumisen vaaratekijöitä. Kaatumisriskin arviointiin ja tasapainon tutkimiseen tarvitaan kliiniseen työhön soveltuvaa tasapainotestiä. Validoitua tasapainotestiä melko hyväkuntoisille kotona asuville iäkkäille ei ole olemassa. Ortostaattinen hypotonia (OH) on yleinen ja alidiagnosoitu ongelma iäkkäillä. Aikaisemmat pitkittäistutkimukset ovat olleet menetelmällisesti heikkoja ja vakioinnit puutteellisia. OH:n ja kaatumisten välinen yhteys on jäänyt epäselväksi.

Tämän tutkimuksen tavoitteena oli kehittää helppokäyttöinen, validoitu ja lyhennetty versio Berg Balance Scalesta (BBS) sekä selvittää lyhennetyn tasapainotestin (BBS-9) soveltuvuutta ja ennustearvoa kaatumisriskin arvioinnissa iäkkäillä. Lisäksi tavoitteena oli arvioida OH:n yleisyyttä ja yhteyttä kaatumisriskiin.

Tutkimuksen aineiston muodostivat Porissa kaatumisten ehkäisyohjelmaan osallistuneet ≥65-vuotiaat, jotka olivat kaatuneet vähintään kerran edeltäneen 12 kuukauden aikana. Kaatumispäiväkirjoista saatiin tiedot kaatumisista 12 kuukauden ajalta. Tiedot hoitoa vaatineista kaatumisista kerättiin terveyskeskuksen ja sairaalan rekistereistä 12 ja 36 kuukauden ajalta. OH määritettiin The American Autonomic Societyn and the American Academy of Neurology and European Federation of Neurological Societyn konsensuksen mukaan. OH mittaukset tehtiin makuulla ja 30 sekuntia sekä 3 minuuttia seisomaan nousun jälkeen.

BBS-9 korreloi vahvasti alkuperäisen BBS:n ja kohtalaisesti staattisen ja dynaamisen tasapainon kanssa. BBS-9 (katkaisupisteellä 32/33) yhdistettynä tietoon näkökyvystä ja säännöllisesti käytettyjen lääkkeiden lukumäärästä ennusti huonosti kaatumisriskiä. OH:n prevalenssi oli 23,4 % (30 sekuntia) ja 7,3 % (3 minuuttia). OH 30 sekunnin tai 3 minuutin kohdalla seisomaan nousun jälkeen oli yhteydessä suurentuneeseen kaatumisriskiin 12 kuukauden seurannassa. Kaatumisriskin arvioinnissa verenpaineen (BP) mittaus 30 sekunnin kohdalla ennusti kaatumisriskiä paremmin kuin 3 minuutin mittaus.

Tutkimustulosten perusteella BBS-9 ei ole riittävä kaatumisriskin seulontaa. BBS-9 yhdessä näön ja säännöllisesti käytettävien lääkkeiden lukumäärän kanssa ennustaa melko huonosti kaatumisrikiä. BP mittaus 30 sekuntia seisomaan nousun jälkeen on suositeltavaa arvioitaessa iäkkäiden OH:ta ja kaatumisriskiä.

AVAINSANAT: kaatuminen, tasapaino, OH, ikääntyneet, kaatumisen riskitekijät, BBS-9

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Abbreviations

AAN	The American Academy of Neurology
AAS	The American Autonomic Society
ABC	Activities-Spesific Balance Confidence Scale
ATC	Anatomical Therapeutic Chemical
AUC	The Area Under Curve
BADL	Basic Activities of Daily Living
BBS	Berg Balance Scale
BBS-9	9-item Berg Balance Scale (short Berg Balance Scale)
BESTest	Balance Evaluation Systems Test
BP	Blood pressure
CG	Control group
CI	Confidence Interval
COP	Center of Pressure
DGI	Dynamic Gait Index
FIST	Function In Sitting Test
FRID	Fall-risk increasing drugs
FSST	Four Square Step Test
GDS	Geriatric Depression Scale
IADL	Instrumental activities of daily living
ICD-10	International Classification of Diseases
IG	Intervention group
IQR	Interquartile Range
IRR	Incidence Rate Ratio
MMSE	Mini Mental State Examination
non-OHG	Non-Orthostatic Hypotension Group
non-RG	Non-Risk group
mini-BEST	mini-Balance Evaluation Systems Test
OH	Orthostatic Hypotension
OHG	Orthostatic Hypotension Group
POMA	Performance-Oriented Mobility Assessment
PPA	Physiological Profile Approach

ProFaNE	The Prevention of Falls Network Europe
RA	Research Assistant
RG	Risk group
ROC	Receiver Operating Characteristic
SPPB	Short Physical Performance Battery
TUG	Timed Up and Go
WHO	World Health Organization

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Hohtari-Kivimäki, U., Salminen, M., Vahlberg, T. & Kivelä, S-L.: Short Berg Balance Scale-correlation to static and dynamic balance and applicability among the aged. Aging Clin Exp Res 2012; 2442–2446.

II Hohtari-Kivimäki, U., Salminen, M., Vahlberg, T., & Kivelä, S-L.: Short Berg Balance Scale, BBS-9, as a predictor of fall risk among the aged: a prospective 12-month follow-up study. Aging Clin Exp Res 2013; 25: 645–650.

III Hohtari-Kivimäki, U., Salminen, M., Vahlberg, T., & Kivelä, S-L.: Predicting Value of Nine-Item Berg Balance Scale Among the Aged: A 3-Year Prospective Follow-up. Study. Exp Aging Res 2016; 42(2): 151–160.

IV Hohtari-Kivimäki, U., Salminen, M., Vahlberg, T., & Kivelä, S-L.: Orthostatic hypotension is a risk factor for falls among the older adults: a 3-year follow-up study. J Am Med Dir Assoc 2021 Nov;22(11):2325–2330. doi: 10.1016/j.jamda.2021.07.010. Epub 2021 Aug 9.

1 Introduction

Falling and unstable balance are common serious problems in old age (Shumway-Cook et al. 1997; Chiu et al. 2003; Kannus et al. 2005). One-third of community-dwelling persons older than 65 years of age fall each year, and half of them fall at least twice a year (de Baat et al. 2017). Falls are the leading cause of injury (Rubenstein 2006; Stevens et al. 2008; Morrison et al. 2013), early institutionalization, and long-term disability in older adults worldwide (Kannus et al. 2005; Bolton 2019). Falls are one of the major causes of mortality in older adults. (Ambrose et al. 2015.) Western Europe is one of the world regions with the highest fall-related injury incidence and mortality rates in older adults (Haagsma et al. 2016; Haagsma et al. 2020).

Falls are an incapacitating problem and represent a significant burden on the health care services (Shumway-Cook et al. 1997; Chiu et al. 2003; Kannus et al. 2005; Voermans et al. 2007; Gardiner et al. 2017; Guirguis-Blake et al. 2018). Surgically treated fall injuries, especially among older women (Burns et al. 2016), are associated with substantial economic costs (Davis et al. 2010; Burns et al. 2016). Hip fracture is an important debilitating condition in older adults. In 98% of the hip fracture patients, the fracture is a result of a fall (Parkkari et al. 1999). It is globally estimated that hip fractures will affect around 18% of women and 6% of men. (Veronese & Maggi 2018.) The global number of hip fractures is expected to increase to 4.5 million by the year 2050. The direct costs associated with this condition are enormous and hip fracture is associated with the development of other negative consequences, such as disability, depression, and cardiovascular diseases. Although the costs of hip fractures are probably quite similar to those of other common diseases, the social costs of hip fractures (due to e.g. poor quality of life, disability and mortality) are greater. (Veronese & Maggi 2018.)

The risk factors of falls have been extensively studied and several factors have been identified (e.g. balance and gait deficits, history of falls, muscle weakness and older age) (Rubenstein & Josephson 2002). Fall risk factors can be categorized as extrinsic (external to the individual) and intrinsic (within-person). Intrinsic factors include several age-related physiologic changes. Age is one of the key risk factors for falls and the risk increases with higher age. (Tinetti et al. 1988; Phelan et al.

2015.) Environmental hazards such as rugs, poor lighting, chairs without handrails, slippery or uneven floors or roads and electrical cords are often classified to extrinsic risk factors (Tinetti et al. 1988; Tinetti et al. 1995; Melton & Riggs 1985; Cameron et al. 2010; Gillespie et al 2009; Gillespie et al. 2012; Karlsson et al. 2013).

Impaired standing balance is commonly present in older adults (Jonsson et al. 2004; Lin & Bhattacharyya 2012; Overstall et al. 1977) and associated with falls (Lin & Bhattacharyya 2012; Rubenstein 2006; Sturnieks et al. 2008; Shaw & Claydon 2014). Previous studies show the high heterogeneity in methods used to assess balance impairment and the results from different studies cannot be critically compared (Deandrea et al. 2010). The fall risk assessment tools currently used for the older adults do not show sufficiently high predictive validity for differentiating high and low fall risks (Park 2018).

Berg Balance Scale (BBS) is an inexpensive and quite commonly used tool. BBS has showed stable and high specificity (Park 2018) and good discriminative ability in predicting multiple falls among community-dwelling older adults. (Muir et al. 2008.) However, among the higher-functioning older adults, a ceiling effect is often evidenced. (Southard et al. 2005) and the length of time needed to perform the BBS is not short. The whole BBS assessment takes 20–30 minutes, depending upon the sensory-motor and cognitive function of the subject (Berg et al. 1989.) There is a need for quicker and validated balance test in clinical practice for community-dwelling older adults.

Orthostatic hypotension (OH) is a common problem (Gupta & Lipsitz 2007) and the prevalence of OH varies from 22% to 30% among older adults. (Liguori et al. 2018; Ricci et al. 2015; Freud et al. 2018.) OH is an over-looked and underdiagnosed disorder in clinical practice (Lahrmann et al. 2006; Mills et al. 2014; Lipsitz 2017) although it causes balance impairment (Mol et al. 2018). The diagnostic evaluation of OH requires careful blood pressure and pulse measurements and test preparation (Gupta & Lipsitz 2007).

The earlier longitudinal studies have failed to show a clear association of OH with falls (McDonald et al. 2017). The meta-analysis by Mol et al. (2019) revealed that the adjustment for potential confounders was limited in the previous studies. The quality of the majority of the previous studies was only moderate or low, and no critical conclusions could be drawn about any causal relationship between OH and falls. (Mol et al 2019.)

The majority of falls result from interactions of multiple risk factors, and the risk of falling increases linearly with the number of risk factors. Two or even more assessment tools used together may be better predictors of falls compared to only one assessment tool. (Park 2018.)

Fall prevention has been targeted at reducing risk factors of falls and by reducing the risks to reduce the incidence of falls and injurious falls (Tinetti 2003; Skelton &

Todd 2005). Assessment tools for fall risks should accurately discriminate fallers from non-fallers in practice. Accordingly, before a fall risk assessment tool is used, its predictive validity should be sufficiently tested. (Scott et al. 2007.)

2 Review of the Literature

2.1 Falls among older adults

2.1.1 Definition of fall

A fall is defined as an event that results in a person unintentionally coming to rest on the ground, floor, or other lower level with or without loss of consciousness or injury (Kellogg International Working Group 1987; Rubenstein et al. 1990; Koski et al. 1996). Falls resulting from extraordinary environmental factors (e.g., traffic accidents and falls while riding a bicycle) are excluded (World Health Organization 1999). Falls that are a result of a heart attack or syncopal event are also excluded from the definition of fall in some epidemiological studies (Ambrose et al. 2013).

Falls have been classified according to their occurrence and consequent injuries. A recurrent fall has been defined as two or more falls occurring within one year or other defined follow-up period (Luukinen 1995; Stalenhoef et al. 2002). An injurious fall has been defined as a fall resulting in fractures, bruises, strains, sprains, cuts or abrasions, pain or any other physical consequences (Campbell et al. 1997).

Prevention of Falls Network Europe (ProFaNE) was a collaborative project to reduce the burden of fall injury in older people through excellence in research and promotion of best practice. The European Commission funds the network, which links clinicians, members of the public, and researchers worldwide. According to ProFaNE consensus a fall should be defined as ‘‘an unexpected event in which the participants come to rest on the ground, floor, or lower level.’’ (Lamb et al. 2005.)

El Khory et al. (2013) review of case definitions has distinguished four categories of injurious falls: those resulting in any reported consequences, including specific symptoms (ranging from bruises and cuts to more serious injuries such as fractures) or medical care; those resulting in medical care; those resulting in serious injuries such as fractures, head trauma, soft tissue injury requiring suturing, or any other injury requiring admission to hospital; and those resulting in fractures.

2.1.2 Incidence of falls

The incidence of falls is high. Approximately 30–40% of community-dwelling people aged 65 and older fall each year, and falls are the most common cause of injuries in people 65 and older. (Tinetti et al. 1997; Gillespie et al. 2003; Rubenstein et al. 2006; Medical Advisory Secretariat 2008; Ambrose et al. 2015.) There is evidence that 75–80% of all falls without injury are not reported at all (Fleming & Brayne 2008). Some retrospective studies suffer from under-reporting of falls and depending on how long after the event of fall is questioned (Cummings et al. 1988). The variations across the methods used to ask falls (self-report, informant interview, or fall diaries) partly explain also some of the disparities among different study results (Ambrose et al. 2013). According to Cuevas-Trisan (2019) study women are more likely to report falling and to report a fall injury than men.

Between 24–45% of fallers suffer from injuries caused by falls. Most injuries are minor, such as wounds, bruises and lacerations. (Tinetti et al. 1988; Stalenhoef et al. 2002.) Falls cause 20–30% of mild to-severe injuries among older adults (Scuffham et al. 2003), and over 50% of those involve treatment requiring hospitalization. (Park 2018.) In 98% of the hip fracture patients, the fracture is a result of a fall (Parkkari et al. 1999).

The percentage of older adults who fall increases every year with age, from 26.7% among persons aged 65 to 74 years, to 29.8% among persons aged 75 to 84 years, to 36.5% among persons aged greater than or equal to 85 years (Cuevas-Trisan 2019.) One-fifth of fall incidents require medical attention (Gillespie et al. 2003). Falls are the second leading cause of accidental or unintentional injury deaths worldwide (World Health Organisation 2018).

The incidence of falls and injurious falls of older adults is estimated to increase in future. The WHO has warned that the number of injuries caused by falls will double by 2030 if a fall prevention strategy does not have a short-term effect (Kannus et al. 2007). Costs for the treatment of injuries caused by falls are constantly increasing too. The most serious consequences of falls include hip fractures and intracranial injury. (Berková & Berka 2018.)

As the size of older population increases, falls become a major concern for public health and there is a pressing need to understand the causes of falls thoroughly (Saftari & Kwon 2018).

2.1.3 Risk factors of falls

Falling in older adults is usually caused by various factors (Cuevas-Trisan 2019). Several risk factors for falls have been identified and they are generally classified into intrinsic (within-person) and extrinsic (external to the individual, environmental factors) (Tinetti et al. 1988; Gillespie et al. 2009; Cameron et al. 2010; Deandrea et al. 2010; Karlsson et al. 2013; Ambrose et al. 2013).

Intrinsic factors for falls consist age-related changes, gender, gait and balance, strength, visual deficits, arthritis, medications, fear of falling, cognition, low body mass, history of previous falls, symptoms and diseases, depression, cognitive impairment and age 80 or more (Tinetti et al. 1988; Gillespie et al. 2009; Cameron et al. 2010; Deandrea et al. 2010; Karlsson et al. 2013; Ambrose et al. 2013). There exist studies testing the associations between orthostatic hypotension and falls and the hypothesis if OH is an intrinsic risk factor of falls (Lahrmann et al. 2006; Lipsitz 2017; Mol et al. 2018; Saedon et al 2020; Mol et al. 2019). Extrinsic risk factors for falls are related to environment. These extrinsic risk factors are for example poor lighting, objects around the home, loose rugs and slippery floors. (Melton & Riggs 1985; Tinetti et al. 1988; Tinetti et al. 1995; Rubenstein & Josephson 2002; Gillespie et al 2009; Cameron et al. 2010; Gillespie et al. 2012; Karlsson et al. 2013; Ambrose et al. 2013; Phelan et al. 2015.)

Unstable walking aids, use of assistive device, chairs without handrails and unsuitable footwear may be classified as means-related risk factors. It seems paradox to refer walking aids to risk factors for falls, as they are supposed to increase users´ base of support and improve balance performance. Nevertheless, missing instructions, inappropriate, unstable usage or the design of the walking aid are the risk factors for falling. (Rubenstein & Josephson 2002; Deandrea et al. 2010; Bradley & Hernandez 2011; Mundt et al. 2019.)

In Arfken et al. (1994) study, the multivariate analyses showed fear of falling remained an independent risk factor of falls resulting in a fracture. Of persons who were very fearful 9% had had a fracture in the past year compared with less than 0.5% of persons without fear. In Cesari et al. (2002) population-based studies 58% of previous fallers had had fear of falling.

The extrinsic and means-related risk factors are more problematic in older adults with visual impairment. Footwear effects postural stability and influences the incidence of accidental falls. (Menz et al. 2006). Older adults who wear slippers has a higher falls risk than those who walked with fastened shoes (Menant et al. 2008). Shoes with heels that are greater than 2.5 cm high are associated with a higher risk of fall compared to canvas shoes (Menant et al. 2008; Tencer et al. 2004).

Many falls result from interactions among multiple risk factors, and the risk of falling increases linearly with the number of risk factors (Tinetti et al. 1988). The presence of either intrinsic or extrinsic factors increase the risk of falling, therefore, the use of multifactorial falls risk assessment is justified (Tinetti et al. 2006).

Most falls have a multifactorial etiology and are thus rarely caused by one single factor They usually result from interactions between long-term or short-term predisposing factors and short-term precipitating factors in a person´s environment and should thus always be evaluated in a multivariate manner (Tinetti 2003; Skelton & Todd 2004). The interaction and probable synergism between risk factors may thus be as important as identifying a single risk factor (American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedis Surgeons Panel on Falls Prevention 2001).

An additional factor to be considered when assessing a person´s risk of falls is exposure to risk. The U-shape association between exposure and risk of falling has been suggested in some studies, the most active and the most inactive being at greatest risk. (Skelton & Todd 2004.)

2.1.4 Fall prevention

Fall prevention has been targeted at reducing risk factors of falls and by reducing the risks to reduce the incidence of falls and injurious falls. Two strategic approaches have usually been used: a single and a multifactorial approach which may be targeted either whole population or selected risk groups. (Tinetti 2003; Skelton & Todd 2005.) According to Gillespie et al. (2012) group and home-based exercise programs, and home safety interventions reduce rate of falls and risk of falling. Multifactorial assessment and intervention programs reduce rate of falls but not risk of falling.

The prevention of falls among the older adults is one of the most important public health issues in today's aging society (Park 2018). According to Panel on Prevention of Falls in Older Persons from the American and British Geriatric Societies (2011) current recommendations are that all older individuals should be asked if they fell in the past year or have experienced difficulties with walking or balance. In those who respond positively or do poorly on a standardized gait and balance test, a trained clinician should conduct a multi-factorial fall risk assessment. (Panel on Prevention of Falls in Older Persons 2011; Ambrose et al. 2013.)

Prevention of falls and injuries is not easy, however, because they are complex events caused by a combination of intrinsic impairments and disabilities with or without accompanying environmental hazards. Intervention in the planning of effective fall prevention have used two different approaches: a single-intervention strategy (such as exercise, vitamin D, or withdrawl of psychotropic drugs) or more multifactorial preventive programs, including simultaneous assessment and reduction of many of the individual´s predisposing and situational risk factors. (Kannus et al. 2005.)

Most fall prevention programs prefer clinician-centric plan development and implementation. Patient fall assessments needs to shift from being clinician-centric to patient-centric. Developing patient-centered programs may allow for implementation of strategies aimed to mitigate modifiable risk factors leading to falls. (Radecki et al. 2018.)

Insight into differences in fall-related injury rates between countries can serve as important input for identifying and evaluating prevention strategies (Haagsma et al. 2020). Effective public health strategies need to be implemented to promote behavioral changes, improve current interventions, and develop new fall prevention strategies to reduce future morbidity and mortality associated with hip fractures among older adults (Stevens & Olson 2000).

A typical hip fracture is the result of a fall and a subsequent impact on the greater trochanter of the proximal femur. The clinical implication of this finding is that effective prevention of hip fractures could be achieved by the diminution of the number and severity of falls of older adults. The severity of the falls (impacts on the greater trochanter) could be decreased by an external hip protector. (Parkkari et al. 1999.)

There are conflicting results regarding the clinical value of hip protectors. This is mainly due to poor acceptance and adherence among users in wearing these devices (Korall et al. 2014). In Srivastava & Deal (2002) study hip protectors have been found to be effective in nursing home population and prescription of hip protectors for residential care home residents are recommended by Luk et al. (2015). According to Oliver et al. (2010) there is no convincing evidence that hip protectors, reduce falls or injury in the hospital setting. In de Bot et al. (2020) study hip protectors are a cost-effective approach in the prevention of hip fractures in populations with high risk of hip fractures especially in long-term care facilities and a geriatric ward in a hospital. Blalock et al. (2010) study findings suggest that the use of hip protectors by community-dwelling older adults is influenced by beliefs about both barriers to use and the amount of protection provided.

The prevention of falls among older adults is one of the most important public health issues in today's aging society (Park 2018). Fall prevention can be successfully integrated into primary care when it is supported by a clinical champion, coupled with timely staff training, incorporated into the electronic health record, and adapted to fit into the practice workflow (Stevens et al. 2017).

Walking aids (rollators) are widely used by older adults, and walking aid use as a means of fall prevention remains an under-researched area. Their use has been linked to increased falls-risk, yet clinicians have no objective way of assessing user stability. For a walking aid to be effective in preventing a fall, it first and foremost must be used in a stable and safe manner. However, at this time it is unknown whether walking aids are used according to the user guidance and training currently provided, and whether that guidance/training indeed facilitates stable, and therefore safe, use of walking aids. (Costamagna et al. 2019.)

Among older adults receiving care at a fall prevention clinic after a fall, a home-based strength and balance retraining exercise program significantly reduced the rate of subsequent falls compared with usual care provided by a geriatrician. These findings support the use of this home-based exercise program for secondary fall prevention but require replication in other clinical settings. (Liu-Ambrose et al. 2019.)

Of single factor interventions physical exercise has probably been studied the most. It seems that individually tailored exercise programs including muscle strengthening combined with balance training are effective in reducing the number of people sustaining a fall or a fall injury (Campbell et al. 1997; Campbell et al. 1999; Robertson et al. 2001), while the effectiveness of non-targeted physical exercise programs has not been demonstrated. (Gillespie et al. 2003.)

Besides a single and a multifactorial approach there are basically two other strategic approaches in fall prevention, a non-selective and a selective approach. A non-selective approach means that the effects of the intervention are investigated in the whole population (population-based, community-based programs) and the program is implemented in whole communities (Skelton & Todd 2005), including or not including institutional residences (McClure et al. 2005). In a selective approach prevention is targeted at persons with the highest risk of falling (e. g. women, previous fallers, frail older adults).

Due to the multifactorial etiology of most falls, a multifactorial approach targeted at several risk factor simultaneously could be a rational strategy to prevent falls. In fact, multifactorial interventions implemented in selected and unselected population seem beneficial, reducing the relative proportions of fallers by 14% to 27%, respectively (Gillespie et al. 2003). Benefits have been gained, especially when activities have been individually tailored and targeted at identified risk factors, while multifactorial assessments, not followed by targeted interventions have been ineffective in preventing falls (Tinetti 2003).

According to American and European guidelines for fall prevention, a multifactorial intervention program ideally consists of gait training and advice on the use of assistive devices, review and modification of medication, exercise programs with balance training, treatment of postural hypotension, modification of the environment and treatment of cardiovascular disorders (American Geriatrics Society, British Geriatrics Society, and America Academy of Orthopaedic Surgeons Panel on Falls Prevention 2001; Skelton et al. 2004).

2.2 Balance

2.2.1 Definition of balance

There is no universally accepted definition of human balance (Berg 1989; Ekdahl et al. 1989; Pollock et al. 2000). The word balance is often used in association with terms such as stability and postural control (Pollock et al. 2000).

The American Posture Institute defines balance as the ability to maintain equilibrium by positioning the center of gravity over the base of support of body. Maintaining postural balance requires censorial detection of the body's movements, integration of sensory-motor information into the central nervous system, and an appropriate motor response. Patients with proper postural balance can resist gravity with upright extended posture and are able to avoid postural collapse with dynamic movements.

Balance is a term frequently used by health professionals working in a wide variety of clinical specialties. Pollock et al. (2000) study identifies mechanical definitions of balance and introduces clinical definitions of balance and postural control. Postural control is defined as the act of maintaining, achieving or restoring a state of balance during any posture or activity. Postural control strategies may be either predictive or reactive and may involve either a fixed-support or a change-in-support response.

Good balance is a rapid synergistic interaction between various physiologic and cognitive elements that allow rapid and precise response to a perturbation (Richardson 2017). It is a remarkably complex relationship between systems that allow for rapid and precise changes to prevent a fall (concept of reaction time) (Cuevas-Trisan 2019).

Posture is characterized as ideal body mass distribution of the patient upright in relation to the force of gravity. Postural control is defined as the act of maintaining, achieving or restoring a state of balance during any posture or activity. Postural control strategies may be either predictive or reactive and may involve either a fixed-support or a change-in-support response. (Pollock et al. 2000.)

2.2.2 Overview of balance measurements

Evidence-based health care requires the use of valid and reliable tests during clinical assessment (Sibley et al. 2011).

Standing balance is regulated through the interaction of the sensory, motor and nervous systems (Sturnieks et al. 2008; Pasma et al. 2014). Traditionally, many tests of balance consist of measures of the length of time subjects can maintain a particular equilibrium position (Graybiel & Fregly 1966; Fregly & Graybiel 1968; Bruininks 1978; Emery 2003).

Many measures of balance are available; a systematic review identified 68 balance tests used to evaluate the effect of resistance training (Sibley et al. 2011). Most clinical balance measures are functional in nature and evaluate performance of behaviors using observed judgments or measurement of a quantifiable parameter (Browne et al. 2000; Sibley et al. 2011).

Mancini & Horak (2010) review summarizes the most commonly used approaches to assess balance and discuss the advantages and limitation of each tool. The commonly used specialized clinical tests to assess balance are Activities-Specific Balance Confidence Scale (ABC), Berg Balance Scale (BBS), Tinetti Balance and Gait, Timed up and go (TUG), One-leg stance, Functional reach, Balance Evaluation Systems Test (BESTest) and Physiological Profile Approach (PPA).

ABC-Scale (Powell & Meyers 1995) is 16-item questionnaire and has good test-retest reliability, but not related to falls (Mancini & Horak 2010).

BBS (Berg et al. 1992,1996) is 14-item functional balance test with high inter-rater reliability and good specificity. Poor sensitivity and ceiling effect are the disadvantages of BBS according to Mancini & Horak (2010) study. The BBS is developed for older adults, in whom a score higher than 45 is related to a low risk of fall history (Conradsson et al. 2007; Mancini & Horak 2010.) The previous study among community-dwelling older adults who were in good health, O´Brien et al. (1997) found that the BBS was less sensitive in predicting falls than reported by the study of Berg et al. (1992) who studied residents of a nursing home. Shumway-Cook et al. (1997) study found BBS scores to be predictive of falls among community-dwelling older adults who had a history of recurrent falls, which according to Boulgarides et al. (2003) indicates that the group was at greater fall risk.

The original BBS may better recognize older adults who have greater impairments and who are at risk for falls than older adults who are in good health and more active but who also may be at risk for falls (Boulgarides et al. 2003). The Berg Balance Scale (BBS) is often used in clinical practice to predict falls in the older adults. However, there is no consensus regarding its ability to predict falls. (Lima et al. 2018.) The fall risk assessment tools currently used for the older adults do not show sufficiently high predictive validity for differentiating high and low fall risks. The Berg Balance scale show stable and high specificity. (Park 2018.)

Tinetti Balance and Gait Assessment (Tinetti 1986) is the oldest clinical balance assessment tool. This 14-item balance and 10-item gait test has good inter-rater reliability and good sensitivity. Ceiling effect and poor specificity are disadvantages of this test. (Mancini & Horak 2010.) This test is also referred to as the performance-oriented mobility assessment (POMA). It is probably one of the earliest tests developed to assess specially fall risk (Tinetti 1986). According to Ambrose et al. (2013) this test is a good indicator of fall risk and has become a widely used clinical assessment tool in older adults.

TUG-test (Mathias 1986) is widely used because it is simple. A stopwatch is used to measure the duration of functional task performed. TUG has excellent inter-rater and test-retest reliability and correlation with the BBS. TUG also predicts falls, but ceiling effect exists and the test is not comprehensive, only one functional task. (Mancini & Horak 2010.) According to Barry et al. (2014) TUG has limited ability to predict falls in community dwelling older adults and should not be used in isolation to identify individuals at high risk of falls. Desai et al. (2010) study evaluated balance performance using TUG and in their study TUG was able to differentiate between the faller and non-faller groups. According to Boulgarides et al. (2003) TUG did not predict falls in a sample of community-dwelling older adults who were active and independent.

One-leg stance (Fregly 1968) test measures time in seconds on one leg stand unassisted with eyes open and arms on the hips. One-leg stance test has good inter-rater reliability and inter-subject reliability. Test is not continuously related to falls and only one task of static balance is evaluated. (Mancini & Horak 2010.)

Functional reach (Duncan et al. 1992) objectively assesses limits of stability by measuring the maximal distance a person can reach. This test has excellent predictive validity of subjects at risk of fall and good inter-rater reliability and test-retest reliability. Only one task is evaluated in functional reach test. (Mancini & Horak 2010.)

BESTest (Horak et al. 2009) is 36-item test. It determines the underlying causes of balance deficits focusing on systems and focuses treatment based on different types of balance problems. BESTest has good inter-rater reliability and correlation with ABC Scale. BESTest needs equipment and its prediction of fall risk is unclear. (Mancini & Horak 2010.)

The mini-balance evaluation systems test (mini-BEST) is a performance based measure that classifies balance problems into six underlying systems that may be impaired: biomechanical, stability limits, postural responses, anticipatory postural adjustments, sensory orientation, dynamic balance during gait and cognitive effects. The mini-BEST has been shown to be a reliable and valid measure of balance in older adults. (King et al. 2012; Ambrose et al. 2013.) The Mini-BESTest had a high correlation with the Berg Balance Scale. (King et al. 2012.)

PPA-test (Lord 1996) consists of a simple, clinical test of vision, cutaneous sensation of the feet, leg muscle force, step reaction time and postural sway. Test needs equipment and it does not measure functional tasks or balance control systems. (Mancini & Horak 2010.)

The dynamic gait index (DGI) was developed as a clinical tool to assess gait, balance and fall risk (Schumway-Cook et al. 2000). It evaluates not only usual steady-state walking, but also walking during more challenging tasks. The DGI showed high test-retest reliability and evidence of concurrent validity with other balance and mobility scales. It is a useful clinical tool for evaluating dynamic balance in ambulatory people with vestibular deficits and chronic stroke (Jonsdottir & Cattaneo 2007). The DGI, although susceptible to ceiling effects, appears to be an appropriate tool for assessing function in healthy older adults (Herman et al. 2009).

The short physical performance battery (SPPB) consists of three types of physical maneuvers: balance tests, gait speed test, and the chair stand test. The SPPB is highly reliable in older adults and has demonstrated a strong and consistent association with health status measures and many outcomes, even when accounting for socioeconomic and cultural differences (Freire et al. 2012; Ambrose et al. 2013.)

The four square step test (FSST) requires subjects to rapidly change direction while stepping forwards, backwards, and sideways over a low obstacle. Time to complete the test is measured. The test has been validated in older adults with a sensitivity of 85% and specificity of 88–100% in predicting fall risk. As a clinical test, the FSST is reliable, valid, easy to score, quick to administer, requires little space, and needs no special equipment. FSST had higher combined sensitivity and specificity for identifying differences between groups in the selected sample population of older adults. FSST is used to assess dynamic stability and the ability of the subject to step over low objects forward, sideways, and backward. (Dite et al. 2002; Ambrose et al. 2013.)

Balance control consists of controlling the body center of mass over its limits of stability (Mancini & Horak 2010). Although balance control is an integral component of all daily activities, its complex and flexible nature makes it difficult to assess adequately (Huxham et al. 2001).

Clinical tests of balance assess different components of balance ability. Health professionals should select clinical assessments based on a sound knowledge and understanding of the classification of balance and postural control strategies. (Pollock et al. 2000.)

Most functional balance assessment scales assess fall risk and the need for balance rehabilitation but do not differentiate types of balance deficits. A system approach to clinical balance assessment can differentiate different kinds of balance disorders. Present new computerized tools mean objective measures of balance using computerized systems. These systems can bring more sensitive, specific and responsive balance testing to clinical practice. Objective measures of balance control using computerized systems are becoming feasible and useful for clinical practice. (Mancini & Horak 2010.)

In Ozdil et al. (2019) study a force platform chair was used for the computerized and the Function in Sitting Test (FIST) for the clinical sitting balance measurement. Their study implied that both the computerized and clinical sitting balance measurements can be used objectively for the assessment of sitting balance but the computerized methods might be preferable due to requiring shorter time with less intra-tester variability. According to Mancini & Horak (2010) objective measures of balance using computerized systems and wearable inertial sensors can bring more sensitive, specific and responsive balance testing to clinical practice.

As shown above, many measures of balance are available. However, these measures consider different components of balance, tasks, scoring formulas, and measurement techniques and are validated for different populations. Thus, different tests may provide different information and make it difficult to compare across measures. (Sibley et al. 2011.)

Sibley et al. (2011) conducted a cross-sectional survey of balance assessment practices among physiotherapists, who treat adult or geriatric populations with balance impairment. 369 respondents completed the questionnaire and only 43.4% of respondents agreed that existing standardized measures of balance meet their needs. Seventy-nine percent of respondents wanted to improve their assessments, identifying individual, environmental and measure-specific barriers. The most common barriers were lack of time and knowledge.

Park et al. (2018) meta-analysis concluded that the predictive validity of the fall risk assessment tools currently used for older adults was not sufficient. The evidence showed that the use of a large variety of fall risk assessment tools in older adults did not predict fallers with sufficient accuracy.

There is need for more challenging performance-based tests to reveal balance deficits that could cause falls in older adults who are high functioning. The development of new tests for this population is indicated. (Boulgardides et al. 2003.)

A comprehensive clinical assessment of balance is important for both diagnostic and therapeutic reasons in clinical practice. Balance disorders can have serious consequences for physical function (leading to fall-related injuries) as well as for social function (fear of falls leading to activity restriction and social isolation.) (Mancini & Horak 2010.)

2.2.3 Balance as a predictor of falls

According to Ambrose et al. (2013) review of the literature impaired balance is one of the major risk factors for falls. Balance disorders are common in older adults and they are associated with increased morbidity and mortality, as well as reduced level of function. Common causes include orthostatic hypotension; however, most gait and balance disorders involve multiple contributing factors. (Salzman 2010.)

Balance as a fall risk factor is amenable to intervention. Miko et al. (2018) investigate the effect of balance-training programme on static and dynamic postural balance. Berg Balance Scale (BBS) test was used to evaluate balance. The 12-month balance-training programme significantly improved postural balance.

Randomized trials have almost without exception shown, and systematic reviews confirmed, that balance and strength training for older adults living in the community can reduce the risk of both non-injurious and injurious falls by 15–50% even cost-effectively (Kannus et al. 2005).

A randomized trial in Oulu, Finland, showed that impact exercise (balance training and jumping) for 30 months reduced fracture risk in 72–74-year-old women by over 60%. Thus, with respect to fall and injury prevention, regular balance and strength exercises can be recommended for older adults. Regular physical activity provides substantial other health related benefits and is cheap, readily available, and a largely acceptable way to reducing the propensity to fall. (Kannus et al. 2005.)

Standing balance is regulated through the interaction of the sensory, motor and nervous systems (Sturnieks et al. 2008; Pasma et al. 2014). In fall prevention, regular strength and balance training, reducing psychotropic medication, and diet supplementation with vitamin D and calcium have been shown to be effective (Kannus et al. 2005).

2.3 Orthostatic hypotension

2.3.1 Definition of orthostatic hypotension

The consensus by the Consensus Committee of the American Autonomic Society and the American Academy of Neurology and European Federation of Neurological Societies defines orthostatic hypotension (OH) as a reduction of systolic blood pressure of at least 20 mm Hg or diastolic blood pressure of at least 10 mm Hg within 3 minutes of standing. (The Consensus Committee of the American Autonomic Society and the American Academy of Neurology, 1996).

To clarify and expand the earlier definition, an update to the Consensus definition of OH was published in 2011. This updated consensus statement, endorsed by the American Autonomic Society, the European Federation of Autonomic Societies, the Autonomic Research Group of the World Federation of Neurology and the Autonomic Disorders section of the American Academy of Neurology, is a refined and updated definition, in which pathophysiology and clinical features of orthostatic hypotension are included. The definitions of two highly prevalent disorders of orthostatic tolerance, neural mediated (reflex) syncope and postural tachycardia syndrome are also added. This update is the product of a group of experts in the field but it is not an evidence based clinical guideline. In this definition, OH is defined as a 20 mmHg drop in systolic BP and/or a 10-mmHg drop in diastolic BP within 3 min of standing unless either the participants has supine hypertension in which case a fall in systolic BP of at least 30 mmHg is required for a diagnosis of OH or the BP nadir occurred within the first 15 sec of standing in which case a 40 mmHg systolic BP and/or 20 mmHg diastolic BP is required for a diagnosis of OH. (Freeman et al. 2011.)

The original guidelines recommending a 3-minute wait from supine to standing have not been updated in over 20 years. Thus, Juraschek et al. (2017) recommended revising these guidelines to earlier measurements. The cohort study by Juraschek et al. (2017) following over 11,000 middle-aged adults found that OH measurements in the first 30–60 seconds had the highest association with symptoms of dizziness as well as with future risk of falls, fracture, syncope, motor vehicle accidents and mortality.

2.3.2 Measuring orthostatic hypotension

The detection of OH requires blood pressure measurements in the supine and standing positions (Arnold & Raj 2017).

Most previous studies have measured blood pressure in 1 and 3 minutes of standing (Mol et al. 2019). According to these studies orthostatic blood pressure changes determined at the 1st minute might be appropriate for older persons (Soysal et al. 2016; Juraschek et al. 2017). Grubb & Kosinski (2001) reported that, as persons arise, the orthostatic stability usually takes place in less than 1 minute.

Juraschek et al. (2017) cohort study found that OH measurements in the first 30-60 seconds had the highest association with future risk of falls. In contrast with prevailing recommendations, OH measurements performed within 1 minute of standing were the most strongly related to dizziness and individual adverse outcomes, suggesting that OH should be assessed within 1 minute of standing. According to Irvin & White (2004) study regarding optimal baseline measurement, the recommendation is to measure blood pressure immediately after the person arises. Kanjwal et al. (2003) reported that, as persons arise, the orthostatic stability usually takes place in less than 1 minute. It seems important to note any immediate fall in blood pressure because, even though the time interval to recovery is very small, an opportunity for fall does exist. The first 15–30 seconds after standing upright can be a particularly vulnerable period for older people with impaired cerebral autoregulation. Any person who falls, faints, or feels dizzy immediately upon standing should have orthostatic blood pressure measurements obtained as soon as possible after assuming an upright stance. (Lipsitz 2017.)

Some patients present with symptomatic orthostatic hypotension that occurs beyond 3 min of standing. The clinical significance of this kind of delayed orthostatic hypotension is unknown. These delayed falls in blood pressure may be a mild or early form of sympathetic adrenergic failure. This disorder may be revealed in persons with suspected orthostatic hypotension by extending the period of orthostatic stress (head-up tilt or stand) beyond 3 min. (Freeman et al. 2011.) The onset of hypotension may be delayed and a standing time of 5 minutes may be needed to ascertain OH in some persons (Naschitz et al. 2007).

Because the body's responses to active standing differ from those of passive tilting, Grubb & Kosinski (2001) suggest that when the patient is standing, pressure determination should be performed with the arm extended horizontally (to avoid the possible hydrostatic effects of the fluid column of the arm).

There is a great deal to unravel in the complex diagnostic, pathophysiologic and symptomatic world of OH in older persons. (Frith et al. 2014).

In a study of 170 nurses working with hospitalized older adults Vloet et al. (2002) found significant variation in measurement techniques. Nurses were inconsistent in cuff placement, arm positioning, and timing of measurements relative to position change. These inconsistencies affect the validity of the results which in turn may have a profound impact on subsequent treatment. (Vloet et al. 2002; Momeyer & Lorraine 2018.)

According to Momeyer & Lorrainen´s (2018) summary, OH is common in hospitalized older adults and is a significant contributor to falls. Acute care nurses play a vital role in accurate assessment, prevention, and supportive care of OH in their older patients. Establishing a routine protocol for assessing OH in hospitalized older adults and overseeing the accuracy of nurse assistants' measurements will aid in identifying those with this condition. Prompt pharmacologic and nonpharmacologic strategies can be instituted. Last, instructing the patient and family on managing OH will be a key for successful management upon discharge.

A step-wise approach to treatment of OH is necessary, starting with nonpharmacological strategies (Mills et al. 2014). The goal of treatment is to improve the individual's functional capacity and quality of life and to prevent injury, rather than to achieve a target blood pressure (Lanier et al. 2011).

2.3.3 Prevalence of orthostatic hypotension

Orthostatic hypotension is a common, yet under diagnosed disorder (Lahrmann et al. 2006; Lipsitz 2017). The true prevalence of OH is difficult to determine due to the uncertain significance of very brief but significant drops in blood pressure (Frith et al. 2014).

The prevalence of OH depends on the population studied and the definition used in quantifying the degree of OH (Task Force for the Diagnosis and Management of

Syncope et al. 2009). The prevalence of OH is reported to be between 5% and 30%, increasing with age (Hiitola et al. 2009; Low 2008).

OH is often found in older persons and in those who are frail (Ooi et al. 1997). It is present in up to 20 percent of persons older than 65 years. The prevalence of OH was 18 percent in persons older than 65 years, but only 2 percent of these older adults were symptomatic. (Rutan et al. 1992; Lanier et al. 2011.)

OH was present in 18.2% of individuals aged 65 and older in a large observational study, of whom 87% were asymptomatic (Rutan et al. 1992). OH is underdiagnosed if based on the presence of symptoms alone (Mills et al. 2014).

2.3.4 Orthostatic hypotension as a risk factor for falls

The association between falls and OH is unclear, particularly because of poor measurement methods of previous studies (Finucane et al. 2017). Hartog et al. (2017) meta-analysis of prospective observational studies showed no significant relationship between OH and falling. Therefore, they suggested that more prospective studies are needed for a precise estimate of the relationship between OH and falling.

OH is considered an important risk factor for falls, but longitudinal studies have failed to show a clear association. This disparity may be because conventional methods of measuring blood pressure changes are too imprecise and/or the diagnostic criteria for OH are inappropriate. Over recent years, beat-to-beat blood pressure monitoring techniques, which enabled accurate measurement of vasodepression, have become widely used and in 2011 the American Academy of Neurology produced revised diagnostic criteria for OH. (McDonald et al. 2017.)

There exist studies testing the associations between OH and falls and the hypothesis if OH is a risk factor of falls (Lahrmann et al. 2006; Lipsitz 2017; Saedon, Tan & Frith 2018; Mol et al. 2018, Mol et al. 2019). The earlier longitudinal studies have failed to show a clear association of OH with falls (McDonald et al. 2017).

According to Menant et al. (2016) orthostatic hypotension increased the risk of unexplained fall in community-living older people. Orthostatic hypotension is significantly positively associated with falls in older adults, underpinning the clinical relevance to test for an orthostatic blood pressure drop and highlighting the need to investigate orthostatic hypotension treatment to potentially reduce falls. (Mol et al. 2019.)

OH is often found in older patients and in those who are frail (Ooi et al. 1997). A blood pressure drop after postural change, is associated with impaired standing balance and falls in older adults (Timmermans et al. 2018). OH is particularly in older populations, associated with cardiovascular and cerebrovascular morbidity and mortality. Therefore, it is important to identify OH in the clinical setting. (Ricci et al. 2015; Arnold & Raj 2017.)

According to Mills et al. (2014) orthostatic hypotension (OH) is an independent risk factor for clinically important adverse events in older adults. Aging itself is a risk factor for developing OH, and this risk increases with use of medications and diseases affecting the nervous system.

In the study of Gangavati et al. (2011) a significant relationship between OH and falls was only found within participants with systolic OH at 1 min. Ooi et al. (1997) reported that OH was an independent risk factor for recurrent falls.

Half of OH diagnosed older adults reported loss of balance (Gray-Miceli et al. 2012). According to Menant et al. (2016) OH increased the risk of unexplained fall in community-living older people. OH is significantly positively associated with falls in older adults, underpinning the clinical relevance to test for an orthostatic blood pressure drop and highlighting the need to investigate OH treatment to potentially reduce falls. (Mol et al. 2019.)

Older adults who have impaired orthostatic blood pressure control have risk of falling and should receive tailored management to reduce this risk (Shaw et al. 2019). Routine screening for OH is recommended even in asymptomatic older adults to predict the risk of future problems (Feldstein & Weber 2012; Momeyer et al. 2018).

The treatment goal of OH should be to improve symptoms and functional status, and not to target arbitrary blood pressure values (Arnold & Raj 2017).

3 Aims

In detail, the aims of this academic thesis were:

1. To create a shorter version of the original Berg Balance Scale (BBS) and to assess correlations between the short BBS (BBS-9) and static and dynamic aspects of balance among community-dwelling older adults with a history of falling. (Study I)
2. To assess the adequacy of the short, 9-item Berg Balance Scale (BBS-9) to predict falls during 12-month follow-up among the community-dwelling older adults with a history of falling, and to determine the cut-off score which has the best predicting value. (Study II)
3. To assess the predicting value of the short, 9-item Berg Balance Scale (BBS-9) for falls during 36-month follow-up among the community-dwelling older adults with a history of falling. (Study III)
4. To assess the prevalence of orthostatic hypotension (OH) and the association of OH with the risk of falls among community-dwelling older adults with a history of falling. (Study IV)

4 Materials and methods

MATERIALS OF THE STUDIES **(Figure 1)**

I MATERIAL SET	Prospective, population-based, longitudinal design (Studies I and II) -persons with original BBS and static and dynamic balance measurements participating in the multifactorial fall prevention conducted in Pori, Finland (n=519)
II MATERIAL SET	Prospective, population-based, longitudinal design (Study III) -the control group of the multifactorial fall prevention conducted in Pori, Finland (n=298) divided into BBS-9 risk group (RG) (n=158) and BBS-9 non-risk group (non-RG) (n=140) according to the sum score of BBS-9 (32/33)
III MATERIAL SET	Prospective, population-based, longitudinal design (Study IV) -persons with OH measurements participating in the multifactorial fall prevention conducted in Pori, Finland (n=561) divided into OH risk group (OHG) and OH non-risk group (non-OHG) according to the consensus definition (AAS & AAN 1996)

BBS-9= short Berg Balance Scale
OH= orthostatic hypotension

Figure 1.

Study I consisted of 591 community-dwellers older adults (65 years or older) having fallen during the previous 12 months living in the town of Pori. The aim of this study was to create a shorter version of the Berg Balance Scale (BBS) and to assess correlations between short BBS and static and dynamic aspects of balance. 519 (88%) subjects were included in the study, for whom BBS, and static and dynamic balance measurements were performed.

Study II consisted of 591 community-dwellers aged (65 years or older) having fallen during the previous 12 months living in the town of Pori. The aim of this study was to assess the adequacy of the short, 9-item Berg Balance Scale (BBS-9) to predict fall risk among the community-dwelling older adults. The subjects of the study I (n=519) were included in the study II.

Study III consisted of 591 community-dwellers aged (65 years or older) having fallen during the previous 12 months living in the town of Pori. The aim of this study was to assess the predicting value of the nine-item Berg Balance Scale (BBS-9) for falls among the community-dwelling older adults. The participants were randomized to two groups. Intervention group consisted of 293 older adults and a control group of 298 older adults. The participants of the control group were included in the study.

Study IV consisted of 591 community-dwellers aged (65 years or older) having fallen during the previous 12 months living in the town of Pori. The aim of this study was to assess the prevalence of OH and the association of OH with the risk of falls among community-dwelling older adults with a previous fall. The subjects (n=561) with blood pressure measurements were included and were classified to those with OH (OH group; OHG) and those without OH (non-OHG group; non-OHG) according to the consensus definition (The Consensus Committee of the American Autonomic Society and the American Academy of Neurology, 1996).

4.1 Settings and populations

The study is a part of a multifactorial fall prevention trial, which was implemented in the city of Pori, in western coastal Finland among the community-dwelling older adults at increased risk of falling. This study is called the original study.

Subjects for the studies of this academic thesis were derived from the participants in this original multifactorial fall prevention intervention conducted in Pori, Finland (Sjösten et al. 2007). The participants of the original study were 65 years of age or over with good or moderate cognitive function (Mini Mental State Examination ≥17), at least one fall during the previous 12 months, and the ability to walk 10 meters independently, with or without walking aids. They lived at home or in sheltered housing. (Salminen et al. 2009). The number of persons participating in the baseline measurements was 591. Subjects recorded falls by fall diaries during a 12-month follow-up. Occurrences of falls requiring treatment were verified from the health center and hospital registers during 12- and 36-month follow-ups.

The following samples from the original study were used as materials of this academic thesis:

1. 519 (88%) subjects were included in the study, for whom BBS, and static and dynamic balance measurements were performed. (Study I)
2. The participants of this study (n=519) included those with baseline data of BBS, use of fall-risk increasing drugs, vision and number of regularly used drugs. These subjects recorded falls by fall diaries during a 12-month follow-up. Occurrences of falls requiring treatment were verified from the health center and hospital registers during 12- and 36-month follow-ups. (Study II)
3. The participants of this study (*n*=298) included the subjects of the control group with no missing items in the baseline data of BBS and possible confounding factors. (Study III)
4. The subjects (n=561) with blood pressure measurements were included. (Study IV)

4.2 Measurements

Data were collected by self-administered questionnaires, interviews, clinical tests, medical records and diaries. Same questionnaires or other measures were used at both baseline and follow-up assessments.

4.2.1 Background variables

Demographic data (age, marital status, living circumstances, educational level) were collected using questionnaires. Marital status was classified in three categories as follows; (1) unmarried, (2) married or common-law marriage and (3) widowed, divorced or judicial separation. Living circumstances were dichotomized to (1) living alone and (2) living with spouse or some other person. Educational level was classified in three categories (1) less than middle school, (2) middle school and (3) more than middle school.

Physical functional abilities were collected by the questionnaire, which included eight questions about basic activities of daily living (BADL) and instrumental activities of daily living (IADL). Both scales consisted of eight items (BADL: using the toilet, bathing (including washing up, taking sauna or shower), dressing, transferring to and from the bed, eating and cutting toenails; IADL: preparing meals, light housework, heavy housework (such as window cleaning), bearing heavy loads, managing finance, using public transportation, taking daily medication, using telephone). The answers were rated as (4) able to perform without any difficulties, (3) able to perform with some difficulties, (2) able to perform with an assistive device, (1) able to perform with a help of some other person and (0) not able to perform, even with another person´s help. The summed score, 32 at the maximum, reflects, therefore, higher capabilities for higher scores in both scales.

Walking ability was measured by a 10-metre walking test which could be performed with or without walking aids.

Functional balance was measured by the Berg Balance Scale (BBS) consisting of fourteen questions with a maximum sum score of 56 (Berg et al. 1992).

Cognitive function was measured by the MMSE (Folstein et al. 1975).

Clinical characteristics were assessed by measuring the blood pressure (mmHg), pulse, weight (kg) and height (cm) of the subjects.

Self-reported *number of falls and injurious falls* during the past 12 months were asked during the interview by the study nurse. In addition, circumstances of a last fall were asked by one question classified into three categories (1) at home (inside or outside), (2) inside other than home and (3) outside other than home.

Medication All regularly and irregularly used prescribed medications were recorded during the geriatric assessment by asking the participants and by verifying the information from the medical records at health centre. The medications were determined according to the Anatomical Therapeutic Chemical Classification System (ATC).

4.2.2 Falls

A fall was defined as an event that results in a person unintentionally coming to rest on the ground, floor, or other lower level with or without loss of consciousness or injury (Kellogg International Working Group 1987; Rubenstein et al. 1990; Koski et al. 1996) during a 12-month follow-up. Falls resulting from extraordinary environmental factors (for example, traffic accidents and falls while riding a bicycle) were excluded (World Health Organization 1999). Falls were recorded in fall diaries that subjects were asked to mail to the research assistants (RAs) monthly during a 12-month follow-up. If a fall diary was not returned at the beginning of the following month, the participant was reminded by telephone. In the case of a fall, the participants were advised to report it as soon as possible by telephone to the RAs who were blinded to their group assignment. If the participant's fall diary indicated a fall that had not been immediately reported, the RAs called the participant later. All participants who had fallen were interviewed during these calls using a structured questionnaire about the fall event and its consequences. The occurrences of falls requiring medical or hospital treatment were verified from the health center and hospital registers. In this study, fall risk was defined as an occurrence of multiple (≥2) falls during a 12-month follow-up. Those with multiple falls were compared to those with only one fall or no falls during a 12-month follow-up. (Salminen et al. 2009).

4.2.3 Balance

All balance measurements were carried out by two trained physiotherapists as baseline measurements for the intervention. The BBS was used to assess functional balance. The BBS comprises 14 items, testing the ability to maintain positions of different difficulty by decreasing the base of support, assessing different transfers and the ability to maintain balance while voluntary movements are performed. Scoring is based on the subject's ability to perform the 14 items or movements independently and to meet certain time or distance requirements. Each item is scored 0–4 (0 cannot perform, 4 normal performance), with the highest total score of 56 (Berg et al. 1992).

Static and dynamic balance was measured with the Good Balance® system (Metitur, Finland) consisting of an equilateral triangular force platform connected to a computer. In static balance, semi-tandem stance (the first metatarsal joint of one foot beside the heal of the other foot calcaneus) was carried out with the subject standing on the force platform for 20 s with eyes open and gaze fixed on a mark ahead, and hands hanging loosely. For the movement of the Center of Pressure (COP), anteroposterior sway velocity, medio-lateral sway velocity, and velocity movement (i.e., the first velocity movement calculated as the mean area covered by the COP displacement during each second of the test, taking into account both distance from the geometrical midpoint of the test and the speed of the movement during the same period) were calculated in semi-tandem stance. The effects of body height were compensated by adjusting the absolute sway measures of antero-posterior and medio-lateral sway velocity according to height ([sway variable/subject's height in cm] × 180) (Era et al. 1996.) In the velocity moment, the effect of body height was compensated according to the formula (sway variable/subject's height in cm2 × 1802). In the dynamic balance test, subjects were asked to move their COP along a track shown on a computer screen. Performance time (time used to complete the test) and distance (length of the path traveled by the COP during the test) were measured.

The results of our study I suggested that Alpha (a) depreciated non-significantly while five aspects of balance were eliminated from the original BBS. BBS-9 was constructed based on these results, and it consists of seven dynamic aspects of balance (sitting to standing, transfers, reaching forward with outstretched arm, retrieving object from floor, turning to look behind, turning 360 and placing alternate foot on stool), and two more difficult static aspects of balance (standing with one foot in front and standing on one foot). Scoring is based on the subject's ability to perform the nine items or movements independently and to meet certain time or distance requirements. Each item is scored on a 0–4 scale (0 = cannot perform, 4 = normal performance), with the highest total score of 36.

4.2.4 Orthostatic hypotension

OH was defined according to the consensus definition by the Consensus Committee of the American Autonomic Society and the American Academy of Neurology and European Federation of Neurological Societies (AAS & AAN 1996; Lahrmann et al. 2006) as a reduction of systolic blood pressure of ≥20 mm Hg or diastolic blood pressure of ≥10 mm Hg within 3 minutes of standing. Systolic and diastolic blood pressures were measured at 30 seconds and 3 minutes after standing.

Blood pressure and heart rate were measured with a standard mercury sphygmomanometer in the supine position and at 30 seconds and 3 minutes after standing. The right arm of the participant was used for measurement. The trained clinical research nurses measured intermittent blood pressures. Measurements were obtained at least 2 hours after breakfast or lunch and 10 minutes lying on the examination bed.

4.2.5 Other measurements

Fear of falling was measured by one dichotomized (yes/no) question "Are you afraid of falling?"

Physical functioning was measured with a three-scale question "What do you consider your physical condition to be?" (1. good, 2. average, 3. poor).

All *regularly used prescribed medications* were recorded by asking participants and verifying the information from the medical records at the health center. The number of these medications was used here by dichotomizing (1. less than four medications; 2. four or more medications).

Participants' height and weight were measured and *body mass index* was defined by the body weight × height squared.

Vision was measured with E-table (farsighted with both eyes without eyeglasses and farsighted with both eyes with eyeglasses).

Depressive symptoms were measured by the 30-item Geriatric Depression Scale (GDS), which represents a valid and reliable self-rating scale for depression among the aged (Brink et al. 1982). Depression was defined according to the validated cutoff score: 11 and above indicating a high amount of depressive symptoms (Lesher 1986; Yesavage, et al. 1982).

4.3 Statistical analyses

Study I

In the first phase, explanatory factor analysis with ML-estimation and oblique oblimin rotation was used to describe the factor content of the BBS with eigenvalue >1 criteria. The correlation matrix in factor analysis was based on Spearman's correlation coefficients. Data analysis was performed with descriptive methods.

In the second phase, five items of the BBS were removed, and the short BBS (BBS-9) was formed from the first factor produced in factor analysis.

Cronbach's alpha was used to describe the internal consistency of the original BBS and BBS-9 produced in factor analysis. Correlations between BBS-9 and static and dynamic aspects of balance were calculated by Spearman correlation analysis. Data are expressed as quartiles.

Study II

Receiver operating characteristic (ROC) curves were used to generate cut-off scores, sensitivities and specificities relative to a history of multiple falls, and ROC analysis was used to determine the cut-off score for BBS-9. The cut-off score was determined as a score with the highest sum of sensitivity and specificity where both sensitivity and specificity were above 0.50. The test outcome of ROC analysis is usually defined as excellent (0.90–1.00), good (0.80–0.89), fair (0.70–0.79), poor (0.60–0.69), and fail (0.50–0.59).

Logistic regression was used to analyze the relationship of BBS-9 and potential confounders with fall risk. Age, gender, use of fall-risk increasing drugs, vision, and the number of regularly used drugs were considered as potential confounders. Areas under curves (AUCs) between different models were compared using a nonparametric approach.

Study III

Categorical variables between BBS-9 risk group and non-risk group were compared with chi-square or Fischer's exact test. The Mann-Whitney *U* test was used to test the differences in continuous variables.

Poisson regression was used to compare the incidences of falls. The results were expressed using incidence rate ratios (IRRs) with 95% confidence intervals (CIs). Age, cognitive function, the number of regularly used drugs, visual acuity, depressive symptoms, time in seconds walking 10 m, and physical competence were considered as possible confounding factors. Confounding factors which were related to incidence of falls, were adjusted for in further analyses.

Firstly, unadjusted IRRs were calculated in model 1. Secondly, Poisson models were adjusted for age in model 2. In model 3, the Poisson model was adjusted for age, number of prescribed medications, and depressive symptoms and in model 4, the Poisson model was adjusted for age, number of prescribed medications, depressive symptoms, and physical competence. Age, number of prescribed medications, depressive symptoms, and time in seconds walking 10 m were used as adjusting variables in model 5.

Study IV

Categorical variables between OHG and non-OHG were compared with chi-square or Fisher´s exact tests. The Mann-Whitney U-test was used to test the differences in continuous variables between OHG and non-OHG.

Poisson regression was used to compare the incidences of falls between OHG and non-OHG. The results were expressed using incidence rate ratio (IRR) with 95% confidence intervals (CI). Age, number of prescribed medications, depressive symptoms, functional balance (BBS-9), walking ability, and physical function were considered as potential confounding factors. These confounding factors were selected by analyzing the associations between previously found potential risk factors of falls and the incidence of falls and those with a significant association were adjusted in further analyses. Confounding factors related to incidence of falls were adjusted in further analyses by taking these factors one by one to the models.

Firstly, unadjusted IRRs were calculated (model 1). Secondly, Poisson models were adjusted only for functional balance (BBS-9) (model 2) and for age and functional balance (BBS-9) (model 3). In model 4, the Poisson model was adjusted for age, functional balance (BBS-9), number of prescribed medications and depressive symptoms. Age, functional balance (BBS-9), number of prescribed medications, depressive symptoms, and physical function were used as adjusting variables in model 5 and age, functional balance (BBS-9), number of prescribed medications, depressive symptoms, and walking ability in model 6.

Statistical programs and definition of statistical significance

The statistical analyses were performed using SAS version 9.1 in study I and SAS version 9.2 in studies II and III. The SAS system for Windows, release 9.4 was used in study IV.

In Studies I–IV, *p*-values ≤ 0.05 were considered statistically significant.

4.4 Ethics

The study was conducted according to the guidelines of the Declaration of Helsinki. The Ethics Committee of Satakunta Hospital District approved the study protocol. The participants gave informed consent in a written form.

5 Results

5.1 Development of short Berg Balance Scale (Study I)

Baseline characteristics

A total of 519 participants (81 men, 438 women) were included in the study. Their mean age was 72.4 years, ranging from 65 to 91 years. Forty-one per cent of subjects were afraid of falling, and 57% had fallen two or more times during the previous 12 months. Only 14% of participants used walking aids. The mean sum score on the BBS was 52.0, ranging from 50.0 to 55.0.

Factor analysis of original BBS

Factor analysis produced two factors. The first consisted of 9 items of the original BBS: seven dynamic aspects of balance (sitting to standing, transfers, reaching forward with outstretched arm, retrieving object from floor, turning to look behind, turning 360°, and placing alternate foot on stool) and two uneasy static aspects of balance (standing with one foot in front, and standing on one foot) (Table 1). The second factor consisted of four easy static aspects of balance (standing unsupported, sitting unsupported, standing with eyes closed, and standing with feet together). Neither the first nor the second factor consisted of the easiest dynamic aspect of balance (standing to sitting). The short version of the BBS (BBS-9) was formed from the 9 items loading in the first factor. The mean score of BBS-9 was 32.1, ranging from 15.0 to 36.0 (standard deviation 3.7). BBS-9 demonstrated good internal consistency reliability (Cronbach's alpha [α]=0.69), the α of the original BBS was 0.74.

Correlations between BBS-9 and static and dynamic aspects of balance

There were significant negative correlations between BBS-9 and static and dynamic aspects of balance measured with the force platform (Table 2). Higher BBS-9 scores were associated with better static and dynamic aspects of balance.

Table 1. Loadings from exploratory factor analysis of original Berg Balance Scale.

Item	Factor 1	Factor 2
1. Sitting to standing	**0.47**	-0.11
5. Transfer	**0.39**	0.16
8. Reaching forward with outstretched arm	**0.52**	-0.01
9. Retrieving an object from floor	**0.48**	0.05
10. Turning to look behind	**0.41**	0.09
11. Turning 360°	**0.64**	-0.03
12. Placing alternate foot on stool	**0.58**	0.01
13. Standing with 1 foot in front	**0.59**	0.01
14. Standing on 1 foot	**0.62**	-0.07
2. Standing unsupported	-0.03	**0.78**
3. Sitting unsupported	-0.07	**0.42**
6. Standing with eyes closed	0.15	**0.54**
7. Standing with feet together	0.21	**0.56**
4. Standing to sitting*	0.18	0.08

*Item load scored below 0.3 on both factors.

Table 2. Correlations[a] between 9-item Berg Balance Scale (BBS) and static and dynamic aspects of balance measured with a force platform (n=519).

	Static balance		**Dynamic balance**		
	Medio-lateral	Antero-posterior sway (mm/s)[b]	Velocity moment sway (mm/s)[b]	Time	Distance (mm2/s)[b]
Total score					
of 9-item BBS	-0.32419	-0.42412	-0.45354	-0.41275	-0.24717
(range 0–36)	p<0.0001	p<0.0001	p<0.0001	p<0.0001	p<0.0001

[a]Spearman's correlation coefficient; [b]Semitandem with eyes open.

5.2 Development of cut-off score of short Berg Balance Scale and falls (Study II)

Baseline characteristics

A total of 519 (88%) participants (81 men, 438 women) were included in the study. The mean age was 72.4 years, ranging from 65 to 91 years. Forty-one per cent of the subjects had feelings of fear of falling, and 57% had fallen two or more times during the last 12 months. Only 14% of the participants used walking aids. 91 (18%) of participants had fallen at least twice during the previous year. The mean sum score on BBS-9 was 32.1 ranging from 15.0 to 36.0.

ROC analysis and BBS-9

To determine the cut-off score for BBS-9 to classify fall risk, the highest sensitivity (0.51) and specificity (0.57) (both being above 0.50) sum score, was within the limit range 32 scores or below (Figure 2). The frequency distribution of the BBS-9 score on fallers and non-fallers is expressed in Figure 3. Among patients scoring 32 or below, the incidence of multiple falls was 20.0% while among those scoring 33–36 it was 15.7% (Table 3). The frequency distribution of occasional fallers and multiple fallers by BBS-9 score is expressed in Figure 4. Of the potential confounders used (age, gender, use of fall-risk increasing drugs, vision, and the number of regularly used drugs), only regularly used drugs (C4 vs. 0–3, odds ratio 1.85, 95% confidence interval 1.15–2.99, p=0.012) and vision (3.97, 1.13–13.98, p=0.032) were significant confounders for fall risk (multiple falls vs. one or no falls) in models where BBS-9 and one confounding variable was included. The short BBS with 9 items was significantly related to the fall risk (0.92, 0.87–0.98, p=0.005) in univariate analysis. In multivariable analysis, vision (4.43, 1.23–15.96, p=0.023), the number of regularly used drugs (1.92, 1.18–3.11, p=0.008) and BBS-9 (0.92, 0.87–0.98, p=0.009) remained significant predictors.

The area under curve (AUC) for model included BBS-9 was 0.57 (95% CI 0.51–0.64) (Table 4). AUC was significantly better in the model adjusted for significant confounders (vision and the number of regularly used drugs) than in the unadjusted model (0.64, 0.57–0.70, p=0.045). The AUCs for models including BBS-9 and vision or BBS-9 and the number of regularly used drugs were not significantly better than in the unadjusted model. In the ROC curve analysis AUC between 0.60–0.69 is poor and 0.50–0.59 is fail.

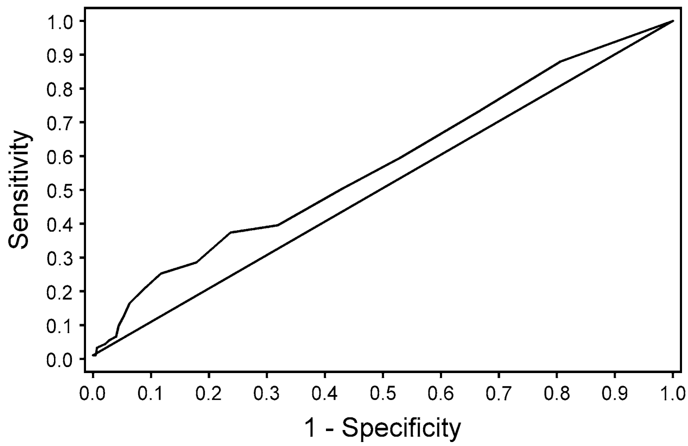

Figure 2. Area under curve for BBS-9 to determine the cut-off value for the fall risk among older adults (n=519).

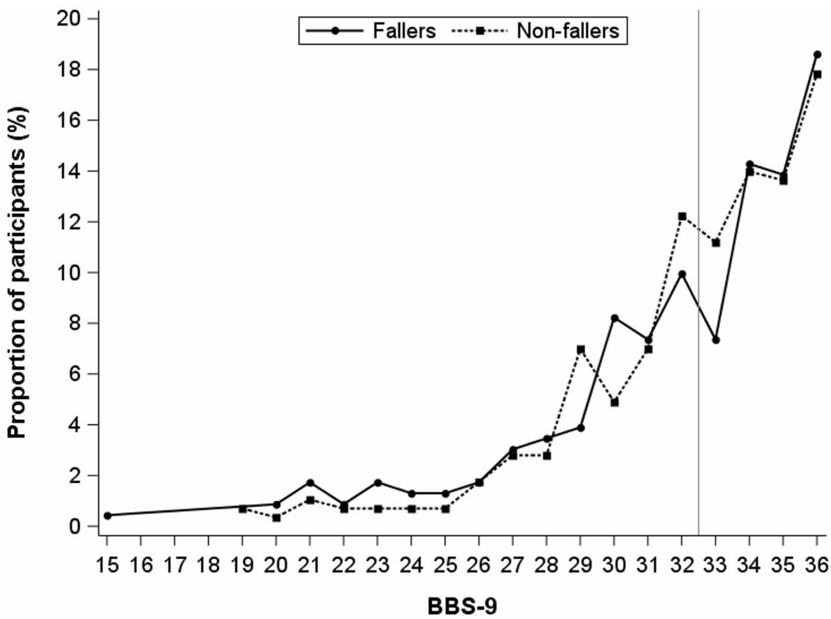

Figure 3. The frequency distribution of the BBS-9 scores on fallers and non-fallers.

Table 3. Numbers of occasional fallers and multiple fallers by the determined cut-off of the Short Berg Balance Scale (BBS-9) among older adults (n=519).

BBS-9 sum score (max 36)	0–1 falls (n=426) n (%)[a]	≥2 falls (n=91) n (%)[a]
0–32	184 (80.0)	46 (20.0)
33–36	242 (84.3)	45 (15.7)

Data of falls missing for 2 persons.
[a] Number of falls during 12-month follow-up period or up to interruption of participation.

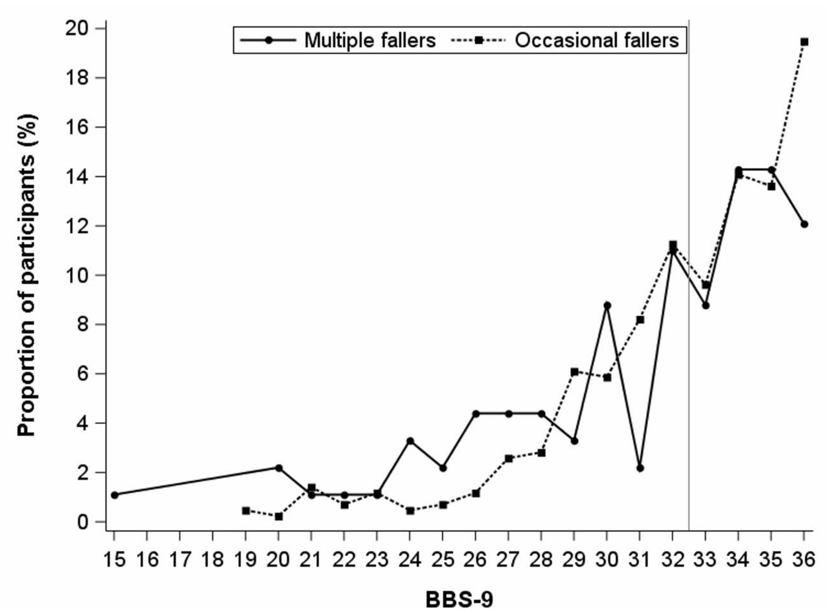

Figure 4. The frequency distribution of occasional fallers and multiple fallers by BBS-9 score.

Table 4. Unadjusted and adjusted ROC analysis for BBS-9 to classify people with a fall risk (n=519).

Predictor	AUC (95% CI)	p value*
BBS-9	0.57 (0.51–0.64)	
BBS-9 and vision	0.60 (0.53–0.67)	0.263
BBS-9 and the number		
of regularly used drugs	0.61 (0.55–0.68)	0.090
BBS-9, vision, and the		
number of regularly		
used drugs	0.64 (0.57–0.70)	0.045

Data of falls missing for 2 persons.
* Compared with the model including only BBS-9.

5.3 Short Berg Balance Scale and predicting value (Study III)

Baseline Characteristics

A total of 298 participants, aged from 65 to 94 years (mean age: 73.5 years), were included in the study. The mean sum score of the BBS-9 was 30.7, ranging from 9.0 to 36.0.

Incidence of falls according to BBS-9

During the 12-month follow-up, 271 falls (171 in RG and 100 in non-RG) and 29 falls requiring treatment (22 in RG and 7 in non-RG) occurred (Table 5). During 36 months, there were 98 falls that required treatment (72 in RG and 26 in non-RG).

Table 5. Number and incidence of falls and falls requiring treatment in the risk group and non-risk group and incidence rate ratios for falls between the groups.

Falls	Number of falls	Incidence(95% CI)	IRR (95% CI)	p value
Falls during a 12-month follow-up Risk group				
(n=157)*	171	1.14 (0.98–1.32)	1.57 (1.23–2.01)	<.001
Non-risk group (n=140)	100	0.73 (0.60–0.88)	1	
Falls requiring treatment during a 12-month follow-up				
Risk group (n=158)	22	0.14 (0.09–0.21)	2.82 (1.20–6.59)	0.17
Non-risk group (n=140)	7	0.05 (0.02–0.10)	1	
Falls requiring treatment during a 36-month follow-up				
Risk group (n=158)	72	0.16 (0.13–0.20)	2.56 (1.63-4.01)	<.001
Non-risk group (n=140)	26	0.06 (0.04–0.09)	1	

Note. IRR = incidence rate ratio; 95% CI = 95% confidence interval.
Risk group includes subjects scoring 0–32 sum points in BBS-9.
Non-risk group includes subjects scoring 33–36 sum points in BBS-9.
∗1 missing value.

The incidence of falls was significantly higher in RG compared with non-RG during the 12-month follow-up ($p < .001$) (Table 6). Also, the incidence of falls requiring treatment was significantly higher in RG than in non-RG during 12 and 36 months (p=.017 and $p < .001$, respectively).

Table 6. Unadjusted and adjusted incidence rate ratios and their 95% confidence intervals and p values for falls between the risk and non-risk groups.

	Falls during a12-month follow-up		Falls requiring treatment during a 12-month follow-up		Falls requiring treatment during a36-month follow-up	
Model	**IRR (95% CI)**	**p value**	**IRR (95% CI)**	**p value**	**IRR (95% CI)**	**p value**
Model I*	1.57(1.23−2.01)	<.001	2.82(1.20−6.59)	.017	2.56(1.63−4.01)	<.001
Model II†	1.67(1.29−2.17)	<.001	2.00 (0.82−4.91)	.129	2.13(1.33−3.41)	.002
Model III‡	1.04(0.78−1.39)	.796	1.55 (0.56−4.30)	.397	1.75 (1.04−2.93)	.034
Model IV§	1.02(0.75−1.38)	.900	1.44 (0.53−3.96)	.475	1.73 (1.03−2.92)	.040
Model V**	0.93(0.69−1.27)	.648	1.17 (0.43−3.44)	.774	1.49(0.87−2.55)	.142

Note. IRR = incidence rate ratio; IRR >1 indicates higher risk for falls in the risk group compared with the non-risk group. 95% CI = 95% confidence interval.
*Unadjusted.
†Adjusted for age (<75, ≥75 years).
‡Adjusted for age (<75, ≥75 years), number of prescribed medications (<4, ≥4), and depressive symptoms (Geriatric Depression Scale).
§Adjusted for age (<75, ≥75 years), number of prescribed medications (<4, ≥4), depressive symptoms (Geriatric Depression Scale), and physical competence.
**Adjusted for age (<75, ≥75 years), number of prescribed medications (<4, ≥4), depressive symptoms (Geriatric Depression Scale), and time in seconds walking 10 m.

5.4 Orthostatic hypotension and the risk of falls (Study IV)

Baseline characteristics

A total of 561 participants, aged from 65 to 94 years (mean age 73.1 years), formed the material. Other baseline characteristics of the participants are expressed in Table 7.

Prevalence of orthostatic hypotension

Prevalence of OH was 23.4% (131/561) according to the 30-second measurement and 7.3% (41/561) according to the 3-minute measurement (Table 8).

Table 7. Baseline characteristics of the participants.

	Total sample (n=561) n (%)	OH group 30 sec (n=130) n (%)	Non-OH group 30 sec (n=429) n (%)	P-value	OH group 3 min (n=41) n (%)	Non-OH group 3 min (n=520) n (%)	P-value
Gender							
Male	92 (16)	29 (22)	63 (15)		10(24)	82(16)	
Female	469 (84)	102 (78)	367 (85)	0.043	31(76)	438(84)	0.151
Age							
65–74	361 (64)	66 (50)	295 (69)		20(49)	341(66)	
≥75 years	200 (36)	65 (50)	135 (31)	<0.001	21(51)	179(34)	0.031
Living circumstances							
Living with a spouse or another person	254 (45)	60 (46)	194 (45)		20(49)	234(45)	
Living alone	307 (55)	71 (54)	236 (55)	0.879	21(51)	286(55)	0.584
Education*							
More than basic	152 (27)	27 (21)	125 (29)		15(37)	137(26)	
Basic	402 (72)	101 (77)	301 (70)		25(61)	377 (73)	
Less than basic	7 (1)	3 (2)	4 (1)	0.089	1(2)	6(1)	0.262
Use of walking aids							
No	456 (81)	102 (78)	354 (82)		34(83)	422(81)	
Yes	105 (19)	29 (22)	76 (18)	0.252	7(17)	98(19)	0.779
Self-assessed physical function							
Good	198 (35)	40 (31)	158 (37)		17(42)	181(35)	
Adequate	299 (54)	75 (57)	224 (52)		14(34)	285(55)	
Bad	62 (11)	169 (12)	46 (11)	0.406	10(24)	52(10)	0.005
Number of prescribed medications							
<4	292 (52)	58 (44)	234 (54)		14(34)	278(53)	
≥4	269 (48)	73 (56)	196 (46)	0.042	37(66)	242(47)	0.017
Body mass index							
<25	102 (18)	27 (21)	75 (17)		6(14)	96(18)	
25–29.99	263 (47)	63 (48)	200 (47)		24(59)	239(46)	
≥30	196 (35)	41 (31)	155 (36)	0.534	11(27)	185(36)	0.298
	Median (IQR)	**Median (IQR)**	**Median (IQR)**		**Median (IQR)**	**Median (IQR)**	
10-meter walk (time in seconds)	6.7 (5.8–7.9)	7.0 (6.0–8.4)	6.6 (5.7–7.7)	0.015	7.1 (6.0–8.6)	6.7 (5.8–7.9)	0.380
Mini-Mental State Examination	28.0 (26.0–29.0)	28.0 (26.0–29.0)	28.0 (26.0–29.0)	0.262	27.0 (24.5–29.0)	28.0 (26.0–29.0)	0.075
Geriatric Depression Scale (GDS)	4.0 (1.0–8.0)	4.0 (2.0–10.0)	4.0 (1.0–7.0)	0.182	6.0 (3.0–11.0)	4.0 (1.0–7.0)	0.023
Visual acuity	0.8 (0.7–1.0)	0.8 (0.6–1.0)	0.9 (0.7–1.0)	0.002	0.8 (0.6–1.0)	0.8 (0.7–1.0)	0.289
Functional balance (BBS-9)	33.0 (29.0–35.0)	32.0 (28.0–34.0)	33.0 (30.0–35.0)	0.002	32.0 (29.0–34.0)	33.0 (30.0–35.0)	0.187

*More than basic = more than six years of school; basic = six years of school; less than basic = less than six years of school

Association of orthostatic hypotension with the incidence of falls

The 30-second measurement definition

By determining OH with the 30-second measurement, 435 falls (127 in OHG and 308 in non-OHG) and 44 falls requiring treatment (18 in OHG and 26 in non-OHG) occurred during the 12-month follow-up (Table 8). During 36 months, there were 150 falls which required treatment (42 in OHG and 108 in non-OHG).

The incidence of falls was significantly higher in OHG compared to non-OHG during the 12-month follow-up. After adjustments, the incidence of falls during the 12-month follow-up remained significantly higher in all five adjusted models.

The incidence of falls requiring treatment was significantly higher in OHG compared to non-OHG during the 12-month follow-up, but no difference was found during the 36-month follow-up. The incidence of falls requiring treatment during the 12-month follow-up remained significantly higher in OHG compared to non-OHG only after adjustment for functional balance (Table 9).

The 3-minute measurement definition

By determining OH with the 3-minute measurement, 440 falls (50 in OHG and 390 in non-OHG) and 40 falls requiring treatment (2 in OHG and 38 in non-OHG) occurred during the 12-month follow-up (Table 8). During 36 months, there were 150 falls which required treatment (12 in OHG and 138 in non-OHG).

By using the 3-minute measurement, the incidence of falls was significantly higher in OHG compared to non-OHG during the 12-month follow-up, and it remained significantly higher after adjustment for functional balance and for age and functional balance (Table 10).

No differences in the incidence of falls requiring treatment during the 12- or 36-month follow-ups were found between OHG and non-OHG.

Table 8. Number and incidence of falls and falls requiring treatment in OHG and non-OHG and incidence rate ratios for falls between groups by determining OH either at 30 seconds or 3 minutes.

	Number of participants	Number of falls 30 sec	Incidence (95% CI) 30 sec	IRR (95% CI) 30 sec	P-value	Number of participants	Number of falls 3 min	Incidence (95% CI) 3 min	IRR (95% CI) 3 min	P-value
Falls during 12-month follow-up										
OH group[1]	130*	127	1.00 (0.84–1.19)	1.35 (1.10–1.66)	0.004	41	50	1.14 (0.85–1.53)	148 (1.04–2.02)	0.013
Non-OH group[2]	429*	308	0.74 (0.66–0.83)	1		518**	390	0.77 (0.70–0.85)	1	
Falls requiring treatment during 12-month follow-up										
OH group[1]	131	18	0.14 (0.09–0.22)	2.04 (1.13–3.66)	0.018	41	2	0.05 (0.01–0.20)	0.58 (0.14–2.37)	0.445
Non-OH group[2]	430	26	0.07 (0.05–0.10)	1		520	38	0.09 (0.06–0.11)	1	
Falls requiring treatment during 36-month follow-up										
OH group[1]	131	42	0.11 (0.08–0.15)	1.28 (0.89–1.83)	0.177	41	12	0.10 (0.06–0.18)	1.13 (0.63–2.03)	0.689
Non-OH group[2]	430	108	0.09 (0.07–0.10)	1		520	138	0.09 (0.08–0.11)	1	

IRR = Incidence rate ratio
95% CI = 95% Confidence interval
[1]Group includes subjects with diastolic or systolic orthostatism (30 seconds or 3 minutes measurements)
[2]Group includes subjects without diastolic or systolic orthostatism (30 seconds or 3 minutes measurements)
*1 missing value
**2 missing values

Table 9. Unadjusted and adjusted incidence rate ratios for falls between OHG and non-OHG (30 seconds measurement).

	Falls during 12-month follow-up		Falls requiring treatment during 12-month follow-up		Falls requiring treatment during 36-month follow-up
	IRR (95% CI)	P-value	IRR (95% CI)	P-value	IRR (95% CI)
Model 1*	1.35 (1.10–1.66)	0.004	2.04 (1.13–3.66)	0.018	1.28 (0.89–1.83)
Model 2†	1.32 (1.08–1.63)	0.008	1.97 (1.09–3.55)	0.025	1.20 (0.84–1.71)
Model 3‡	1.31 (1.06–1.62)	0.012	1.74 (0.96–3.17)	0.068	1.12 (0.78–1.61)
Model 4§	1.27 (1.03–1.58)	0.026	1.57 (0.84–2.93)	0.162	1.03 (0.71–1.49)
Model 5**	1.28 (1.04–1.58)	0.023	1.64 (0.87–3.06)	0.125	1.04 (0.71–1.51)
Model 6***	1.27 (1.03–1.57)	0.028	1.55 (0.83–2.98)	0.171	1.01 (0.70–1.48)

IRR = Incidence rate ratio; IRR>1 indicates higher risk for falls in OHG compared to non-OHG.
95% CI = 95% Confidence ínterval
*Unadjusted
†Adjusted for functional balance (BBS-9; 0–32, 33–36)
‡ Adjusted for age (<75, ≥75 years) and functional balance (BBS-9; 0–32, 33–36)
§ Adjusted for age (<75, ≥75 years), functional balance (BBS-9; 0–32, 33–36), number of prescribed medications (<4, ≥4), and depressive symptoms (GDS; 0–10, 11–15)
** Adjusted for age (<75, ≥75 years), functional balance (BBS-9; 0–32, 33–36), number of prescribed medications (<4, ≥4), depressive symptoms (GDS; 0–10, 11–15) and physical function
*** Adjusted for age (<75, ≥75 years), functional balance (BBS-9; 0–32, 33–36), number of prescribed medications (<4, ≥4) and depressive symptoms (GDS; 0–10, 11–15) and walking ability.

Table 10. Unadjusted and adjusted incidence rate ratios for falls between OHG and non-OHG (3 minutes measurement).

	Falls during 12-month follow-up		**Falls requiring treatment during 12-month follow-up**		**Falls requiring treatment during 36-month follow-up**
	IRR (95% CI)	P-value	IRR (95% CI)	P-value	IRR (95% CI)
Model 1*	1.48 (1.09–2.02)	0.013	0.58 (0.14–2.37)	0.445	1.13 (0.63–2.03)
Model 2†	1.44 (1.06–1.96)	0.021	0.54 (0.13–2.24)	0.399	1.02 (0.57–1.84)
Model 3‡	1.42 (1.04–1.94)	0.027	0.49 (0.12–2.04)	0.330	0.98 (0.54–1.77)
Model 4§	1.30 (0.95–1.78)	0.103	0.48 (0.12–2.03)	0.321	0.92 (0.51–1.68)
Model 5**	1.27 (0.92–1.74)	0.150	0.49 (0.12–2.09)	0.338	0.95 (0.52–1.75)
Model 6***	1.32 (0.96–1.81)	0.087	0.51 (0.12–2.14)	0.358	0.95 (0.52–1.74)

IRR = Incidence rate ratio; IRR>1 indicates higher risk for falls in OHG compared to the non-OHG.
95% CI = 95% Confidence ínterval
*Unadjusted
†Adjusted for functional balance (BBS-9; 0–32, 33–36)
‡ Adjusted for age (<75, ≥75 years) and functional balance (BBS-9; 0–32, 33–36)
§ Adjusted for age (<75, ≥75 years), functional balance (BBS-9; 0–32, 33–36), number of prescribed medications (<4, ≥4), and depressive symptoms (GDS; 0–10, 11–15)
** Adjusted for age (<75, ≥75 years), functional balance (BBS-9; 0–32, 33–36), number of prescribed medications (<4, ≥4), depressive symptoms (GDS; 0–10, 11–15) and physical function
*** Adjusted for age (<75, ≥75 years), functional balance (BBS-9; 0–32, 33–36), number of prescribed medications (<4, ≥4) and depressive symptoms (GDS; 0–10, 11–15) and walking ability.

6 Discussion

Background to this thesis

The incidence of falls is high. One-third of community-dwelling persons older than 65 years of age fall each year, and half of them fall at least twice a year (Tinetti et al. 1997: Gillespie et al. 2003: Rubenstein et al. 2006; de Baat et al. 2016). Although not all falls lead to injury, about 20% need medical attention, 5% result in a fracture and other serious injuries (Kannus et al. 2005). Falls are an incapacitating problem and represent a significant burden on the health care services (Shumway-Cook et al. 1997; Chiu et al. 2003; Voermans et al. 2007; Gardiner et al. 2017; Guirguis-Blake et al. 2018). Surgically treated fall injuries are associated with substantial economic costs (David et al. 2010; Burns et al. 2016).

Several risk factors for falls have been identified and they are classified into intrinsic and extrinsic risk factors (Tinetti et al. 1988; Gillespie et al. 2009; Cameron et al. 2010; Deandrea et al. 2010; Karlsson et al. 2013; Ambrose et al. 2013). Falling in older adults is usually caused by several factors (Cuevas-Trisan 2019). Deandrea et al. (2010) found in their meta-analysis that the history of falls had the strongest association to falls among community-dwelling older adults. According to Ambrose et al. (2013) review of the literature, impaired balance is one of the major risk factors for falls. Balance disorders are common in older adults and they are associated with increased morbidity and mortality, as well as reduced level of function. (Salzman 2010.)

OH is often found in older patients and in those who are frail (Ooi et al. 1997). A blood pressure drop after postural change is associated with impaired standing balance and falls in older adults (Timmermans et al. 2018). Half of OH-diagnosed older adults reported loss of balance (Gray-Miceli et al. 2012). The earlier longitudinal studies have failed to show a clear association of OH with falls (McDonald et al. 2017; Hartog et al. 2017). The association between falls and OH is unclear, particularly because of poor measurement methods of previous studies (Finucane et al. 2017). Some previous studies reported that OH is an independent risk factor for falls (Ooi et al. 1997; Mills et al. 2014). OH is significantly positively associated with falls and it increased the risk of unexplained fall in community-living older people (Menant et al. 2016). In the study of Gangavati et al. (2011) a significant relationship between OH and falls was only seen within participants with systolic OH at 1 min.

Many measures of balance are available, a systematic review identified 68 balance tests (Orr et al. 2008; Sibley et al. 2011). Although a number of review articles have summarized the available standardized balance measures to assist clinicians with selecting appropriate tests, (Browne et al. 2001; Huxham et al. 2001; Mancini & Horak 2010) there is little evidence documenting which measures are the most reliable and valid (Sibley et al. 2011) balance tests for community-dwelling older adults. In their study among community-dwelling older adults who were in good health, O´Brien et al. (1998) found that the BBS was less sensitive in predicting falls than reported by Berg et al. (1992) who studied residents in a nursing home.

The BBS is a widely used measure of functional balance in older adults. It was specifically designed to assess balance among older adults, to monitor changes in balance over time, to screen patients for rehabilitation, and to predict falls in community-dwelling and institutionalized older adults (Berg et al. 1989; Southard et al. 2005; Muir et al. 2008; Park 2018). However, among the higher-functioning older adults, a ceiling effect if often evidenced (Southard et al. 2005) and the length of time needed to perform the BBS is not short (20–30 minutes) (Berg et al. 1989). The applicability for clinical practice is important when choosing a balance test. There is a need for a short, easy-to-use, validated, feasible and inexpensive balance test in health care.

The phrasing of the questions and the aims of this doctoral thesis arose from the results of the previous studies described above.

6.1 Design and population

Population

A total of 591 older adults accepted to participate in fall prevention conducted in Pori. The participants were volunteers. The inclusion criteria were age 65 years or older, falling during previous year and living community-dwelling. Most of the participants were women. Previous fall, gender (female) and age over 65 years have been indicated as risk factors of falls (Close 2005; Deandrea et al. 2010, Tinetti et al. 2010). The limitations of this fall prevention study are that most participants were women (84%). On the other hand, women have higher risk of falling than men (Campbell et al. 1990) and falls and injuries in geriatric age are more frequent in women than in men (Gioffrè-Florio et al. 2018). The participants do not represent an older community-dwelling population. They were a selected group of volunteers having fallen during the previous year.

The majority of the population consisted of the home-dwelling older adults with quite good physical function. This was probably caused by opportunistic recruitment. Due to this, findings of this study can be generalized only to rather high-functioning older adults.

One of the main risk factors for falling is a history of falls (Ganz et al. 2007; Patel & Ackermann 2018). According to Campbell et al. (1989) about 15% of healthy older adults fall each year. In this thesis most of the participants were <75 years and their physical functions were good or adequate. At the beginning of the Pori study 41% of the participants had fallen only once during previous year and 2/3 had fallen outside. Most of the participants had fallen occasionally. Participants consisted of older adults with previous fall during 12 months. Although this population is a risk group, in general falling is rather common within older population.

6.2 Methods

Fall

A fall was defined as an event that results in a person unintentionally coming to rest on the ground, floor or other lower level with or without loss of consciousness or injury during the 12-month follow-up (Rubenstein et al. 1990; Koski et al. 1996). Falls resulting from extraordinary environmental factors (e.g., traffic accidents and falls while riding a bicycle) were excluded (WHO 1999). A fall requiring treatment was defined as a fall leading to examinations and treatment of the injury caused by the fall in a health center or a hospital.

A fall was defined according to this widely used and accepted definition. A large variation of the definitions of fall events exists (Lamb et al. 2005). After the fall prevention study in Pori, the Prevention of Falls Network Europe (ProFaNE) group concluded that there is a need for standardization of definition. The group deduced that this variation was likely to be a major factor explaining differences in fall rates in studies conducted in similar populations (Wolf et al. 1996; Lamb et al. 2005). According to the ProFaNE consensus a fall should be defined as ‘an unexpected event in which the participants come to rest on the ground, floor, or lower level’. (Lamb et al. 2005.)

There are two ways to register falls in epidemiological studies that are most common to get data. Retrospective inquiries and interviews are a cheap, but unreliable way to register falls. Fall diaries are a more reliable, but quite expensive way to monitor falls daily. In this thesis falls were recorded by the most reliable way. They were monitored by fall diaries that subjects were instructed to fill in and asked to mail to the research assistants (RA) monthly during a 12-month follow-up. In addition, the participants were advised to report their falls by telephone to the RA as soon as possible after the fall. If a monthly fall diary was not returned at the beginning of the following month, the RA called participant by telephone and asked whether falls occurred during the previous month. The occurrences of falls requiring treatment were collected from the health center and hospital registers by the RA during the 12- and 36-month follow-ups. The registration of falls is as accurate as possible.

The ProFaNE consensus performed after the beginning of intervention study in Pori. According to this consensus falls should be recorded using prospective daily recording and a notification system with a minimum of monthly reporting. Telephone or face-to-face interview should be used to rectify missing data and to ascertain further details of falls and injuries. (Lamb et al. 2005.)

In this thesis fall diaries were filled during 12 months. There were no resources to call participants during a longer period than 12 months. In addition participants hardly would be eager to fill in fall diaries as long as 36 months. However, it was useful to collect some evidence of falls during a longer period than 12 months. The occurrences of falls requiring treatment were collected from the health center and hospital registers by the RA during the 12- and 36-month follow-ups. The Finnish health care registers are accurate. Our numbers of treatments are reliable.

Balance

Many measures of balance are available; a systematic review identified 68 balance tests (Orr et al. 2008). The choice between balance tests was difficult. For example, the Tinetti test has been recommended and widely used in the older adults to assess mobility, balance and gait, and predict falls. Different versions can be found. A systematic literature search identified 37 publications on the Tinetti test and falls. Wide variations were found concerning name of the instrument, test items, scoring, and cut-off values. This heterogeneity interferes with evaluations of the test's validity, reliability, and generalizability. Researchers and clinicians should be aware of this fact, when dealing with the Tinetti test. (Köpke & Meyer 2006.)

The BBS is a widely used measure of functional balance in older adults. It is a validated test, and the cutoff score has been defined accurately. In studies and literature, it is referred to as only BBS. In previous studies, correlations between the BBS and balance measured by force platform have been evaluated (Frykberg et al. 2007). The BBS is a useful and inexpensive tool. However, among the higher-functioning older adults, a ceiling effect if often evidenced when BBS is used (Southard et al. 2005). The BBS was selected among all balance tests because it is a validated test, which is easy to access. No equipment is needed in this test, which is widely used in Finland.

All balance measurements were carried out by two trained physiotherapists. The BBS was used to assess functional balance. Static and dynamic balance was measured with the Good Balance® system (Metitur, Finland) consisting of an equilateral triangular force platform connected to a computer. Balance measurement with force platform is reliable and force platform is generally considered to be the gold standard measure of balance (Clark et al. 2010; Hrysomallis 2011).

Orthostatic hypotension

Considerable discrepancies exist between the published guidelines regarding the methodology of OH diagnosing (Tzur et al. 2019). In this thesis OH was defined according to the consensus definition by the Consensus Committee of the American Autonomic Society and the American Academy of Neurology and European Federation of Neurological Societies (AAS & AAN 1996; Lahrmann et al. 2006) within 3 minutes of standing. In this thesis systolic and diastolic blood pressures were measured at 30 seconds and 3 minutes after standing.

Blood pressure and heart rate were measured with a standard mercury sphygmomanometer in the supine position and at 30 seconds and 3 minutes after standing. The right arm of the participant was used for measurement. Trained clinical research nurses measured intermittent blood pressures. Measurements were obtained at least 2 hours after light breakfast or lunch and after 10 minutes lying on the examination bed.

According to Tzur et al. (2019) review substantial gaps in the skills and knowledge required for assessment of OH have been reported by clinicians. The various aspects of OH assessment have been extensively discussed. Correct assessment of OH is essential for its accurate diagnosis. (Tzur et al. 2019) In this thesis trained clinical research nurses performed OH measurements. Valid and reliable measurements were used to define OH, and OH was defined according to the consensus definition by the Consensus Committee of the American Autonomic Society and the American Academy of Neurology and European Federation of Neurological Societies.

The earlier meta-analysis made by Mol et al. (2019) consisted of 63 studies. The populations of 17 studies consisted of community-dwelling older adults and nine of these studies were longitudinal and in only four of them OH was defined according to the consensus definition. The meta-analysis by Mol et al. (2019) revealed that the adjustment for potential confounders was limited in the previous studies. The quality of the majority of the previous studies was only moderate or low, and no critical conclusions could be drawn about any causal relationship between OH and falls. In this thesis potential confounding factors were adjusted. They were selected as described in following sectors.

6.3 Results

6.3.1 Development of short Berg Balance Scale (Study I)

Generally accepted scientific research methods and statistical analyses in developing the shorter version of BBS among community-dwelling older adults were used in this thesis.

Firstly, correlations between the original BBS and static and dynamic balance measured with the force platform were examined. After that, an explanatory factor analysis was used to create a shorter version of the BBS. Factor analysis produced two factors. The short version of the BBS was formed from the 9 items loading in the first factor and short version of the BBS was named BBS-9.

Chou et al. (2006) have developed shorter 7-item version of the BBS among stroke patients with poor physical functioning. Six of the items in their 7-item version of the BBS are same as in BBS-9. One item (standing with eyes closed) which was included in their study, did not load in BBS-9. Chou et al. (2006) found the 7-item BBS to be psychometrically similar to the original BBS and because it is simpler and faster to complete, they recommended its use in clinical and research settings.

In BBS-9 development Cronbach's alpha showed non-significant depreciation when five items of the original BBS were eliminated. BBS-9 is as valid as the original BBS among the older adults with good or adequate physical functioning.

6.3.2 Development of cut-off score of short Berg Balance Scale (Study II)

The receiver operating characteristic (ROC) curves were used to determine the cutoff score of the BBS-9 (range 0-36) to classify fall risk. The area under the ROC curve (AUC) is a global measure of the ability of a test to discriminate whether a specific condition is present or not present. An AUC of 0.5 represents a test with no discriminating ability (i.e., no better than chance), while an AUC of 1.0 represents a test with perfect discrimination. (Hoo et al. 2017.)

In this thesis to determine the cut-off score for BBS-9 to classify fall risk, the highest sensitivity (0.51) and specificity (0.57) sum score, was within the limit range 32 scores or below. The test outcome is defined as excellent (0.90–1.00), good (0.80–0.89), fair (0.70–0.79), poor (0.60–0.69), and fail (0.50–0.59).

When conventional statistical techniques of sensitivity and specificity were used to evaluate the performance of the original BBS in predicting falls, the generally used cutoff value of 44/45 was found to be inadequate for identifying the majority of fallers in the community sample of older adults. (Muir et al. 2008.) The only prospective study evaluating the original BBS as a dichotomous scale (Bogle Thornbahn & Newton 1996) did not evaluate an optimal threshold; instead, the threshold was set at 44/45 and it demonstrated a sensitivity of 53%. In addition, it was found that the power of the measurement scale was better for evaluating multiple falls than for evaluating any falls or injurious falls (Muir et al. 2008). Also in the original validation study, the BBS was used to evaluate people for multiple falls (Berg et al. 1992). It may be concluded that the results of these previous studies are inconsistent with the fact that the use of the original BBS as a dichotomous scale and its use alone do not predict future fall risk very well (Berg et al. 1992; Bogle Thornbahn & Newton 1996; Muir et al. 2008.)

Logistic regression was used to analyze the relationship of potential confounders with fall risk. The as-sociation between the cut-off score for BBS-9 and fall risk was tested using the Chi-square test. Regres-sion techniques are versatile in their application to medical research because they can measure associa-tions, predict outcomes, and control for confounding variable effects. As one such technique, logistic regression is an efficient and powerful way to analyze the effect of a group of independent variables on a binary outcome by quantifying each independent variable's unique contribution. Using components of linear regression reflected in the logit scale, logistic regression iteratively identifies the strongest linear combination of variables with the greatest probability of detecting the observed outcome. Important con-siderations when conducting logistic regression include selecting independent variables, ensuring that rele-vant assumptions are met, and choosing an appropriate model building strategy. For independent variable selection, one should be guided by such factors as accepted theory, previous empirical investigations, clinical considerations, and univariate statistical analyses, with acknowledgement of potential confound-ing variables that should be accounted for. (Stoltzfus 2011.)

According to American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention (2001) high age, poor balance and muscle strength, weakened eyesight, side effects of some medicines, impaired cognition, depression, poor cognitive abilities and polypharmacy may be classified as risk factors of falls.

Age, gender, use of fall-risk increasing drugs (yes/no), vision (continuous), and the number of regularly used drugs (0–3/≥4) were considered as potential confounders in this thesis. Thus, they were selected from the risk factors determined by the previous studies.

Most falls have a multifactorial etiology and are thus rarely caused by one single factor (Tinetti 2003; Skelton & Todd 2004). The interaction and probable synergism between risk factors may thus be as important as identifying a single risk factor. (American Geriatrics Society, British Geriatrics Society, and American Academy of

Orthopaedic Surgeons Panel on Falls Prevention 2001). According to this thesis, BBS-9 with cut-off score 32/33 together with data on vision and the number of regularly used drugs predicted fall risk poorly.

In this thesis the risk of falling has been defined as an occurrence of at least two falls during a 12-month follow-up because usually recurrent fallers are the most disabled older adults with high risk of falling. Campbell et al. (1989) has demonstrated that approximately 15% of falls in older adults results from an external event that would cause most people to fall. Older adults experiencing such falls are usually younger, more active and cognitively able, with no need for further preventive action because of the fall (Campbell et al. 2006).

In this thesis 41% of the subjects had fear of falling, and 57% had fallen two or more times during the last 12 months. Fear of falling has been associated with previous falls (Cwikel et al. 1989; Arfken et al. 1994). In Gazibara et al. (2017) multiple logistic regression analysis a fear of falling and a female gender were independent risk factors for falling among older persons. Fear of falling is associated with serious physical consequences. By improving balance with physically exercise it is possible may reduce fear of falling and the occurrence of falls. (Kendrick et al. 2014)

6.3.3 Short Berg Balance Scale and predicting value (Study III)

In this thesis 10% of falls led to open care or hospital treatment during 12 months. Earlier studies have shown a quite similar proportion of 5–20% (Luukinen et al. 1995; Høidrup et al. 2003; Kannus et al. 2005). Thus, only about every tenth fall, those leading to hospital treatment, was recorded. The number of falls leading to treatment shows only the amount of the most severe falls.

The predicting value of BBS-9 was assessed during 12 and 36 months. Age, cognitive function, the number of regularly used drugs, visual acuity, depressive symptoms, time in seconds walking 10 m, and physical competence were used as potential confounding factors.

To be a potential confounder, a variable need to satisfy all three of the following criteria. Firstly, it must have an association with the disease, that is, it should be a risk factor for the disease, and secondly it must be associated with the exposure, that is, it must be unequally distributed between exposure groups. In addition, it must not be an effect of the exposure; this also means that it may not be part of the causal pathway. (Jager et al. 2008.) In this thesis the potential confounders are risk factors for falling. They were selected after accurate consideration. BBS-9, confounding factors, such as age, number of prescribed medications, depressive symptoms, 10-m walk, and self-assessed physical function, were related to fall risk. BBS-9 together with age gave a rather poor estimation of fall risk among the community-dwelling older adults.

According to the earlier studies, original BBS with cut-off score of 44/45 was one of the best tools to identify fallers during a 3-month follow-up of self-reported falls among 76 people with multiple sclerosis (Nilsagård et al. 2009). Among 408 community-dwelling ambulatory stroke patients, BBS score of 42/56 was the single best predictor of multiple and/or injurious falls at 2 months post stroke (Tilson et al. 2012). Among 66 independent-living residents the original BBS with a cut-off score of 44/45 demonstrated high specificity but poor sensitivity for predicting who would fall during a 6-month follow-up (Bogle Thornbahn & Newton 1996). In the study of Muir et al. (2008), the use of the BBS as a dichotomous scale, with a cut-off score of 44/55, was inadequate for the identification of the majority of 210 community-dwelling older adults at risk for falling during 1-year follow-up.

In this thesis BBS-9 with a cutoff score of 32/33 predicted falls poorly during the 12-month follow-up and falls requiring treatment during the 12- and 36-month follow-ups among community-dwelling older adults. The low sensitivity and specificity for predicting multiple or injurious falls reflect the multiple causes of falls and suggest that the measure of balance, although useful, cannot independently account for fall risk (Weerdesteyn et al. 2008). This thesis showed that confounding factors (age, number of prescribed medications, depressive symptoms, 10-m walk and self-assessed physical function) were related to fall risk.

Steffen et al. (2002) study among community-dwelling older adults has suggested that age-related norms may be needed for the BBS, although Bogle Thorbahn and Newton (1996) did not find a relationship between age and BBS among older adults living in life care communities. Steffen et al. (2002) study data suggested the need for using age-related data in order to make judgments for older adults between 60 and 90 years of age. In the (ROC) curve analysis AUC is poor (0.60-0.69) and fail (0.50-0.59). Thus, the BBS-9 fails to divide the older adults into two distinctive groups, which would be necessary for a screening tool. The results demonstrate that the BBS-9 alone is not specific and sensitive enough (AUC 0.57) to be used as a screening tool. BBS-9 together with the data on vision and the number of regularly used drugs improves the specificity and sensitivity of the tool but is still poor (AUC 0.64) to predict falls.

BBS-9 with cut-off score of 32/33 is not applicable as a screening tool for fall risk among the community-dwelling older adults having fallen during the previous 12 months with moderate or good physical function. Future studies are needed to assess the predicting value of BBS-9 among different older adults. BBS-9 could not be recommended to use as a screening tool for fall risk.

Significant amount of the population in this thesis consisted of occasional fallers. Falls were usually caused by external factors.

The ProFaNE aims to bring together European researchers and clinicians to focus on the development of effective falls prevention programs for older people. One of the objectives is to identify suitable balance assessment tools. (Lamb et al. 2005.) At present developed BBS-9 is not yet applicable balance test for screening fall risk among community-dwelling older adults with quite good physical function. Large-scale balance test, BBS-9 combined to fall risk factors (e.g., OH), should be examined.

6.3.4 Orthostatic hypotension and the risk of falls (Study IV)

The results show the prevalence of OH to be 23.4% according to the 30 seconds measurement and only 7.3% according to the 3 minutes measurement. According to earlier studies the prevalence of OH is age dependent ranging from 22% to 30% among the older adults (Ricci et al. 2015; Liquori et al. 2018; Freud et al. 2018). Half of OH diagnosed older adults reported loss of balance (Gray-Miceli et al. 2012) and OH increased the risk of unexplained falls in community-living older people (Menant et al. 2016).

The main finding of standardized longitudinal orthostatic hypotension study with adjustments for several potential confounding factors showed that OH measured at 30 seconds after standing was related to the risk of falls occurring during 12 months after measuring OH. In addition, OH measured at 30 seconds after standing was related to the risk of the occurrence of falls leading to treatment during 12 months, but this finding was noticed only after adjusting for functional balance.

By determining OH at 3 minutes after standing OH was associated with falls during 12 months after adjusting for functional balance or functional balance and age during 12 months. However, no association with the occurrence of falls leading to treatment during 12 months was found.

The follow up of falls leading to treatment during 36 months did not show any associations of OH with injurious falls. Both OH measured by determining blood pressure at 30 seconds or 3 minutes after standing verified this non-existence. No management to treat OH and no intervention to adjust medication were involved. There may be intervening causes for the difference between the results according to the length of the follow-up which have not been measured.

According to Mol et al. (2019) most of previous studies are of a moderate or low quality, and no conclusions about any causal relationship between OH and falls can be drawn. The adjustments of potential confounders are limited. This thesis used age, number of prescribed medications, depressive symptoms, functional balance, walking ability, and self-assessed physical function as potential confounding factors. The amount of adjusted potential confounders was substantial. With adjustment for potential confounding factors showed that OH is a risk factor for falls during a 12-

month follow-up. The 30 seconds measurement is a better predictor than 3 minutes measurement. These findings show that blood pressure is levelled rapidly after standing. The 3 minutes measurement is a poor indicator of OH and cannot be used as a single measure in determining OH.

The cohort study by Juraschek et al. (2017) found that OH measurements in the first 30–60 seconds had an association with future risk of falls. This thesis showed that 30 seconds measurement is a valid and reliable measure in determining OH, because it is a good risk indicator of future falls.

The high prevalence of OH in older adults and the association of OH with future risk of falls and fractures shown by previous studies and our study give evidence to include the measurement of OH in screening programs of older adults. Doyle et al. (2021) suggested that screening might be useful, as there are treatments (e. g. antihypertensive or antidepressant medication) that might lower risk of OH in community-dwelling older adults. Older adults who have impaired orthostatic blood pressure control have risk of falling and should receive tailored management to reduce this risk (Shaw et al. 2019). Routine screening for OH is recommended even in asymptomatic older adults to predict the risk of future problems (Center for Disease Control 2017; Feldstein & Weber 2012; Momeyer et al. 2018). According to this thesis it is recommended that OH measurements should be routinely done in geriatric care.

Thesis strengths and limitations

The strength of this thesis was its high number of participants, compared with earlier studies (Bogle Thorbahn & Newton 1996; Muir et al. 2008; Nilsagård et al. 2009; Tilson et al. 2012), longitudinal design, proper registration of falls and valid methods and reliable measurements used in defining OH. This thesis used the standardized technique, timing and positioning during the accurate OH assessment. The trained clinical research nurses made all the measurements. OH was defined according to the consensus definition and the blood pressure measurements were made with a standardized mercury sphygmomanometer. Six potential confounding factors that used were age, number of prescribed medications, depressive symptoms, functional balance, walking ability, and self-assessed physical function. These confounding factors were selected by analyzing the relationships between previously found potential risk factors of falls and the incidence of falls and those with a positive relationship were adjusted in further analyses. Falls were recorded during 12 months by monthly falling diaries and by phone calls to participants who did not send their diaries back after the recording period of one month. The method used in this thesis belongs to the best possible methods used in falling studies. No diaries were used after this follow-up. Only falls leading to treatment were recorded from the hospital and health center registers after the follow-up of 12 months, and they were recorded also during the first 12 months. The Finnish health care registers are accurate. Our numbers of treatments are reliable.

There were some limitations which must be taken into account in interpreting the results. This thesis was not a population-based one and the participants were volunteers having fallen during the previous 12 months, and their physical function was quite good. The number of the population was quite small for subgroup analyses. Most participants (84%) were women. A previous fall is a risk factor for future falls in older persons and women are at higher risk than men. The population is a risk population of falls. The selection of the population may have affected the results. Even quite weak associations may have appeared as stronger ones. Only a single OH measurement was used. A half of our population participated in the multifactorial prevention intervention during the Pori study. Withdrawal of drugs with OH as an adverse effect did not belong to the prevention. Neither were other means to limit the occurrence of OH used. Arguably the prevention intervention has not affected the results. OH was measured in the beginning of the follow-up. OH is an adverse effect of many medications. New illnesses and new prescriptions of the participants during the follow-up are unknown. They are intervening variables that must be taken into account in assessing the results. The follow-up of 36 months is a long period to detect associations because of many possible intervening variables during the follow-up. This thesis used only the variable describing the occurrence of falls leading to treatment in measuring falls during this long period, which leads to weaknesses in our results during the longer follow-up.

The participants may not be representative of the general older adults because they were volunteers participating in the Pori study on the prevention of falls. Probably because of an opportunistic recruitment, the functional abilities of the participants were quite good. Due to this, findings can be generalized only to rather high-functioning older adults.

7 Conclusions

The incidence of falls during the 12-month follow-up and the incidence of falls requiring treatment during the 36-month follow-up remained significantly higher in RG compared with non-RG also after adjustment for age ($p < .001$ and $p=.002$, respectively). After the adjustment for age, number of prescribed medications, and depressive symptoms ($p=.034$) and for age, number of prescribed medications, depressive symptoms, and physical competence ($p=.040$), the incidence of falls requiring treatment during the 36-month follow-up was significantly higher in RG compared with non-RG.

In the ROC curve analysis AUC is poor (0.60–0.69) and fail (0.50–0.59).

The created shorter version of the original Berg Balance Scale BBS-9 fails to divide the older adults into two distinctive groups, which would be necessary for a screening tool. The results demonstrate that the BBS-9 alone is not specific and sensitive enough (AUC 0.57) to be used as a screening tool. BBS-9 together with the data on vision and the number of regularly used drugs improves the specificity and sensitivity of the tool but is still poor (AUC 0.64) to predict falls.

The prevalence of orthostatic hypotension (OH) is quite high among older persons and in many cases asymptomatic. OH at 30 seconds or 3 minutes after standing is associated with a greater risk for falling within 12 months in older adults. The 30 seconds blood pressure measurement is more reliable in finding out the risk than the 3 minutes measurement. The results support the usability of 30 seconds measurement in determining OH and the risk for falling among older persons.

8 Recommendations

1. More efforts should be focused to fall prevention and screening of balance and OH in older adults.
2. BBS-9 alone should not be used as a screening tool.
3. Large-scale balance test, BBS-9 combined to fall risk factors (e.g., OH), should be examined.
4. OH measurements should be routinely done in geriatric care.
5. The 30 seconds blood pressure measurement is usable in determining OH and the risk for falling among older adults.
6. To assess the fall risk among older adults three different multifactorial fall prevention tools should be developed; one for institutionalized older adults, another for older adults in home care and third for community-dwelling older adults.

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