Postural control and the effects of multi-sensory balance training

Unsteady older adults and people with fall-related wrist fractures

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Jafnvægisstjórnun og áhrif skynþjálfunar

Óstöðugt eldra fólk og einstaklingar sem hlotið hafa úlnliðsbrot við byltu

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Ágrip

Markmið: Markmið þessarar doktorsrannsóknar var að rannsaka áhrif skynörvandi jafnvægisþjálfunar fyrir óstöðugt eldra fólk og miðaldra einstaklinga sem höfðu úlnliðsbrotnað, ásamt að rannsaka hvað einkenndi þátttakendur sem höfðu brotnað á úlnlið. Ritgerðin byggir á þremur vísindagreinum. Nánari markmið voru:

Vísindagrein I: Að kanna áhrif skynörvandi jafnvægisþjálfunar á jafnvægi, starfræna færni, öryggi við daglegar athafnir og byltur á meðal eldra fólks með óstöðugleika.

Vísindagrein II: Að rannsaka starfsemi jafnvægiskerfis innra eyra, skyn í fótum, jafnvægi, gönguhraða, vöðvastyrk og upplifun á svima og öryggi við daglegar athafnir einstaklinga 50-75 ára sem hlotið höfðu úlnliðsbrot við byltu. Einnig að kanna hvort einhver þessara breyta tengdist því marktækt að hafa úlnliðsbrotnað.

Vísindagrein III: Að kanna hvort skynörvandi jafnvægisþjálfun bæti jafnvægisstjórnun, starfsemi jafnvægiskerfis í innra eyra, skyn í fótum og starfræna færni hjá einstaklingum sem hlotið hafa úlnliðsbrot við byltu, samanborið við stöðugleikaþjálfun fyrir úlnlið eingöngu.

Aðferðir: Vísindagrein I lýsir hálf-staðlaðri tilraunameðferð með fyrir og eftir-prófi. Þátttakendur (meðalaldur: 80,8 ár±7,1ár; spönn 70-92) voru 37 óstöðugir eldri einstaklingar með sögu um byltur. Þjálfunartímar voru átján undir handleiðslu sjúkraþjálfara. Mælingar voru gerðar fyrir og eftir skynörvandi jafnvægisþjálfun. Jafnvægisstjórnun var metin með skynúrvinnsluprófi, gönguhraði var metinn með 30 metra göngu með snúningi, starfrænn styrkur í neðri útlimum var metinn með fimm sinnum standa-sitja prófi, stigafærni með tímatöku við að ganga upp og niður 11 þrep og öryggi við daglegar athafnir var metið með ABC sjálfsmatskvarða jafnvægis. Fjöldi byltna var skráður tólf mánuðum fyrir þjálfun, á þjálfunartímabilinu og sex mánuðum eftir að því lauk.

Vísindagrein II var samanburðarrannsókn með 98 þátttakendum, 50-75 ára, sem leituðu á bráðamóttöku Landspítala í kjölfar byltu og greindust með úlnliðsbrot. Í samanburðarhópi voru 48 heilbrigðir einstaklingar án sögu um úlnliðsbrot. Pörun var gerð m.t.t. aldurs, kyns og hreyfingar síðastliðna tólf mánuði. Starfsemi jafnvægiskerfis innra eyra var metin með höfuð-skak prófi (Head-Shake Test). Þrýstingsskyn undir iljum var metið með Semmes-

Weinstein einþráðum (Semmes-Weinstein monofilaments), titringsskyn í fótum var metið með titringsskynmæli (biothesiometer) og tónkvísl. Jafnvægisstjórnun var metin með skynúrvinnsluprófi. Starfrænn styrkur í neðri útlimum var metinn með fimm sinnum standa-sitja prófi og gönguhraði með 10 metra gönguprófi. ABC sjálfsmatskvarði jafnvægis og DHI svimakvarði voru notaðir til að meta eigin upplifun þátttakenda á öryggi og svima í daglegu lífi.

Vísindagrein III var slembuð samanburðarrannsókn. Níutíu og átta einstaklingar (meðalaldur: 61,9 ár±7,1ár; spönn 50-75) sem hlotið höfðu úlnliðsbrot við byltu, tóku þátt í rannsókninni, tveimur til fimm mánuðum eftir brotið. Þeim var slembiraðað í annað hvort skynörvandi jafnvægisþjálfun eða stöðugleikaþjálfun fyrir úlnlið, til viðbótar við hefðbundna brotameðferð. Mælingar voru gerðar fyrir og eftir þjálfun. Starfsemi jafnvægiskerfis innra eyra var metin með höfuð-skak prófi og höfuð-rykkja prófi (video-Head Impuls Test). Skyn í fótum var metið með Semmes-Weinstein einþráðum og titringsskynmæli. Jafnvægisstjórnun var metin með skynúrvinnsluprófi, gönguhraði með 10 metra gönguprófi og starfrænn styrkur í neðri útlimum með fimm sinnum standa-sitja prófi. ABC sjálfsmatskvarði jafnvægis og DHI svimakvarði voru notaðir til að meta eigin upplifun þátttakenda á öryggi og svima í daglegu lífi. Þátttakendur í báðum hópum, fengu skriflegar heimaæfingar og mættu í sex þjálfunartíma undir handleiðslu sjúkraþjálfara í þrjá mánuði.

Niðurstöður: Vísindagrein I: Marktækar framfarir komu fram í öllum mældum breytum eftir skynörvandi jafnvægisþjálfunina ($p<0.001$). Þrjátíu og fjórir þátttakendur höfðu hlotið 159 byltur síðustu tólf mánuði fyrir upphaf þjálfunar, sex tilkynntu 7 byltur á þjálfunartímabilinu og sjö tilkynntu 17 byltur hálfu ári eftir að þjálfun lauk.

Vísindagrein II: Þeir sem höfðu dottið og úlnliðsbrotnað voru með marktækt fleiri byltur ($p<0.001$) og beinbrot ($p<0.001$) að baki en þeir sem ekki höfðu hlotið úlnliðsbrot við byltu. Tíðni ósamhverfrar starfsemi í jafnvægiskerfi innra eyra ($p=0.012$), þrýstingsskyn undir iljum ($p<0.001$), jafnvægisstjórnun ($p<0.001$), gönguhraði ($p<0.001$) og styrkur í fótum ($p<0.001$) var jafnframt marktækt verri hjá fólki með úlnliðsbrot. Einnig upplifðu þeir sem höfðu úlnliðsbrotnað marktækt meiri svima ($p=0.005$), óstöðugleika og óöryggi ($p<0.001$) við daglegar athafnir. Þeir þættir sem spáðu sterkast fyrir um líkur þess að tilheyra hópnum sem hafði úlnliðsbrotnað, voru ósamhverf starfsemi í jafnvægiskerfi innra eyra (OR: 5.424; $p=0.008$) og skerðing á þrýstingsskyni undir iljum (OR: 3.886; $p=0.014$).

Vísindagrein III: Í skynþjálfunarhópnum minnkaði ósamhverf starfsemi í jafnvægiskerfi innra eyra um 16% en náði ekki marktækni ($p=0.058$). Engin

breyting kom fram hjá þeim sem tóku þátt í stöðugleikaþjálfun fyrir úlnlið. Eftir að leiðrétt hafði verið fyrir upphafsmælingum, aldri og kyni með línulegri aðhvarfgreiningu, kom í ljós marktækur munur á milli þjálfunarhópanna á skynúrvinnsluprófi (p=0.01), skynþjálfunarhópnum í vil, en ekki í öðrum breytum. Undirgreining gagna meðal þátttakenda sem skoruðu undir aldurstengdum viðmiðunarmörkum á skynúrvinnsluprófi við upphaf þjálfunar, gaf til kynna að skynþjálfunin bætti meira 10 metra göngupróf, (p=0.04), fimm sinnum standa-sitja próf (p=0.04), þrýstingsskyn undir iljum (Semmes-Weinstein einþræðir) (p=0.04) og skynúrvinnslupróf (p=0.04) heldur en úlnliðsþjálfunin.

Ályktanir: Skynörvandi jafnvægisþjálfun bætir jafnvægi, starfræna færni, og öryggi við daglegar athafnir á meðal óstöðugra aldraðra einstaklinga. Niðurstöður gefa til kynna að skynþjálfunin geti fækkað byltum hjá óstöðugum eldri einstaklingum. Þjálfunin bætir jafnvægisstjórnun hjá 50-75 ára einstaklingum sem hlotið hafa úlnliðsbrot við byltu, sérstaklega hjá þeim sem eru með jafnvægisstjórnun undir aldurstengdum viðmiðunarmörkum á skynúrvinnsluprófi við upphaf þjálfunar.

Fólk sem hefur úlnliðsbrotnað við byltu er með hærri tíðni ósamhverfrar starfsemi í jafnvægiskerfi innra eyra, minnkað þrýstingsskyn undir iljum og verri jafnvægisstjórnun, samanborið við jafnaldra sem ekki hafa dottið og úlnliðsbrotnað. Ósamhverf starfsemi jafnvægiskerfis innra eyra og skerðing á þrýstingsskyni undir iljum geta verið mikilvægir undirliggjandi orsakaþættir byltna sem leiða af sér úlnliðsbrot. Meta ætti áhættu fyrir frekari byltum og brotum hjá einstaklingum sem hlotið hafa úlnliðsbrot við byltu og fræðsla um byltuvarnir ætti að standa þeim til boða.

Lykilorð:

Jafnvægisstjórnun, ósamhverf starfsemi í jafnvægiskerfi innra eyra, þrýstingsskyn undir iljum, úlnliðsbrot, byltuvarnir, endurhæfing.

Abstract

Aims: The aim of this thesis was to evaluate the effects of a new multi-sensory balance training program: the "Reykjavik Model" among unsteady older adults as well as middle aged and elderly people with wrist fractures. Additionally, to explore the characteristics of the people with wrist fractures. Three papers are included in this thesis. The more specific aims were:

Paper I: To evaluate the effects of the "Reykjavik Model" on postural control, functional abilities, confidence in activities of daily living and falls among unsteady older adults.

Paper II: To investigate vestibular function, mechanoreceptive sensation in lower limbs, postural control, functional abilities, perceived dizziness and confidence in individuals between 50 and 75 years of age with and without fall-related wrist fractures and to evaluate whether these variables are independently associated with having sustained a fall-related wrist fracture.

Paper III: To investigate whether "the Reykjavik Model" improves postural control, vestibular function, foot sensation and functional abilities among people with fall-related wrist fractures compared with wrist stabilization training.

Methods: Paper I was a quasi-experimental intervention study with pre- and post-test design. Participants were 37 unsteady older adults with a history of falls. Treatment consisted of eighteen multi-sensory balance training sessions (MST) supervised by a physiotherapist. Measurements before and after training were: The Sensory Organization Test (SOT) to assess postural control, the Five-Times-Sit-to-Stand Test (FTSTS) to measure lower limb strength, 30-m normal and fast walk with a turn to measure walking speed, Ascending-Descending 11 steps to assess proficiency in stairs and the Activities-specific Balance Confidence Scale (ABC) to assess confidence during daily activities. Information was gathered about number of falls one year prior to training, during training and six months after completion of training.

Paper II was a case-control study with 98 persons aged 50-75 years, having sustained a fall-related wrist fracture. Forty-eight sex, age and physical activity matched individuals, without previous history of wrist fractures, served as controls. Measurements included: Head-Shake test (HST) to measure function of the vestibular system, Tuning fork, Biothesiometer (BT) and Semmes-Weinstein monofilaments (SWM), to measure sensation in feet, SOT to assess postural control, FTSTS to assess lower limb strength, 10-meter-walk test (10MWT) to measure walking speed, the ABC and the Dizziness Handicap Inventory (DHI) scales to assess self perceived confidence and dizziness during daily activities.

Paper III was a randomized controlled intervention study. Ninety-eight participants, age 50-75 years, were randomized to multi-sensory (MST) or wrist stabilization training (WT). Treatment consisted of six training sessions supervised by a physiotherapist and daily home exercises for both groups. Results from: HST, video-Head Impulse Test (vHIT), SWM, BT, SOT, 10 MWT, FTSTS, ABC and DHI were compared before and after training.

Results: In Paper I significant improvement was observed in all measured parameters ($p<0.001$) post-training. The people aged between 70 and 92 years (mean age 80.8 years), had several comorbidities. Thirty-four of them reported 159 falls in the year prior to the study. Six persons reported 7 falls during the training period and seven reported 17 falls in the six months follow-up period.

In Paper II The wrist fracture people had sustained a significantly higher number of previous falls ($p<0.001$) and fractures ($p<0.001$) than controls. Vestibular asymmetry was apparent in 82% of wrist fracture people and 63% of controls ($p=0.012$). Plantar pressure sensation ($p<0.001$), SOT composite scores ($p<0.001$), 10MWT ($p<0.001$), FTSTS ($p<0.001$), ABC ($p<0.001$) and DHI ($p=0.005$) were significantly poorer among cases than controls. The strongest predictors of a fall-related wrist fracture were a positive HST (OR: 5.424; $p=0.008$) and SWF sensation (OR: 3.886; $p=0.014$).

In Paper III there was a 16% non-significant ($p=0.058$) reduction in asymmetric vestibular function (HST) in the MST group but no change in the WT group. There were significant endpoint differences in SOT ($p=0.01$) between the two groups, in favour of the MST group, but no changes were seen in other outcome variables. Subgroup analysis with participants below normal baseline SOT composite scores indicated that the MST was more effective in improving 10MWT fast ($p=0.04$), FTSTS ($p=0.04$), SWM ($p=0.04$) and SOT scores ($p=0.04$) than the WT.

Conclusions: The multi-sensory balance training program, the “Reykjavik Model”, improves postural control, functional ability and confidence in ADL among unsteady older people. The results suggest that this multi-sensory balance training program can reduce the rate of falls among older unsteady individuals. The program improves postural control among people age 50-75 years who have sustained a fall-related wrist fracture, especially those with balance scores below age related norms on the sensory organization test.

People with wrist fracture have a higher incidence of asymmetric vestibular function, reduced plantar pressure sensation and poorer standing and dynamic postural control compared with matched controls. Asymmetric vestibular function and reduced plantar pressure sensation are strongly associated with a fall-related wrist fracture and could be important contributing factors to falls and subsequent wrist fractures among the ageing population. People who sustain a wrist fracture should be screened for fall and fracture risk besides fracture treatment and education regarding fall-prevention should be provided to all persons who fracture their wrist.

Keywords:

Postural control, vestibular-asymmetry, plantar sensation, wrist fracture, fall-prevention, rehabilitation.

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Contents

List of abbreviations

ABC	Activities-specific Balance Confidence
BPPV	Benign Paroxysmal Positional Vertigo
BT	Biothesiometer
CNS	The Central Nervous System
DHI	Dizziness Handicap Inventory Scale
FTSTS	Five-Times-Sit-to-Stand Test
HST	Head-Shake Test
MDC	Minimal Detectable Change
OKN	Optokinetic Nystagmus
PBT	Perturbation-based Balance Training
LUH	Landspítali – The National University Hospital
MST	The Multi-Sensory Training
SOT	Sensory Organization Test
SWM	Semmes-Weinstein-Monofilament
vHIT	Video-Head Impulse Test
VOR	Vestibulo-Ocular Reflex
WT	Wrist Stabilization Training
10MWT	Ten-Meter-Walk-Test

List of figures

List of tables

List of original papers

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals (I-III):

I. Kristinsdottir E. K., Baldursdottir B. (2014). Effect of multi-sensory balance training for unsteady elderly people: pilot study of the "Reykjavik Model". *Disabil Rehabil,* 36(14):1211-8.

II. Baldursdottir B., Petersen H., Jonsson P. V., Mogensen B., Whitney S. L., Ramel A. & Kristinsdottir E. K. (2018). Sensory impairments and wrist fractures: A case-control study. *J Rehabil Med,* 50(2):209-215.

III. Baldursdottir B., Whitney S. L., Ramel A., Jonsson P. V., Mogensen B., Petersen H. & Kristinsdottir E. K. (2019). Multi-sensory training and wrist fractures: A randomized controlled trial. *Aging Clin Exp Res.* doi.org/10.1007/s40520-019-01143-4

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Declaration of contribution

I designed the multi-sensory balance training method the “Reykjavik Model” described in this thesis, together with Ella K. Kristinsdóttir. I took part in all parts of planning and performance of the studies in this thesis. This includes preparation of protocols, applications for the necessary permissions and funding, preparation of the balance laboratory, enrollment of patients and data collection. I supervised the multi-sensory balance training (MST) in Paper I and directed the training in Paper III. I conducted measurements in Paper II and III. I collected the data and performed the statistical analysis described in all the Papers. I participated in drawing conclusions, wrote the drafts of Paper I, II and III, participated in all subsequent revisions and prepared the final manuscripts for submission.

1 Introduction

1.1 Instability falls and fractures

Postural instability and falls are a major health concern associated with increasing age. About one-third of all people over 65 years of age sustain a fall each year and the likelihood of falling doubles every five years with advancing age (AFAR & Alliance for Aging Research, 1995, Morrison, Fan, Sen, & Weisenfluh, 2013; Stevens, Mack, Paulozzi, & Ballesteros, 2008).

Injuries and fractures are common consequences of falls (Jonsson, Siggeirsdottir, Mogensen, Sigvaldason, & Sigurdsson, 2004; Kannus et al., 1999). Moderate to severe injuries are sustained by 20 to 30% of people who fall. These can range from lacerations to fractures and traumatic brain injuries (Sterling, O'Connor, & Bonadies, 2001). Consequently, sufferers of falls may lose independence in activities of daily living and develop fear of falling (Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij, 2008). Fear of falling can result in self-restricted activity levels and has shown to be an independent predictor of decline in physical function and risk of further falls (Deshpande et al., 2008).

It is well established that previous fracture is associated with a significantly increased risk of a fracture later in life (Jonsson, Siggeirsdottir, Mogensen, Sigvaldason, & Sigurdsson, 2004; Klotzbuecher, Ross, Landsman, Abbott, & Berger, 2000). Wrist fracture (distal forearm fracture) is the most common first fracture among Icelandic women, with a sharp increase in incidence between 45 and 60 years of age and is the third most common first fracture among men (Siggeirsdottir, Aspelund, Jonsson, et al., 2014). The incidence of wrist fractures increases progressively with age and varies from 0.85 (age 50-54 years) to 14.38 (85-89 years) per 1000 people each year according to published studies (Kanis et al., 2000; Karl, Olson, & Rosenwasser, 2015; Siggeirsdottir, Aspelund, Johansson, et al., 2014). Age-specific male to female ratios has been reported as 1:4.8 (Siggeirsdottir, Aspelund, Johansson, et al., 2014). A wrist fracture has been reported to be a strong predictor of future fracture risk (Cuddihy, Gabriel, Crowson, O'Fallon, & Melton, 1999; Endres et al., 2006; Schousboe et al., 2005) and is often precursor to the more serious hip fracture (Johnson et al., 2017; H. Mallmin et al., 1993). A hip fracture can lead to reduced quality of life, increased health cost and even death (Autier et al., 2000; Braithwaite, Col, & Wong, 2003; Kannus, Parkkari, Niemi, & Palvanen, 2005).

The mean age of people who sustain a hip fracture is 80-84 years and approximately 70% are women (Diamantopoulos, Hoff, Skoie, Hochberg, & Haugeberg, 2013; Lund, Moller, Wetterslev, & Lundstrom, 2014; Magnusson et al., 2016; Mundi, Pindiprolu, Simunovic, & Bhandari, 2014). Hip fractures in older adults have been associated with decreased ability to perform activities of daily living (Dolan et al., 2000), fewer live in their own home post fracture (Magnusson et al., 2016), and the probability of requiring long-term nursing home care increases (Magnusson et al., 2016; Tajeu et al., 2014). Mortality one year after a hip fracture among people 60 years and older in Iceland has been reported to be 27%. This mortality rate is eight times higher on average than among the general population of the same age in Iceland (Magnusson et al., 2016). Mortality one year after a hip fracture has been found to be 21 to 30% in other countries (Diamantopoulos et al., 2013; Lund et al., 2014; Mundi et al., 2014). Thus, hip fractures cause serious disruption to people's lives and provide socioeconomic challenges for society.

1.2 Postural control

The human upright standing position is biomechanically unstable. The base of support provided by the feet is relatively small and the centre of body mass, levelled with the upper part of sacrum, is situated high above it. The line of gravity passes through the cervical and lumbar spine and hip joints but is situated in front of the atlanto-occipital joints, the thoracic spine, knee and ankle joints (Williams 1995). Thus, the head tends to rotate forwards on the cervical spine and the whole body forwards around the ankle joints. To work against these gravitational forces and withhold the upright position, several muscles, especially the gastrocnemius and the soleus, work continuously during standing (Kleiber, Horstmann, & Dietz, 1990). Small corrective movements, mainly sway around the ankles, are thus produced to adjust posture and maintain stability (Andreasen & Böjsen-Möller, 1982).

The maintenance of upright posture is dependent on sufficient and coherent sensory information from the somatosensory system, vision and the vestibular system (H. Diener & Dichgans, 1988). The Central Nervous System (CNS) integrates and processes this multi-sensory information in order to evaluate position and movements of the body. The CNS generates and coordinates multiple motor outputs to muscles for postural adjustments and movements (Massion, 1994; Nashner & McCollum, 1985). This happens throughout an on-going mechanism, which includes corrective feed-forward (predictive) and feedback (reactive) movement control system (Massion, 1992; Alexandrov et al., 2005), see Figure 1.

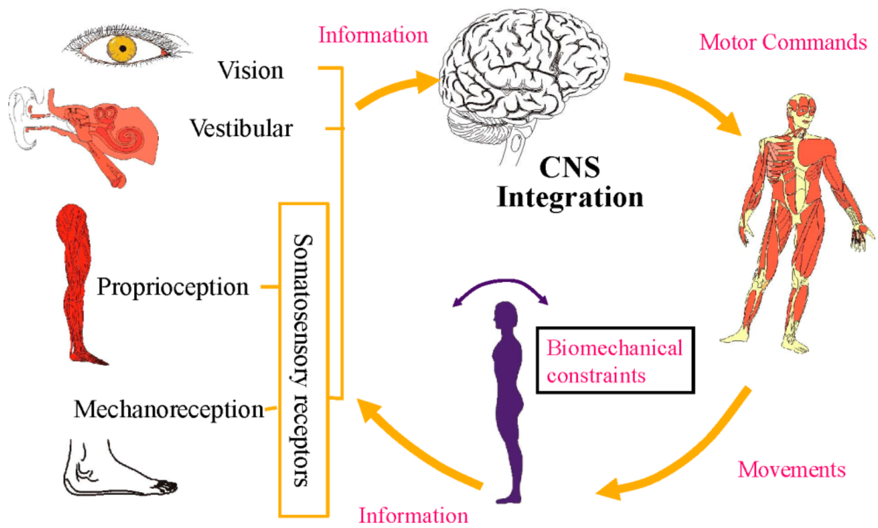

Figure 1. Human postural control.

1.2.1 The Somatosensory receptor system

The somatosensory system has a major role in the control of posture and consists of two special types of receptors, proprioceptors and mechanoreceptors.

Proprioceptors provide information about joint position and body movement. They are found in muscles, tendons and in and near joint capsules. They consist of muscle spindles, Golgi tendon organs and joint receptors. Information from the proprioceptors are of utmost importance for coordination and grading of muscular contraction and maintenance of stability (Williams, 1995).

Mechanoreceptors, located at various depths in the skin, sense pressure and forces acting on the skin. Mechanoreceptors in the soles of the feet are divided into slowly adapting (Ruffini corpuscles and Merkels disk receptors) and rapidly adapting (Pacinian and Meissner´s corpuscles) mechanoreceptors (Inglis, Kennedy, Wells, & Chua, 2002). Slowly adapting mechanoreceptors sense touch, pressure and stretch of the skin, and are most likely involved in the continuous activities of postural control, sensing movement below the frequency of 5 Hz (Vedel & Roll, 1982). Rapidly adapting mechanoreceptors detect touch and vibration of the skin and the swift changes of movement needed for the control of posture (Inglis, Horak, Shupert, & Jones-Rycewicz, 1994). These mechanoreceptors provide important information about weight distribution on the soles of the feet and can supplement joint position sense and movement detection, which is of particular importance for postural stability (Kennedy & Inglis, 2002; Maurer, Mergner, Bolha, & Hlavacka, 2001).

The somatosensory receptors in the neck are also importance for postural control. They provide information about the position of the head relatively to the trunk and the CNS uses this information to integrate vestibular information with the motions of the entire body (Mergner, Huber, & Becker, 1997).

1.2.2 The Vestibular System

The vestibular organs in the inner ears are adapted to sense motion and position of the head in space. They are anatomically and physiologically separated into the semicircular canals and otolith organs (Guyton, 1981). The three semicircular canals are arranged in three different planes, at approximate right angle to each other. They record angular acceleration of the head in every direction (Harada, 1983). The otolith organs consist of the two sensory organs termed maculae, one situated in the utriculus and the other in the sacculus. This system is sensitive to tilt of the head with respect to gravity and linear acceleration and deceleration (Jaeger & Haslwanter, 2004). The vestibular nerve transmits the information to the vestibular nuclei. There are widespread connections from the nuclei, to the different parts of the CNS. Most important for postural control are connections to the muscles of the eyes, neck, trunk and limbs via vestibulo-ocular reflexes and vestibulo-spinal tracts. The vestibulo-ocular reflex helps to maintain visual fixation during movements of the head, by producing compensatory short latency eye rotations. Vestibulo-spinal reflexes stabilize the head and help keep an upright posture and prevent falling, by generating muscle activity in the neck, trunk and limbs (Brodal, 1998; Kandel, 1991). The vestibular organs also contribute to the estimation of the internal representation of body vertical (Hlavacka, Mergner, & Krizkova, 1996) and mental representation of position in space (Karnath, Fetter, & Dichgans, 1996).

1.2.3 The Visual System and control of eye movements

Vision provides information which enables the individual to make a conscious analysis of the surroundings and predict the possible effect of any hindrance in the light of previous experience (Enbom, 1990). Visual information is of importance, but in regulating standing postural control, it is not essential (H. C. Diener, Dichgans, Guschlbauer, & Bacher, 1986).

Movement of the visual environment relative to the eyes causes a slip of image on the retina. This triggers compensatory eye movements to keep focus on the moving object. A movement of the object out of or near the field of vision may cause an optokinetic nystagmus reflex movement of the eye (OKN) (Magnusson, 1986). During movements of the head the vestibulo-ocular reflex (VOR) facilitates a compensatory movement of the eyes in the opposite direction. The vestibulo-ocular reflex and the optokinetic reflex co-operate to keep the moving visual image on the retina during movements of the head (Magnusson, 1986).

1.2.4 Sensory Integration and the Central Nervous System

The CNS integrates and processes information from the different receptor systems, which are involved in maintaining balance. Information from the somatosensory, vestibular and visual systems is coordinated at different levels in the CNS. Information from the vestibular organs and somatosensory receptors interact in the brainstem and the spinal cord, affecting muscles reflexes and movements (Fanardjian & Sarkisian, 1988; Wilson, 1988).

Afferent information from vision, somatosensory and vestibular receptors unite with the output signals generated in the motor cortex in the cerebellum. The primary task of the cerebellum, mainly through a feed-back mechanism, is to control the smoothness and precision of on-going movements (Robinson, 1995). The cerebellum is also involved in the planning, learning and coordination of movement tasks, as well as in controlling the gain of various reflexes, such as the vestibulo-spinal and vestibular-ocular reflexes (Robinson, 1995; Jankowska, 1989; Arshavsky & Orlovsky, 1986). These responses are learned and stored through repetition.

Most motor responses need neural activity at several anatomic levels. These include the brainstem, spinal cord and cerebellum, as well as cerebral cortex and basal ganglia (Fanardjian & Sarkisian, 1988; Wolpaw, 1994).

The basal ganglia are important in the planning, initiation and control of motor programs. Via the pyramidal nerve pathways, motor activities, initiating in the primary motor cortex, are transmitted to the skeletal muscles. Both the cerebellum and the basal ganglia use the motor structures of the brain stem and the motor cortex to execute their outputs (Zarzecki & Asanuma, 1979).

Anticipatory postural adjustments act to stabilize the supporting body segments prior to movement, such as during step initiation (Massion 1992). The supplementary motor area has been shown to contribute to generating the amplitude and timing of anticipatory postural adjustments (Jacobs, Lou, Kraakevik and Horak, 2009). Somatosensory information from a fingertip has been shown to be useful in a feed-forward manner to trigger activation of postural muscles for controlling body sway (Dickstein, Shupert & Horak, 2001).

Thus, the CNS deals with body perturbations through implementation of two main strategies: Feed-forward (anticipatory) postural adjustments control the position of the center of body mass by activating the trunk and leg muscles prior to a forthcoming body perturbation, thus minimizing the danger of losing equilibrium (Massion 1992). Feedback, compensatory postural adjustments are initiated by the sensory feedback signals and serve as a mechanism of restoration of the position of the centre of mass after a perturbation has already occurred (Alexandrov et al., 2005).

1.3 Age-related degenerative changes and imbalance

All domains involved in postural control, are affected by age related degenerative changes, which become apparent between the ages of 40 and 50 years (Keller & Engelhardt, 2013; Magnusson & Pyykko, 1986; Park, Tang, Lopez, & Ishiyama, 2001) and accumulate exponentially with age.

Plantar pressure sensation deteriorates with increasing age (Rinkel et al., 2017), as well as vibration perception (Wells, Ward, Chua, & Inglis, 2003; Wiles, Pearce, Rice, & Mitchell, 1991) and proprioception in the lower limbs (Kaplan, Nixon, Reitz, Rindfleish, & Tucker, 1985; Skinner, Barrack, & Cook, 1984). Reduced tactile sensitivity (plantar pressure sensation) has been associated with reduced postural performance and increased postural sway in older adults (Dettmer, Pourmoghaddam, Lee, & Layne, 2016; Peters, McKeown, Carpenter, & Inglis, 2016). Compensatory stepping reactions to sudden postural perturbations have shown to be affected by reduced plantar support information (Perry, McIlroy, & Maki, 2000). Decreased vibration sensation in the legs has been connected with increased postural sway among healthy older adults (Kristinsdottir, Jarnlo, & Magnusson, 1997). Impairment in vibration sense at the knee has been related to impaired walking ability and a tendency to fall in a population of older people (Stephen R. Lord, Lloyd, & Li, 1996).

Common to nearly all types of vestibular cells is a significant age-related degeneration, although the onset and rate of decline is to some extent disputed in published studies (Zalewski, 2015). These include the sensory end organ hair cells (Rauch, Velazquez-Villasenor, Dimitri, & Merchant, 2001), the nerve fibres (Bergström, 1973), Scarpa ganglion cells (Park et al., 2001), vestibular nucleus neurons (Tang, Lopez, & Baloh, 2001-2002), and even a significant decline in the number of Purkinje cells within the cerebellum (T. C. Hall, Miller, & Corsellis, 1975). Age-related degenerative changes in the vestibular organs affect control of posture significantly, especially if these occur with an asymmetry (Kristinsdottir, Fransson, & Magnusson, 2001). An association of vestibular asymmetry with falls and wrist fracture (Hansson, Dahlberg, & Magnusson, 2015; Kristinsdottir, Nordell, et al., 2001) as well as hip fractures (Kristinsdottir, Jarnlo, & Magnusson, 2000) has been reported.

As a part of the ageing process muscle mass decreases, mainly due to loss of type II muscle fibres, leading to a reduction in strength and rapid force production (Harbo, Brincks, & Andersen, 2012; Keller & Engelhardt, 2013; Vandervoort, 2002). Age-related changes in muscle strength and power are particularly evident in the lower extremities (Menz, 2015) and have consistently been identified as risk factors for falls and injuries related to them (Benichou & Lord, 2016).

Age-related changes are also apparent in the central and peripheral nervous system. There is a loss of nerve cells with atrophy of the brain (Henderson, Tomlinson, & Gibson, 1980; Meier-Ruge, Ulrich, Bruhlmann, & Meier, 1992; Walhovd et al., 2005). Motor neuron populations in the spinal cord decreases (Tomlinson & Irving, 1977) and conduction time from the spinal cord to muscles increases (Rossini, Desiato, & Caramia, 1992). Slow reaction time (Stephen R. Lord et al., 1996) and impaired central integration in the brain stem (Perrin, Jeandel, Perrin, & Bene, 1997) have been related to postural imbalance and falls. In addition to the constant decline in sensory function with age, loss of cognitive/executive function leads to problems in sensorimotor processing (Sturnieks, St George, & Lord, 2008).

Gait tends to change with age. There is a reduction in speed, steps become shorter and wider with relatively longer time spent in the double-support phase. These spatiotemporal gait patterns are more common in fallers compared to non-fallers (Sturnieks et al., 2008). Alterations in locomotion pattern have been associated with peripheral sensory loss among patients with neuropathy (Wuehr et al., 2014) and among older adults with asymmetric vestibular function (Larsson, Miller, & Hansson, 2016).

Several medical ailments like eye pathologies such as macular degeneration, glaucoma and cataracts (Kahn et al., 1977), benign paroxysmal positional vertigo (BPPV) (Ribeiro et al., 2018) and diabetic peripheral neuropathy (Mustapa, Justine, Mohd Mustafah, Jamil, & Manaf, 2016) become more prevalent with increased age and contribute to deficits in postural control. Whatever the cause, when elements of sensory, motor or central processing systems are inadequate, there is a greater reliance on the remaining systems with increased postural control challenges.

According to previous studies, sensation, strength and physical function decrease with age (Keller & Engelhardt, 2013; Rinkel et al., 2017; Wells et al., 2003; Xie, Liu, Anson, & Agrawal, 2017; Zalewski, 2015). However, it is not clear whether these age-related degenerative changes have started to have clinical impact on balance between 50 and 75 years of age.

1.4 Training and postural control

Diverse training methods have been used to improve postural stability and decrease the rate of falls. According to a meta-analysis, balance training as a single intervention can prevent falls (Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011) and fall-preventive exercise programs for older adults seem to prevent injuries caused by falls and reduce the number of falls resulting in hospitalisation or other medical care (El-Khoury, Cassou, Charles, & Dargent-Molina, 2013). However it is difficult to determine the most effective training procedure, as the programs differ in content and some trials include a mixture of different types of exercises (Alfieri et al., 2012; Herdman, 2013; Howe, Rochester, Neil, Skelton, & Ballinger, 2011; Nitz & Choy, 2004).

Both conventional and enhanced balance training have been reported to improve functional balance and mobility in unstable individuals, independent of strategy (Steadman, Donaldson, & Kalra, 2003). Their conventional therapy consisted of functional activities, such as walking, stair practice and transfers, without progressive grading in complexity. The enhanced therapy additionally included a sequence of graded activities specific to functional balance. So far, the core of conventional balance training consists of static and dynamic exercises, performed on stable and unstable surfaces, standing on one or both legs with eyes open or closed (Granacher, Muehlbauer, Zahner, Gollhofer, & Kressig, 2011).

Emphasis has been placed on increasing muscle strength and power to increase functional performance and prevent falls in older adults (Orr, 2010; Pamukoff et al., 2014). Progressive resistance training, has not, as an isolated intervention, consistently improved balance performance in older adults (Alfieri, Riberto, et al., 2010; Orr, Raymond, & Fiatarone Singh, 2008) although there is some evidence of a relationship between muscle strength and balance performance (Orr, 2010).

Multisensory exercises are characteristically defined as exercises that stimulate all the three afferent sensory systems including the vestibular, visual and somatosensory pathways. Training directed at improving function of the sensory systems has reduced body sway (Alfieri, de Jesus Guirro, & Teodori, 2010; Alfieri et al., 2012) and improved functional mobility in older adults living in the community (Alfieri, Riberto, et al., 2010).

Vestibular rehabilitation is an exercise program widely used for people with peripheral and central vestibular disorders (Whitney, Alghwiri, & Alghadir, 2016). It was designed to adapt the gain of the vestibulo-ocular reflex, habituate the individual to movements, teach sensory substitution as well as to improve postural control (Whitney & Rossi, 2000). A growing number of studies have reported a positive effect of vestibular rehabilitation in reducing symptoms of dizziness and enhancing postural control in a variety of conditions (Clendaniel, 2010; Halmagyi, Weber, & Curthoys, 2010; Herdman, Hall, Schubert, Das, & Tusa, 2007; Jung, Kim, Chung, Woo, & Rhee, 2009; Mohammad, Whitney, Sparto, Jennings, & Furman, 2010; Suarez et al., 2003).

Balance training during dual- and multi-task conditions consists of exercises where motor and cognitive tasks are performed simultaneously. The purpose of a dual-task is to direct the attention of the performer towards another assignment (e.g. a cognitive challenge such as counting backwards, random letter generation tasks, or a manual task such as carrying an item), while performing a primary postural task (Halvarsson, Dohrn, & Stahle, 2015). Dual task training has been shown to improve physical function and decrease fear of falling among older adults in the community (Halvarsson, Franzen, & Stahle, 2015). There is clear evidence, according to a recent meta-analysis, for a positive effect of dual-task training for improving postural stability among older adults at risk for falling and in individuals affected by stroke (Ghai, Ghai, & Effenberg, 2017).

Perturbation based balance training consists of repeated postural perturbations, which are aimed at improving control of rapid balance reactions. Perturbation based balance training appears to decrease the rate of falling among older adults and individuals with Parkinson's disease (Mansfield, Wong, Bryce, Knorr, & Patterson, 2015) and has shown to improve reactive balance recovery among healthy adults (Krause et al., 2018).

Findings of a systematic review indicate that task specific exercises of increasing complexity are more efficient in promoting balance recovery and improving postural stability than general nonspecific exercises (Granacher et al., 2011). According to findings in a meta-analysis, up to 42% of falls can be prevented by well designed exercise programs and the more challenging the exercises are for the control of balance, the greater the reduction in fall rates (Sherrington et al., 2008).

1.4.1 Multi-Sensory Training – the "Reykjavik Model"

Research carried out by Kristinsdottir and colleagues (Kristinsdottir, Fransson, et al., 2001; Kristinsdottir et al., 1997) revealed that older adults with decreased vibration sensation in lower limbs had increased vibration-induced postural sway and unfavourable postural strategies compared with those with good vibration sensation. The older people with decreased vibration sensation showed a decreased ability to readjust their posture with smooth corrective motions at the ankles and used high frequency movements at the hips and upper body instead. During vibration stimulation to the calf muscles, lasting only 205 seconds postural sway gradually decreased among the individuals. Thus, to a certain extent they learnt to adapt their postural control responses with regards to the stimulation. These results lead to the idea that targeted sensory training might improve the use of mechano- and proprioceptive impulses resulting in more efficient control of posture.

Age-related degenerative changes in the vestibular organs affect control of posture especially if these occur with an asymmetry (Kristinsdottir et al., 2000; Kristinsdottir, Nordell, et al., 2001). Asymmetrical vestibular function was found amongst 37% of healthy older adults who had not sustained a fracture. In contrast, vestibular asymmetry was seen in 68% of those post hip fracture and 76% of the people post wrist fracture. Vestibular asymmetry may interfere with movements related to falls prevention, with some authors suggesting that movements become smaller or distorted leading to increased danger of falling in connection with head movements (Allum, Carpenter, Honegger, Adkin, & Bloem, 2002; Vidal, de Waele, Baudonniere, Lepecq, & Ba Huy, 1999). Vestibular asymmetry, falls, and fractures seem to be related. It is unclear if a falls prevention program in persons with vestibular disorders can improve postural control and decrease the danger of falling.

Based on the above-mentioned research a new targeted multi-sensory balance training method, consisting of combined mechano- and proprioceptive, vestibular and fall-prevention training was initiated at the Department of Geriatrics at Landspitali University Hospital, Reykjavik, Iceland to improve postural control and prevent falls. This training method has been named the "Reykjavik Model".

2 Aims

The primary aim of this thesis was to evaluate the effects of the "Reykjavik Model" among unsteady older adults and middle aged and old people with wrist fracture. Secondly, to explore the characteristics of people with wrist fractures.

2.1 Specific aims

Paper I

To evaluate effects of combined mechano- and proprioceptive, vestibular and fall-prevention training program on postural control, functional abilities, confidence in activities of daily living (ADL) and falls among unsteady older adults.

Paper II

To investigate vestibular function mechanoreceptive sensation in lower limbs, postural control, functional abilities, perceived dizziness and confidence in individuals between 50 and 75 years of age with and without fall-related wrist fractures.

To examine the association between sensory and physical dysfunction and ageing.

To determine whether vestibular, mechanoreceptive and physical function are independently associated with having sustained a fall-related wrist fracture.

Paper III

To investigate whether multi-sensory balance training improves postural control, vestibular function, foot sensation and functional abilities among people with fall-related wrist fractures.

To investigate whether potential changes in postural control, vestibular function, foot sensation and functional abilities are affected by baseline balance control.

Hypotheses tested were:

Paper I:

- Multi-Sensory training improves postural control, increases functional abilities, confidence in activities of daily living and reduces the rate of falls among elderly individuals.

Paper II:

- Vestibular asymmetry and reduced mechanoreceptive sensation (vibration and pressure sensation) in the lower limbs is more common among individuals in the age range of 50-75 years who have sustained a fall-related wrist fracture than among those without a fall-related wrist fracture.
- Individuals aged 50-75 years, who have sustained a fall-related wrist fracture, perceive greater dizziness, have poorer postural control, poorer functional abilities and less confidence in activities of daily living than those without a history of fall-related wrist fracture.
- Sensory and physical dysfunction is associated with ageing.
- Vestibular asymmetry, decreased mechanoreceptive, and physical functioning are independently associated with having sustained a fall-related wrist fracture.

Paper III:

- Multi-sensory training improves postural control, vestibular function, sensation in the feet and functional abilities among people with fall-related wrist fractures.
- Potential changes after a multi-sensory training program are affected by baseline postural control.

3 Materials and methods

In this chapter, the study´s materials and methods are discussed. For detailed descriptions about materials and methods, refer to Papers I, II and III. Table 1 and Table 2 represent an overview of the materials and methods used in the three studies.

Table 1. Overview of the Research Designs, Settings and Samples for Papers I, II and III.

	Paper I Pilot Study	Paper II Case Control Study	Paper III Intervention Study (RCT)
Research design	Quasi-experimental intervention study, pre- and post-test design.	Case-control study.	Randomized controlled intervention study, parallel group design.
Settings	Dept. of Geriatrics at Landspitali – The National University Hospital (LUH).	Laboratory of balance, University of Iceland.	Laboratory of Balance, University of Iceland (pre- and post-measurements). Styrkur PT Clinic (MST). LUH PT Out-patient Clinic (WT).
Sample	Unsteady older adults with a history of falls. 32 females, 5 males.	Cases (n: 98): People with wrist fracture. 85 females, 13 males. Control (n: 48): Age, gender and physical activity-matched individuals without a history of wrist fracture. 38 females, 10 males.	Individuals with a fall related wrist fracture (n: 98). 85 females, 13 males.
Participants	Age 70 –92 years. Mean 80.8 years.	Age 50 –75 years. Mean 60.8 years.	Age 50 –75 years. Mean 61.9 years.
Intervention	Multi-sensory training (MST).	No intervention.	Multi-sensory training (n:38). Wrist training (n:42).
Training	Six weeks: 18 physiotherapy (PT) supervised sessions, three times a week.		12 weeks: 6 PT supervised sessions and daily home exercises for both groups. Exercise diaries.

Table 2. Overview of the Research Measures and Analysis for Papers I, II and III.

	Paper I Pilot Study	Paper II Case Control Study	Paper III Intervention Study (RCT)
Questionnaires			
Medical history		X	X
Activities-specific Balance Confidence Scale (ABC)	X	X	X
Dizziness handicap Inventory Scale (DHI)		X	X
Instrumentation and measurements			
Tuning fork	X	X	
Biothesiometer		X	X
Semmes-Weinstein monofilaments		X	X
Stepping test	X		
Video-head impulse test (vHIT)			X
Head-shake test		X	X
Sensory Organization Test	X	X	X
Five-Times-Sit-To-Stand Test	X	X	X
Normal and fast 30-m walk	X		
10-m walk test		X	X
Ascending-descending 11 steps	X		
Analysis			
	Descriptive statistics.	Descriptive statistics.	Descriptive statistics.
	Kolmogorov-Smirnov test.	Kolmogorov-Smirnov test.	Kolmogorov-Smirnov test.
	Wilcoxon signed-rank test.	Mann-Whitney *U* test.	Mann-Whitney *U* test.
	Effect size (Cohen's d statistics).	Independent sample *t*-test.	Independent sample *t*-test.
		Spearman´s rho.	Wilcoxon signed-rank test.
		Kruskal-Wallis test.	Paired sample *t*-test.
		One-way ANOVA.	Effect size (r)
		Post hoc test: LSD.	Linear models.
		Logistic regression models.	

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3.1 Design

The effects of the multi-sensory balance training method were investigated in two interventions, using a pre-test and post-test design. The first intervention was a pilot study, enrolling one exercise group (Paper I). The second intervention was a randomized controlled trial with two parallel exercise groups: 1) Intervention group with multi-sensory balance training and 2) comparison group with wrist stabilisation training (Paper III).

The clinical characteristics of individuals who had sustained a fall-related wrist fracture were compared with matched controls by using a case control design (Paper II).

3.2 Setting and participants

Participants in study I were consecutively recruited outpatients, 70-92 years of age, attending physiotherapy at the Department of Geriatrics at the Landspitali National University Hospital (LUH), Reykjavik, Iceland. They had a history of fall/falls, complained of unsteadiness and/or fear of falling, were able to stand unsupported for 2 minutes, walk 30 meters unsupported or with and aid of a stick/crutch and scored more than 21 on the Mini Mental State Examination Scale (Folstein, Folstein, & McHugh, 1975).

Participants in studies II and III were aged 50-75 years and had sustained a fall-related wrist fracture. They were identified from medical records at the emergency department of LUH. Excluded from the study were patients with a confirmed diagnosis of degenerative CNS disease, such as Parkinson´s, Alzheimer´s or other diseases possibly impairing mobility and cognitive function. A comparison group in study II was comprised of a convenience sample of healthy individuals, without a previous history of fall-related wrist fracture, matched according to age, gender and weekly physical activity level during the previous 12 months. In study III, the multi-sensory balance training was conducted in a private physiotherapy clinic and the wrist stabilisation training in an out-patient physiotherapy department at LUH.

3.3 Instrumentation and measurements

3.3.1 Questionnaires

3.3.1.1 Medical history, falls, fractures and level of physical activity

The participants in studies II and III answered a questionnaire in an electronic survey about their general health including medications, previous falls and fractures and circumstances of the fall that had caused the distal forearm fracture. They were also asked about their level of physical activity the previous 12 months. The definition of physical activity level encompassed both strenuous activities of daily living and recreation. It was grouped into three levels: less than 1 h/week, 1 to 3 h/week and 4 h/week or more. The questions used to collect information about medical history, falls, fractures and physical activity level were obtained from the AGES-Reykjavik Study Questionnaire (Harris et al., 2007), and adapted for this study (See the questions in Icelandic in Appendix 1).

3.3.1.2 Activities-specific Balance Confidence Scale (ABC)

The Activities-specific Balance Confidence Scale (ABC) was used to provide a description of fear of falling among the participants (Powell & Myers, 1995). The individuals rated their level of confidence while performing 16 activities of daily living, on a percentile scale from zero (indicating no confidence) to 100 (indicating complete confidence). Individual items ranged in difficulty from walking on level surfaces inside the home to walking outdoors on icy sidewalks. The ABC Scale has been validated in older adults (Lajoie & Gallagher, 2004; Powell & Myers, 1995), persons with vestibular disorders (Friscia, Morgan, Sparto, Furman, & Whitney, 2014; Whitney, Hudak, & Marchetti, 1999), and people who survived stroke (Botner, Miller, & Eng, 2005). (See the Icelandic version of the ABC in Appendix 2).

3.3.1.3 Dizziness handicap Inventory Scale (DHI)

Self-perceived handicap resulting from dizziness was assessed with the Dizziness Handicap Inventory Scale (DHI). The scale contains 25 items relating to physical, emotional and functional domains that cover aspects of dizziness and disequilibrium. The range of possible scores on the DHI is 0 to 100. The higher the score, the greater the level of perceived handicap caused by dizziness (Jacobson & Newman, 1990). The psychometric properties of the DHI have been examined and found to be good to excellent (Enloe & Shields, 1997; Fielder, Denholm, Lyons, & Fielder, 1996; Jacobson & Newman, 1990). (See the Icelandic version of the DHI in Appendix 3).

3.3.2 Assessment of mechanoreceptive sensation in feet

3.3.2.1 A tuning fork

A tuning fork (128 Hz) was used to assess vibration perception in the lower limbs. Sensation was graded from 1 to 3 according to the following criteria: Sensation 1: vibration detected at the base of first metatarsal bone, medial malleolus and tibial tuberosity. Sensation 2: vibration detected at the medial malleolus and tibial tuberosity. Sensation 3: vibration detected only at the tibial tuberosity (Figure 2). This method was used in accordance with other studies, on estimation of vibration sensation in the lower limbs among elderly people (Kristinsdottir, Fransson, et al., 2001; Kristinsdottir et al., 1997, 2000).

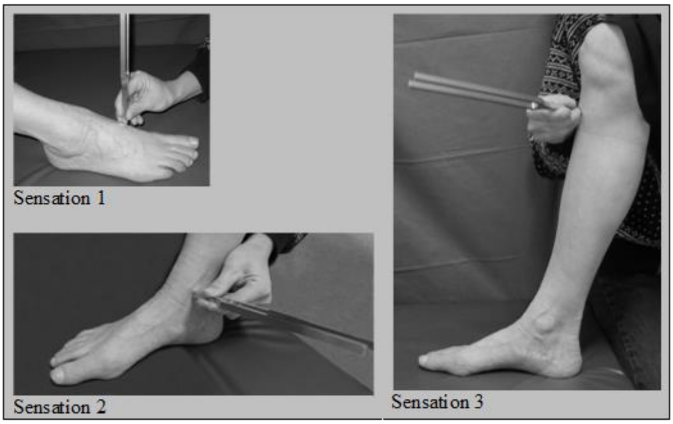

Figure 2. The three locations that the tuning fork was utilized to assess lower extremity sensation.

3.3.2.2 A biothesiometer electronic device

A biothesiometer (Model EG electronic BioThesiometer, Newbury, OH, USA) that generated a 120 Hz vibration of varying amplitude (in µm) was used to measure vibration perception on the plantar surface of the foot (Figure 3). Vibration was applied to the plantar surface of the first metatarsal bone (the base of the big toe), the fifth metatarsal bone (the base of the little toe) and the centre of the plantar surface of the heel. The participants were asked to notify the examiner whether they were could feel the vibration (yes/no) (Modig, Patel, Magnusson, & Fransson, 2012). Vibration was applied once in increasing intensity until the subject could feel the vibration and then in decreasing intensity until the subject could no longer feel the vibration. Vibration was applied again in increasing intensity until the subject could sense the vibration, which was registered as the perception threshold, in line with operational instructions from the manufacturer of the biothesiometer. The biothesiometer has been shown to have excellent reliability in testing vibration perception threshold within mild to moderate neuropathy (van Deursen et al., 2001).

Figure 3. Biothesiometer.

3.3.2.3 Semmes-Weinstein pressure aesthesiometer

Semmes-Weinstein pressure aesthesiometer (Semmes-Weinstein Mono-filaments, San Jose, CA, USA) (SWM) was used to measure tactile sensitivity (Figure 4). The aesthesiometer is composed of 20 nylon filaments of equal length, with varying diameters. The filaments were applied to the plantar surface of the same three points as the biothesiometer, and participants were instructed to report whether they felt it on the ‘‘heel.’’ ‘‘at the big toe’’, or ‘‘at the little toe’’. To determine tactile sensation threshold, suprathreshold filaments were initially presented and then thinner and thinner filaments until the subject could no longer detect them (S. R. Lord, Clark, & Webster, 1991). Then the examiner applied thicker filaments until the subject could detect them, which was determined as the touch threshold and is presented as pressure (in g). The test has demonstrated acceptable interrater and intra-rater reliability among healthy adults (Snyder, Munter, Houston, Hoch, & Hoch, 2016).

Figure 4. Semmes-Weinstein Monofilaments. Note the deflection of the monofilament during the pressure testing.

3.3.3 Vestibular function tests

3.3.3.1 Stepping test

The stepping test was used as an indicator for vestibular asymmetry (unilateral vestibular hypofunction). The participants walked 50 steps in place in bare feet, with outstretched arms and eyes closed (Fukuda, 1959). They were instructed to stay at the starting spot while stepping at a comfortable pace. Rotation relative to the initial standing position was noted. A rotation of greater than 30° suggests asymmetrical labyrinthine function, with the weaker side identified by the direction of rotation (Fukuda, 1959). Within-subject variability for the Fukuda stepping test has shown to be large which is a weakness for interpreting test-retest results of a patient in a clinical setting (Paquet, Taillon-Hobson, & Lajoie, 2014). Test-retest reliability of the stepping test has been shown to be moderate among healthy adults (Bonanni & Newton, 1998) and the authors concluded that this method should not be used alone as a screening measure for labyrinthine paresis but, rather, with other tests for the vestibular system. The stepping test has shown moderate sensitivity (50%) and specificity (61%) among patients with chronic balance disorders (Honaker, Boismier, Shepard, & Shepard, 2009) and the authors suggest its use solely as part of parallel strict test protocol (i.e. additional clinical tests are positive to suggest peripheral vestibular lesions).

3.3.3.2 Video-head impulse test

The video-head impulse test (vHIT) was used to assess the function of the horizontal semicircular canals by measuring the eye movement response to brief (about 10-20 degrees), unpredictable, passive head rotation in the plane of the lateral semicircular canals. The vHIT test was performed with a set of ICS impulse video goggles (GN Otometrics, Taastrup, Denmark), with a camera speed of 250 frames/s, recording motion of the right eye (Figure 5). Participants were seated and tested in a well-lit room with an eye-level target at a distance of one meter, which they were instructed to maintain their gaze on. Twenty passive horizontal head turns both in the right and left directions were performed. The main measure of canal adequacy is the ratio of the eye movement response to the head movement stimulus, i.e. the gain of the vestibulo-ocular reflex (VOR). The measurement of the horizontal VOR by the vHIT has previously been described in detail (MacDougall, Weber, McGarvie, Halmagyi, & Curthoys, 2009; Riska, Murnane, Akin, & Hall, 2015). The vHIT test has been demonstrated to be a valid clinical tool for testing the function of the horizontal semicircular canals and simple to use (MacDougall et al., 2009; Weber, MacDougall, Halmagyi, & Curthoys, 2009).

Figure 5. Video-head impulse test.

3.3.3.3 Head-shake test

The head-shake test (HST) was used to assess symmetry of vestibular function. Goggles, equipped with an infrared charged device camera, (no visual cues), were used to record eye movements. Participants underwent a passive head shaking test (~ 2 Hz/20 s) in the supine position with the head in 30° of neck flexion and eyes closed (Figure 6). After a sudden stop of the head shaking, the eyes were immediately opened and eye movements were recorded (Vitte & Semont, 1995). A specialist in neuro-otology experienced in nystagmoscopy, evaluated the eye movements from the recordings. He was blinded to whether the recordings were from people with wrist fractures or controls, as well as whether the recordings were pre- or post-training. The test is considered positive for vestibular asymmetry when eye deviation occurs with three or more interposed fast phases, i.e. nystagmus (Harvey, Wood, & Feroah, 1997). An eye deviation of more than one interposed fast phase is considered a sign of weak asymmetry, especially if it prevails on repeated testing (Kristinsdottir, Nordell, et al., 2001). In this study two or more fast eye beats were defined as a positive test for asymmetric vestibular function, as has been used in previous studies (Kristinsdottir et al., 2000; Kristinsdottir, Nordell, et al., 2001).

Figure 6. Head-shake test.

3.3.4 Assessment of postural control

3.3.4.1 Sensory Organization Test with the Smart Balance Master

The Sensory Organization Test in the Smart Balance Master (NeuroCom Inc., Clackamas, OR, USA) was utilized to measure postural control (Figure 7). The test evaluates the patient´s ability to make effective use of somatosensory, visual and vestibular inputs and to suppress inappropriate sensory information. Inadequate information is given by disturbing somatosensory and visual cues, by tilting the support surface and/or visual surround in unison with the subject´s postural sway. The Sensory Organization Test calculates postural sway under six conditions (Figure 8). The first two conditions provide a basic measurement of the subject´s stability. The support surface is fixed and the subject´s eyes are open (condition 1) or closed (condition 2). In condition 3, eyes are open, the support surface is fixed, and the visual surround moves in unison with the subject´s postural sway. The support surface tilts in harmony with the subject´s postural sway with eyes open in condition 4 and with eyes closed in condition 5. Eyes are open in condition 6, support surface and visual surround moves with the subject´s sway. Postural sway is measured and recorded during three trials of 20 sec. for each condition. Composite scores of postural sway from the six different sensory conditions were used for analysis. A score of 100 represent no postural sway, while 0 indicates sway exceeding the limit of stability, resulting in a fall. Computerized dynamic platform posturography such as the Sensory Organization Test has gained wide acceptance as a method of measuring postural control (Lichtenstein, Shields, Shiavi, & Burger, 1988; Norré, Forrez, & Beckers, 1987; Wolfson et al., 1992). The test has fulfilled most criteria that would be required of a reliable and valid test of postural stability (Chien, Hu, Tang, Sheu, & Hsieh, 2007; Cohen & Kimball, 2008; Ford-Smith, Wyman, Elswick, Fernandez, & Newton, 1995; Whitney, Marchetti, & Schade, 2006).

Figure 7. Smart Balance Master. Image courtesy of Natus Medical Incorporated.

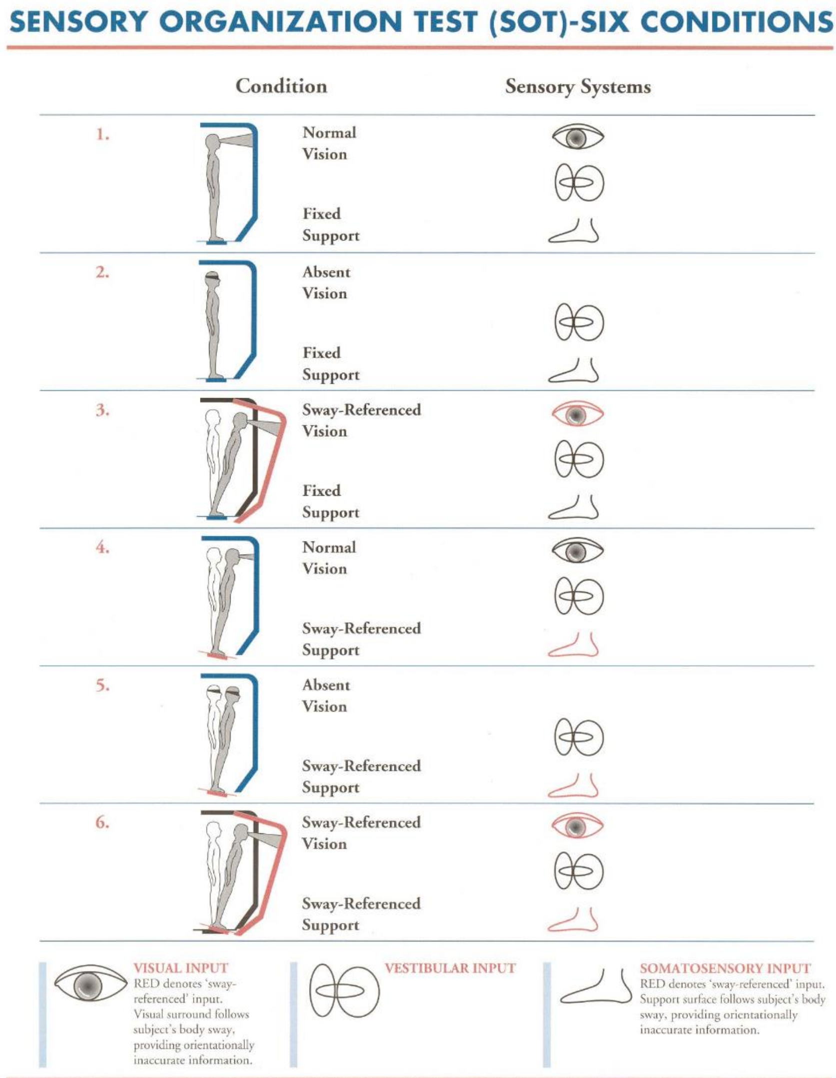

Figure 8. Sensory Organization Test - Six Conditions. Image courtesy of Natus Medical Incorporated.

3.3.5 Physical function tests

3.3.5.1 Five-Times-Sit-To-Stand Test

Functional lower limb muscle strength was measured with the Five-Times-Sit-To-Stand Test (FTSTS). The participants were instructed to rise from a chair with a seat height of 43 cm, as fast as possible, 5 times, with their hands crossed on their chest. Time (in seconds) was recorded (S. R. Lord, Murray, Chapman, Munro, & Tiedemann, 2002). The test has displayed discriminative and concurrent validity properties and reproducibility (Newcomer, Krug, & Mahowald, 1993; Whitney et al., 2005).

3.3.5.2 Normal and fast 30-m walk

Normal and fast 30-m walk with a turn after 15 m, was timed to assess the key elements in walking and safety during turning. The test is reliable and easy to perform in clinical settings (Andersson et al., 2011; Kwon et al., 2001).

3.3.5.3 10-m walk test

Gait speed was measured with the 10 MWT to assess locomotion as a part of balance control. A 20-m straight path was used, with 5 m for acceleration, 10 m for steady-state walking, and 5 m for deceleration. Markers were placed at the 5- and 15-m positions along the path. Participants began to walk at one end of the 20-m path and continued walking until they reached the other end. Timing started at the first marker and stopped when the participants crossed the second marker. The test was performed at their preferred walking speed and repeated at the subject's fastest speed. Gait speed was calculated (in m/s) as the distance covered divided by the time it took the individual to walk the distance (Perera, Mody, Woodman, & Studenski, 2006). The test has shown excellent test-retest and inter- and intrarater reliability and displayed excellent predictive and convergent validity (Bohannon, 1997; Tyson & Connell, 2009; van Hedel, Wirz, & Dietz, 2005; Wolf et al., 1999).

3.3.5.4 Ascending-descending 11 steps

Ascending-descending 11 steps was timed to test the ability of performing this important activity. It involves the subject ascending one flight of stairs, turning around and descending to the starting point. The test is an objective measure of functional ability and musculoskeletal integrity and has shown to have good inter-rater reliability and moderate to good concurrent validity (Almeida, Schroeder, Gil, Fitzgerald, & Piva, 2010; Nightingale, Pourkazemi, & Hiller, 2014).

3.4 Interventions

3.4.1 Multi-Sensory Training - the “Reykjavik Model”

The Multi-Sensory Training program (MST) consisted of:

- proprioceptive training, mainly for the lower limbs
- vestibular and eye control training
- facilitation and integration of proprioceptive and vestibular impulses
- fall prevention movements

The exercises were performed in bare feet on firm and soft surfaces, during quiet stance and movements. During exercises, participants were encouraged to pay attention to and control weight distribution on the soles of the feet and movements of the body. They were also encouraged to be aware of their postural control pattern and taught to readjust their posture with smooth corrective motions at the ankles and avoid using high frequency movements at the hips and upper body. The participants were discouraged to use hands or the body for external support. Control of posture was practised during fixation of gaze and movements of the head in different directions, head kept still, and eyes moving, as well as head movement with eyes closed. The participants were taught how to react to sudden disturbances by taking a step to hinder falling and use stepping reactions when their stability was challenged by manual push in different directions. The exercises were chosen from a list (Appendix 4) according to the main deficits noted for each participant, tailored close to the limits of their capability and progressed continuously according to their improvement. The exercise program in its entirety can be watched at: https://vimeo.com/album/4948077.

Figure 9. Fall-reaction training. A person taught how to react to sudden disturbances by taking a step to hinder falling.

Figure 10. Combined proprioceptive and vestibular training.

3.4.2 Wrist Stabilization Training

The wrist stabilization training (WT) consisted of stabilization and strength training for the fractured wrist. All exercises were performed in a sitting position (Appendix 5). The performance of the wrist stabilization exercises can be watched at: https://vimeo.com/252677340/f0bc12ac32.

Figure 11. Wrist stabilisation training with the Inimove® training equipment.

Figure 12. Wrist stabilisation training with a red elastic resistance band.

Exercise diaries used in the randomized controlled trial (Paper III) can be seen in Appendix 6 and 7.

3.5 Statistical analysis

SPSS version 11 (Paper I) and 24 (Paper II and III) was used to analyse the data. Significance level was set at $p < 0.05$.

In all of our papers we used standard or frequently used approaches in statistics in order to answer the research questions in each paper. Distribution of data affected the choice whether we used parametric tests or non-parametric equivalents. We frequently used bivariate comparisons or bivariate correlation analyses in order to get indications or ideas about the connection between variables. However, usually at the later stages of the calculations we used statistical models with adjustment/correction for confounding variables which allowed us to get a clearer picture on how a certain exposure or independent variables were related to the outcome independently from confounders, e.g., age or gender. Our statistical approach is very much in line with what is done in similar studies/publications. As statistics can get more advanced as the number of participants increases, the complexity of calculations, e.g. number of covariates in models, was certainly limited by the number of participants in the present study.

Data were checked for normality using the Kolmogorov-Smirnov test. Descriptive analysis was used to summarize the demographic characteristics of participants, including means, standard deviations median, percentile and percentages. Comparisons between groups at baseline were made using the Mann-Whitney-U test or independent samples t-test.

In Paper II correlations between variables were calculated using Spearman's rho. The Kruskal Wallis Test and One Way Anova, including Fisher´s least significant difference (LSD) post hoc test, were used to find characteristics of variables by age group. Logistic regression models were used to find associations of variables with having obtained a fall-related wrist fracture.

Wilcoxon signed-rank test and paired samples t-test were used to compare measurements before and after training. Effect sizes were calculated using Cohen's d statistic (Paper I) and effect size (r) (Paper III). Univariate general linear models with statistical adjustment for baseline values, gender and age were used to compare endpoint differences between training groups (Paper III).

3.6 Ethical issues

Study I was conducted with the approval of the Bioethics Committee of Landspitali National University Hospital (96/2004) and reported to The Data Protection Authority of Iceland (2004120667). Studies II and III were approved by the Icelandic National Bioethics Committee (VSNb2013110036/03.11). All studies were performed in accordance with ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All participants gave their informed written consent prior to inclusion in the studies.

4 Results

The results of the three studies are presented in this chapter. For detailed results, refer to the respective publications (Papers I, II and III).

4.1 Paper I – Pilot study of the “Reykjavik Model” (Study I)

The participants had numerous comorbidities and had sustained multiple falls and fractures. Decreased vibration perception, as measured with a tuning fork, and vestibular dysfunction, according to performance on the stepping test, were frequently observed at baseline (Table 3). Post training there was a decrease in the rate of falls and at six months (table 4). Significant differences were revealed in all outcome measures ($p<0.001$) after the multi-sensory balance training. The improvements were revealed by medium effect sizes for all measurements except for the Five-Times-Sit-To-Stand Test, showing a medium effect size (Table 5).

Table 3. Vibration sensation and performance on the stepping test.

Sensation	n = 37		Stepping Test	n = 37	
1	6	16%	No Rotation	5	13%
2	6	16%	Rotation	25	68%
3	25	68%	Incapable	7	19%

Incapable = Unable to perform the test because of falling tendencies.

Table 4. Self-reported falls.

	Subjects (n/N)	Falls (N)
Prior to the study	34 / 37	159
During the study	6 / 37	7
Six months after the study	7 / 34	17

Prior = 1 year prior to training.

During = 6 weeks training period.

After = 6 months after completion of training.

Table 5. Postural control, physical function and level of confidence before and after multi-sensory training.

	Before multi-sensory training			After multi-sensory training				
	Mean	Range	SD	Mean	Range	SD	p	ES
SOT	51.61	20 - 75	12.33	58.14	25 - 78	13.02	**<0.001**	0.52
FTSST	18.87	11 - 31	5.19	16.50	10 - 52	7.00	**<0.001**	0.38
WALK-N	38.40	24 - 58	8.44	33.04	23 - 52	6.30	**<0.001**	0.71
WALK-F	30.51	18 - 45	6.14	26.81	18 - 38	4.80	**<0.001**	0.67
STAIRS	22.90	12 - 51	9.45	18.74	11 - 47	6.84	**<0.001**	0.50
ABC	57.04	20 - 90	16.41	66.00	33 - 90	15.51	**<0.001**	0.54

SOT = Sensory Organization Test (composite scores).
FTSST = Five-Times-Sit-to-Stand Test (seconds).
WALK-N = 30 m walk with a turn at normal speed (seconds).
WALK-F = 30 m fast walk with a turn (seconds).
STAIRS = ascending and descending 11 steps (seconds).
ABC = Activities-specific Balance Confidence Scale (scores).
Significant values are shown in bold.

SD = standard deviation.
p = values; Wilcoxon signed-rank test.
ES = effect size.

4.2 Paper II – Case-control study (Study II)

There were significant differences between the wrist fracture group and the control group for most of the variables. The people with wrist fractures had a higher incidence of asymmetrical vestibular function (82%/63%, p=0.012), decreased plantar pressure sensation (p<0.001), poorer postural control (p<0.001), slower walking speed (p<0.001) and reduced strength in their lower limbs (p<0.001) compared to the matched controls. In addition, people with wrist fractures had sustained a higher number of previous falls (p<0.001) and fractures (p<0.001) than controls and they perceived more dizziness handicap (p=0.005) and less confidence during daily activities (p<0.001). Vibration sensation did not differ between the groups (Table 6). The most frequently reported reason for the fall was tripping, accounting for 41% of the participants (Figure 13).

The characteristics of the participants (all participants included, fracture and control groups) categorized by age group, 50-58 years, 59-66 years and 67-75 years, are shown in Table 7. Vibration sensation, i.e. biothesiometer (p=<0.001) and tuning fork (p=0.02), walking speed; comfortable walking speed (p=0.001), fast speed (p=<0.001) and lower limb functional muscle strength (p=0.038) were the only variables that were significantly different between the three age groups.

Logistic regression models revealed that mechanoreceptive sensation; biothesiometer (OR 0.843; 95% confidence interval (95% CI) 0.737–0.965) and monofilament (OR 5.643; 95% CI 2.363–13.473), a positive HST (OR 3.874; 95% CI 1.544–9.724), SOT (OR 0.899; 95% CI 0.835–0.968) and FTSTS (OR 2.040; 95% CI 1.389–2.997]) were associated with being in the wrist fracture group, but not walking speed, perceived dizziness handicap and confidence (Table 8).

The association between SOT and a fall-related wrist fracture was partly explained by perceived dizziness handicap and confidence, although the SOT composite score remained significant (OR 0.921; 95% CI 0.850–0.998). The association between the SOT and a fall-related wrist fracture disappeared when corrected for walking speed and functional strength in the lower limbs. In the final model a positive HST (OR 5.424; 95% CI 1.570–18.740) and monofilaments sensation (OR 3.886; 95% CI 1.318–11.457) showed the strongest association with having obtained a fall related wrist fracture.

Table 6. Characteristics of the participants categorized by group.

Characteristics	Fracture group (n = 98)		Control (n = 48)		p-value*
	Median	25^{th}-75^{th} (percentile)	Median	25^{th}-75^{th} (percentile)	
Age, years	62	(56 - 67)	61	(55 - 67)	0.440
Falls previous 12 months (n)	1	(1 - 3)	0	(0 - 1)	**<0.001**
Physical activity previous 12 months (h/week)	2	(2 - 3)	2	(2 - 3)	0.735
Total fractures over lifespan (n)	2	(1 - 2)	0	(0 - 1)	**<0.001**
Body mass index (kg/m²)	28	(25 - 31)	25	(23 - 29)	**0.002**
10-m walk comfortable speed (m/s)	1.4	(1.3 - 1.5)	1.5	(1.4 - 1.6)	**<0.001**
Monofilament (g)	1.15 [a]	(0.76 - 2.21)	0.66	(0.41 - 1.13)	**<0.001**
Biothesiometer (µm)	1.38	(0.74 - 2.80)	1.48	(0.72 - 2.89)	0.935
Tuning fork (score)	1	(1 - 2)	1	(1 - 2)	0.506
Sensory Organization Test composite (score)	74 [a]	(69 - 78)	79	(75 - 82)	**<0.001**
Activities-specific Balance Confidence Scale (score)	92	(82 - 97)	97	(94 - 99)	**<0.001**
Dizziness Handicap Inventory (score)	2	(0 - 16)	0	(0 - 4)	**0.005**
Head shake test (% positive) †	82%		63%		**0.012**
	Mean	SD	Mean	SD	
10 meter walk fast speed (m/s)	1.9	0.3	2.1	0.3	**<0.001**
Five-Times-Sit-to-Stand-Test (s)	12	2.5	9	1.4	**<0.001**

* Differences between groups according to Mann-Whitney U test (not normally distributed variables) and independent samples t-test (normally distributed variables).

Monofilament and Biothesiometer; mean values measured on centre of heel, basis big toe and little toe, left and right.

† Positive head shake test: ≥ 2 fast eye beats.

[a] Number of participants with missing data for the variable: Monofilaments: 2; SOT: 15.

Significant values are shown in bold.

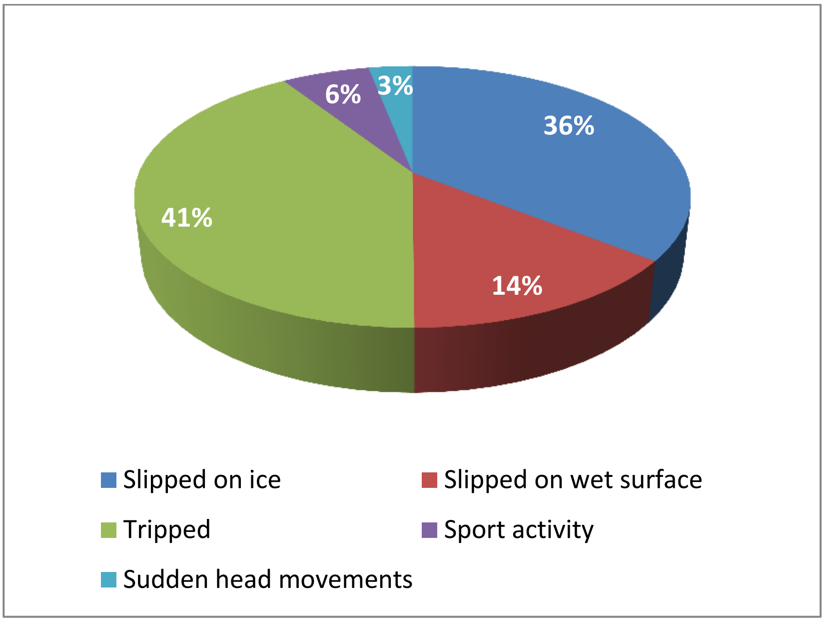

Figure 13. Circumstances of falls among people with wrist fracture.

Table 7. Characteristics of participants categorized by age; 50-58 years, 59-66 years and 67-75 years. (All subjects included n=146).

	Group 1 Age 50-58 years (n=51)		Group 2 Age 59-66 years (n=59)		Group 3 Age 67-75 years (n=36)		
	Median	Range	Median	Range	Median	Range	*p*-value
Physical activity previous 12 months (h/week)	2.0	(1 - 4)	2.0	(1 - 4)	2.0	(1 - 4)	0.83
Total fractures over lifespan (n)	1.0	(0 - 5)	2.0	(0 - 8)	1.0	(0 - 7)	0.36
Body mass index (kg/m²)	27.4	(20 - 59)	27.3	(19 - 35)	26.3	(17 - 38)	0.91
10-m walk, comfortable speed (m/s)	1.5	(1.1 - 1.9)	1.4	(0.7 - 1.9)	1.3	(0.7 - 1.7)	**0.001** [a]
Monofilament (g)	0.9	(0.16 - 7.67)	0.9	(0.21 - 4.37)	1.3	(0.03 - 4.67)	0.09
Biothesiometer (µm)	0.9	(0.29 - 20.00)	1.6	(0.29 - 14.77)	3.2	(0.52 - 25.5)	**<0.001** [b]
Tuning fork (score)	1.0	(1 - 4)	1.0	(1 - 4)	1.5	(1 - 4)	**0.020** [c]
Sensory Organization Test composite score	78.0	(52 - 87)	75.5	(50 - 87)	76.0	(50 - 86)	0.41
Activities-specific Balance Confidence Scale (score)	95.1	(40 - 100)	93.8	(43 - 100)	92.6	(57 - 100)	0.18
Dizzinesss Handicap Inventory (score)	2.0	(0 - 66)	0.0	(0 - 62)	2.0	(0 - 60)	0.50
Head-Shake test (% positive)	71%		80%		75%		0.55
	Mean	SD	Mean	SD	Mean	SD	
10-m walk fast (m/s)	2.0	± 0.3	1.9	± 0.2	1.8	± 0.3	**<0.001** [d]
Five Times Sit to Stand Test (s)	10	± 2.2	10.6	± 2.6	11.4	± 2.96	**0.038** [e]

P values based on Kruskal Wallis Test (not normally distributed variables) and One Way Anova (normally distributed variables). Post hoc test: LSD

t1: Age group 1; t2: Age group 2; t3: Age group 3

a t1 vs t2 p=0.044; t2 vs t3 p=0.033; t1 vs t3:p<0.001

b t1 vs t2 p=0.013 ;t2 vs t3 p=0.002; t1 vs t3 p<0.001

c t2 vs t3 p=0.48; t1 vs t3: p=0.006

d t1 vs t2 p=0.044; t2 vs t3 p=0.18; t1 vs t3:p<0.001

e t1 vs t3: p=0.011

Positive Head-Shake Test: ≤ 2 fast eye beats. Significant values are shown in bold.

Table 8. Logistic regression models for a fall-related wrist fracture.

	Model 1				Model 2			
	Function of sensory systems				Additional: postural control			
	OR	95%CI		*p*-value	OR	95%CI		*p*-value
Biothesiometer (μm)	0.843	0.737	0.965	**0.013**	0.860	0.748	0.989	**0.034**
Monofilament (g)	5.643	2.363	13.473	**<0.001**	4.640	1.900	11.332	**0.001**
Head-Shake Test †	3.874	1.544	9.724	**0.004**	3.603	1.337	9.709	**0.011**
SOT (score)					0.899	0.835	0.968	**0.005**
	Model 3				Model 4			
	Additional: dizziness and confidence				Additional: functional ability			
	OR	95%CI		*p*-value	OR	95%CI		*p*-value
Biothesiometer (μm)	0.849	0.732	0.986	**0.032**	0.818	0.696	0.962	**0.015**
Monofilament (g)	4.663	1.806	12.041	**0.001**	3.886	1.318	11.457	**0.014**
Head-Shake Test †	4.430	1.502	13.061	**0.007**	5.424	1.570	18.740	**0.008**
SOT (score)	0.921	0.850	0.998	**0.045**	0.971	0.891	1.059	0.508
ABC (score)	0.934	0.862	1.013	0.101	0.970	0.883	1.066	0.529
DHI (score)	1.021	0.963	1.083	0.488	1.035	0.974	1.099	0.266
10-m walk (m/s)					4.574	0.167	125.288	0.368
FTSTS (s)					2.040	1.389	2.997	**<0.001**

†Head-Shake Test: ≥ 2 fast eye beats; SOT: Sensory Organization Test; ABC: Activities-specific Balance Confidence Scale.

DHI: Dizziness Handicap Inventory; FTSTS: Five Times Sit to Stand Test.

OR: odds ratio; 95% CI: 95% confidence interval. Significant values are shown in bold.

4.3 Paper III – Randomized controlled trial (Study III)

The two training groups were largely comparable, except for vibration sensation that was significantly poorer in the MST group at baseline ($p = 0.02$) (table 9.).

Within-group changes after the intervention revealed a significant improvement in both groups in FTSTS (MST: $p<0.001$; WT: $p<0.01$) and SOT (MST: $p<0.01$; WT: $p<0.01$). A significant improvement on the DHI was only observed in the MST group ($p=0.01$) but not in the WT group. There was a 16% non-significant ($p=0.058$) reduction in asymmetric vestibular function (HST) in the MST group but no change in the WT group (Table 10).

Linear models, correcting for baseline values, age and gender, revealed a significant between group difference in endpoint SOT (MST +3.1, $p = 0.01$), but not in other outcome variables (Table 11).

Within-group changes in participants with below normal baseline SOT composite scores indicated that the MST was more effective in improving 10MWT fast ($p=0.04$), FTSTS ($p=0.04$), SWF ($p=0.04$) and SOT scores ($p=0.04$) than the WT (Table 12). A comparison between groups showed that the MST had a higher endpoint SOT than the WT group (+7.4, $p = 0.012$).

Table 9. Characteristics of participants categorised by training group.

Variable	Wrist training (n = 42)					Multi-sensory training (n = 38)					
	Mean	±	SD	Median	Range	Mean	±	SD	Median	Range	*p*-value*
Age (years)	60.8	±	6.7	61	50 - 75	62.7	±	7.9	63	50 - 75	0.38
Sex; females/males (n)			36/6					33/5			
BMI (kg/m²)	28.5	±	6.0	27	19 - 59	28.4	±	6.2	28	19 -57	0.97
Phys. act. prev. 12 months (h/week)	2	±	0.8	2	1 - 3	2	±	0.6	2.0	1 - 3	0.36
Falls previous 12 months (n)	2	±	1.3	1	1 - 5	2	±	1.3	1.0	1 - 6	0.26
Total fractures over lifespan (n)	2	±	1.2	2	1 - 6	2	±	1.6	2.0	1-8	0.52
10MWT comfortable speed (m/s)	1.4	±	0.19	1.4	1.0 - 1.8	1.4	±	0.19	1.4	0.7 - 1.7	0.93
10MWT fast speed (m/s) [b]	1.9	±	0.3	1.8	1.4 - 2.7	1.8	±	0.30	1.8	1.1 - 2.5	0.42
FTSTS (s) [b]	11.4	±	2.41	11.2	5.9 - 15.9	11.70	±	2.61	11.9	6.8 - 19.1	0.50
Monofilament (g)	1.6	±	1.6	1.1	0.3 - 7.7	1.6	±	1.1	1.3	0.4 - 4.3	0.46
Biothesiometer (µm)	2.5	±	3.8	1.1	0.3 - 20.0	3.6	±	4.9	1.8	0.6 - 25.5	**0.02***
Head Shake Test (% positive) †			76.2%					89.5%			0.12
vHIT left (gain)	0.9	±	0.1	0.9	0.8 - 1.1	0.9	±	0.1	0.9	0.7 - 1.2	0.35
vHIT right (gain)	1	±	0.1	1.0	0.9 - 1.3	1.0	±	0.2	1.0	0.8 - 1.6	0.99
SOT composite (score)	72	±	7.4	73	50 - 81	74	±	7.8	76	52 - 86	0.11
DHI (score)	9	±	14.9	1	0 - 62	13.0	±	19.6	4	0 - 66	0.33
ABC (%)	88	±	13.1	93	43 - 100	87.0	±	13.3	90	40 - 100	0.59

* Difference between groups according to Mann-Whitney U test (not normally distributed variables) and independent samples t-test (normally distributed variables).

[b] normally distributed variables.

BMI: Body mass index; 10MWT: 10 Meter Walk Test; FTSTS: Five Times Sit to Stand Test.

Monofilament and Biothesiometer; mean values measured on plantar surface of heel, caput of the first and fifth metatarsal bones, left and right.

†Head-Shake Test: ≥ 2 fast eye beats

vHIT: video-Head-Impulse-Test; SOT: Sensory Organization Test; DHI: The Dizziness Handicap Inventory.

ABC: Activities-specific Balance Confidence Scale. Significant values are shown in bold.

Table 10. Within-group changes in functional ability, postural control, sensation, perceived dizziness and balance confidence after the interventions.

	Wrist training (n = 42)				Multi-sensory training (n = 38)			
Outcome Measure	Δ	95% CI		p-value*	Δ	95% CI		p-value*
SOT composite (score)	3.58	1.363	5.813	<0.01*	4.22	1.495	6.943	**<0.01***
Monofilament (g)	-0.2	-0.465	-0.012	0.14	-0.1	-0.360	0.222	0.08
Biothesiometer (µm)	-0.3	-0.697	0.133	0.11	-0.2	-0.629	0.179	0.38
Head Shake Tes positive[a] (%)	0.0	-0.195	0.195	1.0	-15.8	-0.320	0.005	0.06
vHIT left (gain)	0.01	-0.012	0.037	0.30	0.0	-0.011	0.045	0.23
vHIT right (gain)	0.0	-0.042	0.005	0.15	0.0	-0.066	0.027	0.41
10MWT comfort speed (m/s)	0.0	-0.025	0.063	0.39	0.0	-0.032	0.064	0.51
10MWT fast speed (m/s)	0.0	-0.037	0.082	0.45	0.1	-0.002	0.094	0.06
FTSTS (s)	-1.0	-1.537	-0.444	**<0.01***	-1.5	-1.964	-0.996	**<0.001***
DHI (score)	-2.3	-5.673	1.088	0.21	-4.7	-8.283	-1.086	**0.01***
ABC (score)	0.9	-1.152	2.935	0.98	2.3	-0.141	4.743	0.69

* Baseline - endpoint differences: Wilcoxon non parametric test and paired samples t test.

Δ: mean change. SOT: Sensory Organization Test.

Monofilament and Biothesiometer; mean values measured on plantar surface of: heel, caput of the first and fifth metatarsal bones, left and right.

† Positive HST: ≥ 2 fast eye beats; vHIT: video-Head-Impulse-Test. 10MWT: 10 Meter Walk Test; FTSTS: Five Times Sit to Stand Test.
DHI: The Dizziness Handicap Inventory; ABC: Activities-specific Balance Confidence Scale.

Significant values are shown in bold.

Table 11. Endpoint differences between groups in functional ability, sensation, postural control, perceived dizziness and balance confidence.

Outcome Measure	B	95% CI		*p*-value
SOT composite (score)	3.095	0.797	5.393	**0.01***
Monofilament (g)	0.134	-0.158	0.426	0.36
Biothesiometer (µm)	0.250	-0.139	0.639	0.20
Number fast eye beats	0.135	0.382	0.950	0.88
vHIT left (gain)	0.006	-0.025	0.037	0.71
vHIT right (gain)	0.002	-0.037	0.040	0.93
10MWT comfortable speed (m/s)	0.002	-0.056	0.060	0.94
10MWT fast speed (m/s)	0.012	-0.056	0.081	0.73
FTSTS (s)	-0.463	-1.184	0.258	0.20
DHI (score)	-0.571	-4.079	2.938	0.75
ABC (score)	1.303	-1.318	3.924	0.33

* Results show MST compared to WT based on univariate general linear models which corrected for base line values, age and gender.

SOT: Sensory Organization Test.

Monofilament; mean values measured on plantar surface of heel, caput of the first and fifth metatarsal bones, left and right.

vHIT: video-Head-Impulse-Test. 10MWT: 10 Meter Walk Test; FTSTS: Five Times Sit to Stand Test.

DHI: The Dizziness Handicap Inventory; ABC: Activities-specific Balance Confidence Scale.

Significant values are shown in bold.

Table 12. Within-group changes in functional ability, pressure plantar sensation and postural control after the intervention among participants with SOT baseline values below age norms.

	Wrist training (n = 8)				Multi-sensory training (n = 5)			
Outcome Measures	Δ	95% CI		*p*-value*	Δ	95% CI		*p*-value*
SOT composite (score)	9.5	5	14	**0.01***	16.8	12.1	21.5	**0.04***
Monofilament (g)	0.1	-0.2	0.4	0.31	-0.4	-1.2	0.4	**0.04***
10MWT fast speed (m/s)	0.0	0.0	0.1	0.12	0.1	0.0	0.2	**0.04***
FTSTS (s)	-1.1	-3.0	0.8	0.16	-2.9	-4.7	-1.1	**0.04***

*Baseline - endpoint differences: Wilcoxon non parametric test. Δ: mean change SOT: Sensory Organization Test composite scores.

Monofilament; mean values measured on plantar surface of: heel, caput of the first and fifth metatarsal bones, left and right.

10MWT: 10 Meter Walk Test; FTSTS: Five Times Sit to Stand Test.

SOT composite age norms (scores): 20-59 years: ≥70; 60-69 years: ≥68; 70-79 years: ≥64.

Significant values are shown in bold.

5 Discussion

The overall aim of this thesis was to evaluate the effects of a multi-sensory balance training method, the “Reykjavik Model” (MST), among unsteady older adults and middle aged and old people with wrist fracture. Also, to explore the characteristics of the people with wrist fracture and examine whether vestibular, mechanoreceptive and physical function were independently associated with having sustained a fall-related wrist fracture. Additionally, to study the association between sensory and physical dysfunction and ageing.

The effects of the MST among the older adults, investigated in a pilot study, revealed a significant improvement in all measured parameters post-training. There was as well a reduction in the rate of falls among participants during the training and the following six months (Paper I).

The people in the pilot study significantly improved their performance on the SOT after the training by 6.5 composite points. These improvements are somewhat greater than Bao et al. (Bao et al., 2018) reported among community-dwelling healthy older adults (3 points), after a long-term (8 weeks) progressive balance training program (Klatt et al., 2015). The results in the present study are in line with SOT composite score improvements after traditional balance training (6.4 scores) among older patients with Parkinson´s Disease (Liao et al., 2015). Minimal detectable change (MDC) in composite SOT score, indicating a change due to rehabilitation, was previously determined to be greater than 8.1 scores, for young adults (Wrisley et al., 2007). The MDC in the composite SOT score has not been reported among elderly people. However, the improvements observed on the SOT test in the pilot study indicate that the multi-sensory training program enhances central integration of the different sensory impulses.

The old people in the pilot study significantly improved their confidence in daily activities post-training. Their mean score of 57 on the ABC scale before training increased to 66 post-training. A cut-off score on the ABC scale of ≤ 58 between fallers and non-fallers has been reported (Moiz et al., 2017). The MDC for the ABC score for older adults was recently determined to be 15 points (Wang et al., 2018). Even though the results in the pilot study were less than the 15 points reported by Wang et al, the significant improvement in confidence could be of major importance. Increased balance confidence could break up the vicious circle of fear of falling and avoidance of physical activity which can lead to increased disability and risk of further falls.

The people in the pilot study also showed significant improvement in all functional tests. Improvements in the Sit-to-Stand test and ascending/ descending stairs indicate increased functional strength in the lower limbs, even though the multi-sensory training did not include specific strengthening exercises. The people significantly improved their performance on the FTSTS after the training by 2.4 seconds. A clinically meaningful change of 2.3 seconds or more on the FTSTS, has previously been reported among old adults with vestibular dysfunction (Meretta, Whitney, Marchetti, Sparto, & Muirhead, 2006).

The improvement found in the 30 m fast walking speed test was different from the findings by Hansson et al (2015), which did not observe any changes in fast walking speed in people aged 73 +/- 8 years, after 3 months of vestibular training (Hansson, Dahlberg, & Magnusson, 2015). A meaningful change in normal walking speed has been established at 0.1 to 0.2 m/s across multiple patients' groups (Bohannon & Glenney, 2014). The mean change in normal walking speed among the old people in the present study was 0.18 m/s. Improvement in walking speed is of importance, as increase in gait speed due to intervention has been proven to increase survival in older adults (Studenski, Pereira, & Patel, 2011) and reduced preferred walking speed is strongly associated with increased risk for falls (Abellan van Kan et al., 2009).

There was a considerable reduction in the incidence of falls post training. At first attendance 34 of the old people reported a total of 159 falls in the preceding year. This information is unreliable as it was based on the peoples´ memory but not collected in a systematic manner. However, it indicates that the participants in the study had sustained a great number of falls prior to training. The reported falls during the training period and the following six months are more trustworthy as they kept a diary on falls. Only 13 individuals reported falls during this period. Thus, it is reasonable to assume that the multi-sensory training method can reduce the number of falls among unsteady elderly people. According to previous meta-analysis by Sherrington et al. (2008), moderate to high challenging balance training was the only exercise approach that reduced falls. Sherrington et al (2008) report is in line with the procedures in the MST, in which progression of the exercises was emphasised and the level of difficulty kept at, or above the capability of each individual. A more recent meta-analysis by Mansfield et al (2015) reported a beneficial effect of perturbation based balance training (PBT) in decreasing the rate of falling among older adults and individuals with Parkinson disease. Perturbation based balance training consists of repeated postural perturbations, aiming at improving control of rapid balance reactions. This approach is similar to part of the multi-sensory training regimen that includes practice of stepping reactions to prevent falling, when the person´s stability is challenged by unexpected manual pushes in different directions.

Based on the results of the pilot study, further research on the efficiency of the multi-sensory training model was then conducted in a randomized controlled trial. In this study the effects of the MST were compared to wrist stabilisation training (WT) among younger people, aged 50-75 years, having sustained a fall-related wrist fracture. The reason for choosing this cohort were results from previous studies, revealing that wrist fracture is a strong predictor of future fracture risk (Cuddihy et al., 1999), and precursor to hip fractures (Johnson et al., 2017; H. Mallmin et al., 1993). Furthermore, previous studies had found a connection between asymmetrical vestibular function and wrist fractures (Hansson et al., 2015; Kristinsdottir, Nordell, et al., 2001). As part of prevention of falls and subsequent fractures, we wanted to study whether people who had sustained a fall-related wrist fracture would benefit from the MST. Post-training, a direct comparison between MST and WT showed that the MST group displayed significantly higher scores on the SOT than the WT, but no changes were seen in other outcome variables (Paper III).

These modest findings were somewhat unexpected, compared to the greater improvements in composite SOT scores (6.5 vs. 4.2), FTSTS (-2.4 vs. -1.5) and ABC scores (9.9 vs. 2.3) in the pilot study. Possible reasons for the difference in outcomes between the studies are discussed in Paper III and may be due to two main reasons. The two study populations were dissimilar and there was a difference in the design of the training. The people in the pilot study were between 70-92 years of age, with numerous medical ailments. In the randomized controlled trial, the people were younger, 50-75 years of age and healthy. Furthermore, the study protocols were different, there were six supervised training sessions and prescribed home exercises in the randomized controlled trial, compared to 18 supervised training sessions in the pilot study.

The people in the pilot study were older, had sustained multiple falls and fractures, most of them had decreased sensation in their lower limbs and they had numerous comorbidities. They were physically weaker, more unstable and less confident during daily activities, as demonstrated by their poorer performance in the different tests and questionnaire (ABC scale) at baseline. The wrist fracture people in the randomized controlled trial were younger, healthier and generally in good physical condition, which might have made it more difficult to achieve significant improvements with the MST training.

Subgroup analysis with the few wrist fracture participants (WT n=8; MST n=5) with below normal baseline SOT composite scores support this. Reduced postural control at baseline was associated with a better improvement in postural control during the intervention. Additionally, the effects of the intervention among participants with reduced postural control at baseline demonstrated that the MST resulted in significant better outcomes than the WT for these participants. The WT group showed a mean change of 9.5 composite scores on the SOT, which is close to a learning effect (8 scores) due to repeated measurements (Wrisley et al., 2007). However, the MST group exceeded that with mean change of 16.8 scores. Fast walking speed increased by 0.1 m/s post training among the MST participants, but no change was observed in the WT group. This increase in fast walking speed has been established as a clinically meaningful change among older people after hip fracture (Palombaro, Craik, Mangione, & Tomlinson, 2006). Tactile sensitivity improved as well only in the MST group. Although minimal clinically important differences in tactile sensitivity have not been reported, it has been shown that reduced tactile sensitivity is associated with fall-related wrist fractures (Paper II). Additionally, a clinically meaningful change of 2.9 seconds was reached in the FTSTS (Meretta et al., 2006) in the MST group. These results imply that the MST was more effective than the WT among people with reduced postural control. However, as the number of participants with reduced postural control at baseline was very small, these findings need to be confirmed using a larger sample size before firm conclusions can be drawn.

The number of training sessions in the pilot study was dictated by the Icelandic social security reimbursement rules. Each referral included twenty reimbursed sessions, lasting approximately 45 minutes each, of which two were used for pre- and post-assessments and the remaining eighteen for training. The frequency of supervised training sessions in the randomized controlled trial was lower than in the pilot study, consisting of only six 30 minutes supervised sessions and prescribed home exercises. This reduction in supervised sessions was based on the author´s clinical experience, where six supervised sessions of the MST and daily home exercises had been found to decrease dizziness and improve postural stability among people with unilateral and bilateral peripheral vestibular hypofunction. This approach is in line with the clinical practice guidelines from the American Physical Therapy Association for vestibular rehabilitation for peripheral vestibular hypofunction (C. D. Hall et al., 2016). According to these guidelines, based on expert opinion, persons with chronic unilateral vestibular hypofunction may need supervised sessions once a week for 4-6 weeks, together with daily home exercises. However, there is limited consensus in the clinical research literature on optimal frequency and duration for effective balance exercise interventions (Shubert, 2011). According to a systematic review and meta-analysis by Lesinski et al. (2016), an effective balance training protocol among healthy old adults is characterized by a training periods of 11-12 weeks, a frequency of three sessions per week and duration of 30-45 min of a single session (Lesinski, Hortobagyi, Muehlbauer, Gollhofer, & Granacher, 2016). The MST protocol used in the pilot study was somewhat similar to findings revealed in this systematic review, with three training sessions per week, each lasting approximately 45 minutes. However, the length of the training period was shorter or six weeks. A recent systematic review and meta-analysis reported that supervised balance/resistance training was superior compared with unsupervised training in improving balance and muscle strength/power, among older adults (Lacroix, Hortobagyi, Beurskens, & Granacher, 2017). The results from our two studies are in line with these previous reports. There were greater improvements in measured parameters post training in the pilot study, compared to the modest improvements post training in the randomized controlled trial. The pilot study consisted entirely of training sessions supervised by a physiotherapist, on the other hand the randomized controlled trial comprised mostly of home exercises and only few supervised sessions.

In our two studies on the effects of the MST program, one variable of interest was asymmetric vestibular function., This has been shown to be associated with, falls, wrist and hip fractures (Hansson et al., 2015; Hansson & Magnusson, 2013; Kristinsdottir et al., 2000; Kristinsdottir, Nordell, et al., 2001). Symmetry of vestibular function was assessed with a stepping test in the pilot study and with a HST in the randomized controlled trial. According to results from these measurements, asymmetric vestibular function was common among the participants. The incidence of asymmetry was 68% in the pilot study and 89% among participants in the MST in the randomized controlled trial. The stepping test was not repeated among the elderly people after the training. The test is not a precise instrument and has shown large within-subject variability (Paquet et al., 2014), which is a weakness for interpreting test-retest results of a person in a clinical setting. Therefore, no information was gathered on post training vestibular status in the pilot study. However, in the randomized controlled trial, there was a 16% borderline significant ($p=0.06$) reduction of vestibular asymmetry in the MST group post training, as measured by the HST. On the other hand no change was observed in the group receiving the WT. Previously, Hanson et al. found an 18.5% reduction of vestibular asymmetry among people with wrist fractures after nine weeks of vestibular rehabilitation, consisting of group sessions 2 times/week (Hansson et al., 2015). The reduction in vestibular asymmetry post training in our study, indicates that the MST can positively affect asymmetric vestibular function. This is of importance with regards to fall prevention, as vestibular asymmetry has been found to adversely affect postural control among healthy older adults (Kristinsdottir, Fransson, et al., 2001) and to be associated with falls, wrist and hip fractures. However, as our findings did not reach statistical significance, no firm conclusions on the effect of the MST on vestibular asymmetry can be drawn from this study.

The characteristics of the people with wrist fractures were further explored in the case-control study (Paper II). A significant difference was found in almost all observed parameters between the people with wrist fractures and the age-, sex- and physically activity-matched controls with no previous history of a wrist fracture. The wrist fracture people had a higher incidence of asymmetric vestibular function, decreased plantar pressure sensation and poorer postural control compared with matched controls. They also had slower walking speed and reduced strength in their lower limbs. In addition, people with wrist fractures perceived more dizziness handicap and less confidence during daily activities. They also had sustained a higher number of previous falls and fractures than people in the control group. The characteristics of people who have sustained a wrist fracture has previously been explored to some extent (Nordell, Kristinsdottir, Jarnlo, Magnusson, & Thorngren, 2005; Vergara et al., 2016). However, to the best of our knowledge, no previous studies have compared the characteristics of individuals with and without a fall-related wrist fracture, matched according to age, sex and weekly physical activity level.

In our study, one-third of the individuals had sustained one to five falls during the previous twelve months in addition to the fall that resulted in a wrist fracture. Previous fractures were common among them, ranging from one to seven prior fractures. This is in line with previous findings by Nordell et al (2005) among 50-86 years old people with distal forearm fractures. Women comprised the majority of the people with wrist fractures who agreed to participate in our study (87%). A similar proportion (83%) was female when examining the whole sample of eligible participants. Consequently, the male to female ratio was comparable to findings reported previously for this population (H. Mallmin & Ljunghall, 1992; Nordell et al., 2005; O'Neill et al., 2001; Orces & Martinez, 2011; Siggeirsdottir, Aspelund, Jonsson, et al., 2014) .

Despite the statistical difference found between the cases and people in the control group in our study, the people in the wrist fracture group were well functioning and quite healthy. Their walking speed and lower limb functional muscle strength were within normal ranges for their age (Bohannon, 2006; Fritz & Lusardi, 2009) and balance performance as well for 84% of them, as measured by the SOT (NeuroCom., 2000). Vibration perception (tuning fork and biothesiometer) was also mostly (89%) within normal range in our participants (Maffei et al., 2014). On the other hand, tactile sensitivity was reduced among 35% of the participants, as defined by Rinkel et al (2017) and the prevalence of vestibular asymmetry was high (83%) as assessed with the HST.

Nystagmus after passive head shaking is generally considered pathological (Perez et al., 2004) and demonstrates asymmetry of the vestibular system (Hain, Fetter, & Zee, 1987). Age related degenerative loss in the vestibular organs is well established (Zalewski, 2015; Rauch, Velazquez-Villasenor, Dimitri, & Merchant, 2001; Tang, Lopez & Baloh, 2001-2002). The degeneration might occur with some asymmetry similar to what is seen in the cochlea, causing presbycusis. The vestibular asymmetry associated with ageing might then need to be compensated for within the central nervous pathways of the vestibular reflexes (Jäger & Henn, 1981). Vestibular adaptation is mainly effective in the lower frequency range of the vestibular system (Jäger & Henn, 1981). Therefore, the initial fast head movements in a fall might be in a frequency range outside that of the typical compensation (Kristinsdottir et al, 2001).

The high incidence of vestibular asymmetry among our people with wrist fractures is like previous findings (76%) by Kristinsdottir et al. (2001) among people with fall-related wrist fractures. Hansson et al. (2014) found a somewhat lower incidence of vestibular asymmetry (65%) in a similar research group. In our group of participants, the occurrence of nystagmus was seen, yet the individuals were asymptomatic, physically active, and not complaining of dizziness or unsteadiness, as demonstrated by their low DHI and high ABC scores. These individuals were unaware of any disturbance in their control of balance. Therefore, they might not be as careful in circumstances that can be challenging for their balance, compared to people aware of their instability from previous experiences.

The prevalence of vestibular asymmetry was significantly higher in our people with wrist fractures than in the controls (63%), indicating a possible association between vestibular asymmetry and fall-related wrist fractures. Vestibular information is important in fast postural movements and hence important when preventing a slip turning into a fall (Petersen, Magnusson, Fransson & Johannsson, 1994). Tripping and slipping were the most frequent reported reasons for the fall among our people with wrist fractures. Usually, when people trip or slip, preventive postural reactions are triggered by a combination of proprioceptive and vestibular inputs to avoid a fall (Allum & Honegger, 1995). The vestibular system provides information on the direction and magnitude of head and body movements. Via the vestibulo-spinal tract, the brain generates muscle activity in the neck, trunk and limbs that help maintain an upright posture and prevent falling (Brodal, 1998; Kandel, 1991). An asymmetric vestibular function provides inaccurate information on the direction and magnitude of head and body movements, which might cause under or over estimation of the avoidance reactions, resulting in a fall (Vidal et al., 1999).

We additionally studied the association between sensory and physical dysfunction and age in our case-control cohort. Our results revealed that higher age was related to a lower vibration sensation, slower walking speed and poorer functional muscle strength in lower limbs. This is in accordance with the results of other studies (Kristinsdottir et al., 1997; S. R. Lord et al., 2002; Xie et al., 2017). However, there were no differences between age groups in SOT, DHI and ABC, possibly indicating that relevant changes in these variables occur later in life. There were no differences in monofilament sensation between age groups, which contrasts with findings by Rinkel et al (2017), who reported age-related changes in monofilament sensation among healthy individuals in the age range 20.8-89.8 years, arranged into seven groups, each with a ten-year span. The apparent discrepancy in monofilament sensation and age could possibly be explained by the use of different test locations in the two studies. Rinkel et al used five locations; pulp of the first and fifth toes, medial heel, first web, and lateral foot, chosen in accordance with the nerve distribution of the foot. In the present study three locations were used; plantar surfaces of the caput of the first and fifth metatarsal bones as well as the centre of the plantar surface of the heel. These points were chosen as they play a major role in detecting weight distribution on the soles of the feet.

We further examined whether some of the observed parameters in the case-control study were independently associated with having sustained a fall-related wrist fracture. Our results revealed that by having two or more fast eye beats on the HST, i.e. an asymmetric vestibular function, the risk of a wrist fracture increased five times. With each additional gram needed to sense plantar pressure the risk of being in the wrist fracture group increased almost four times. With each additional micrometre needed to sense plantar vibration the likelihood increased 18%. These associations were independent of postural control, perceived dizziness handicap and confidence, walking speed or lower limb muscle strength. We also found a positive association between lower limb functional muscle strength and fall-related wrist fracture. With each additional second on the FTSTS the likelihood of being in the fracture group increased two times. Similar analysis has not been conducted previously, to the best of our knowledge. However, these variables are known to be associated with instability, falls and fractures (Benichou & Lord, 2016; Dettmer et al., 2016; Hansson & Magnusson, 2013; Kristinsdottir, Fransson, et al., 2001; Kristinsdottir et al., 1997, 2000; Kristinsdottir, Nordell, et al., 2001; Peters et al., 2016).

5.1 Methodological strengths and limitations

The studies in this thesis had several limitations, some of which have been mentioned previously.

In the pilot study (Paper I), no comparison group was included, so outcomes could not be compared with another training method among the study population. Vibration perception was measured with a tuning fork and vestibular function with a stepping test. Neither of these measurements are precise, therefore they were not repeated after training and no information was gathered on post training sensory status.

The participants in the randomized controlled trial (Paper III) were healthy and well functioning as they were at a relatively young age, thus possibly masking the true potential of the MST. By using no upper age limits for participation in the training, it is likely that a higher proportion of the individuals would have had age- and disease-related degenerative changes affecting balance control. Adding inclusion criteria for participation in the training, such as impaired sensation or balance, could also have been relevant. Both are likely to have increased the number of participants that would have benefited from the MST. The participants completed an exercise diary, but their adherence to the home exercises cannot be verified. The protocol of the randomized controlled trial was not prospectively registered to an international public trial registry, as this was not a common practice in physiotherapy research in Iceland at the initiation of this project.

In the case-control study (Paper II), the size of the control group was determined as 1:2 in relation to the size of the group of people with fracture due to homogeneity among control subjects. However, by increasing the number of people in the control group to match the number of people in the fracture group, the power of results might have increased further. Vestibular asymmetry was identified with the HST, which has shown good specificity (82%) but less sensitivity (45%) in pooled analysis (Dros et al., 2010). Thus, the proportion of participants correctly identified as having asymmetric vestibular function, could have been overestimated. It should as well be noted that an observed association in a case-control study does not necessarily imply causality. Future epidemiological studies with a longitudinal design or intervention studies are needed to confirm our findings.

The studies had several strengths that are highlighted below. The MST was a novel exercise training method that had not previously been described or tested. To the best of our knowledge, no previous studies have compared the function of the sensory systems, postural control and functional abilities between individuals with and without a fall-related wrist fracture, matched according to age, sex and weekly physical activity level. It was as well a strength in the case-control study, to select the age range 50-75 years. It is likely that this age group had fewer comorbidities and age related changes, than people at higher age, which could have affected the results.

6 Future perspectives

As described in the introduction of this thesis (1.1. Instability falls and fractures) falls and fractures are a major health concern associated with increasing age.

- About one-third of all people over 65 years of age sustain a fall each year and the likelihood of falling doubles every five years with advancing age.
- Injuries and fractures are common consequences of falls.
- Previous fracture is associated with a significantly increased risk of a fracture later in life.
- Wrist fracture is often precursor to the more serious hip fracture.
- Hip fractures cause serious disruption to the life of the sufferer and socioeconomic challenges for society.

Predictive and preventive measures are therefore important to prevent future falls and fractures.

In the present study we found that people age 50-75 years, with a fall-related wrist fracture, had developed various factors that are known to increase fall risk. Additionally, we revealed that some of them are strongly associated with having sustained a fall-related wrist fracture. Consequently, these factors could be used to screen for fall risk and identify those who are in need for further assessment and treatment. In the current emergency care settings in Iceland, this patient group receives treatment for the wrist fracture. Education regarding fall-prevention is not provided as part of standard care. Factors that we found to be strongly associated with a fall-related wrist fracture, such as postural control, vestibular function, sensation in the feet and lower-limb strength are usually not evaluated. Individuals who are considered potentially to benefit from a fall preventive service should have access to an evidence-based balance training program, such as the “Reykjavik Model”.

Additional research is needed to explore further the effectiveness of the multi-sensory balance training regimen, the “Reykjavik Model”, used in present study. It could be meaningful to investigate how this training impacts function of the sensory systems and confirm whether it has the potential to reduce the number of falls. Such a study of the effectiveness of the MST could be conducted among unsteady people who have fallen, using sensitive and modern assessment tools and collect information about fall-rates in a systematic manner. By adding a comparison group, enlarging the sample size and performing the study in multiple rehabilitation settings, generalization of potential findings would be reinforced. It would be interesting to study the effects of multi-sensory balance training program among other groups, such as people with reduced sensation in their lower limbs, including people with diabetic peripheral neuropathy. Additionally, it is of interest to explore the true potential of the MST among people with confirmed vestibular dysfunction, including those with asymmetric vestibular function. People with neurological diseases, such as stroke, Multiple Sclerosis or Parkinson´s disease would as well be of interest for future studies.

It should be emphasized that an observed association in a case-control study does not necessarily imply causality. Future epidemiological studies with a longitudinal design or intervention studies are needed to confirm our findings.

7 Conclusions

People with wrist fracture have a higher incidence of asymmetric vestibular function, reduced plantar pressure sensation and poorer standing and dynamic postural control compared with matched controls.

Asymmetric vestibular function and reduced plantar pressure sensation are strongly associated with a fall-related wrist fracture and could be an important contributing factor to falls and subsequent wrist fractures among the ageing population.

The multi-sensory balance training program, the “Reykjavik Model”, described and studied in this thesis, improves postural control, functional ability and confidence in activities of daily living among unsteady older people. The results suggest that this multi-sensory balance training program can reduce the rate of falls among older unsteady individuals.

The multi-sensory training program improves postural control among people age 50-75 years who have sustained a fall-related wrist fracture. The results further suggest that the program is more effective for people with wrist fractures with balance scores below age related norms on the Sensory Organization Test.

People with wrist fractures in this study were healthy and functioned well within the community, but were shown to have risk factors for future falls and fractures. They should therefore be screened for fall and fracture risk besides fracture treatment. Education regarding fall-prevention should be provided to all persons who fracture their wrist.

Interest should be directed to balance and vestibular dysfunction together with the status of sensation in the lower extremities among people with fall-related wrist fractures. By better screening for future fall risk, there could be a reduction in catastrophic falls.

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RESEARCH PAPER

Effect of multi-sensory balance training for unsteady elderly people: pilot study of the "Reykjavik model"

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Abstract

Purpose: To evaluate effects of combined mechano- and proprioceptive, vestibular and fall-prevention training on postural control, functional ability, confidence in activities of daily living (ADL) and frequency of falls among unsteady elderly people. *Method*: Subjects were 37 elderly outpatients attending physiotherapy because of instability. Treatment consisted of 18 multisensory balance training sessions. Results from Sensory Organization Test, Five-Times-Sit-to-Stand Test, 30-m normal and fast walk with a turn, Ascending–Descending 11 steps and Activities-specific Balance Confidence Scale were compared before and after training. Information was gathered about number of falls 1 year prior to training, during training period and for 6 months after completion of training. *Results*: Significant improvement was observed in all measured parameters ($p < 0.001$). The subjects aged between 70 and 92 years (mean age 80.8 years), had considerable medical history. Thirty four of them reported 159 falls in the year prior to the study. Six subjects reported seven falls during the training period and seven subjects reported 17 falls in the 6 months follow-up period. *Conclusions*: Combined vestibular, proprioceptive and fall-prevention training improve postural control, functional ability, confidence in ADL and might even decrease the risk of falling among elderly people.

Keywords

Balance, elderly, fall prevention, postural control, proprioception, training, vestibular

History

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➤ Implications for Rehabilitation

- Decreased proprioception in the lower limbs and vestibular dysfunction is common among elderly people.
- Stimulation of the sensory systems and training of fall-prevention movements is essential when improving postural control among elderly people.
- Multisensory training increases functional abilities, confidence in activities of daily living and possibly reduces rate of falls among elderly individuals.

Introduction

Postural instability and unsteadiness of gait together form one of the major problems faced by the older population. It compromises the ability to perform safely everyday activities and to interact with various types of environments in daily living. The impaired functional mobility not only leads to a sense of bodily insecurity with consequent restriction of activity but also is frequently the cause of damaging falls [1,2]. About one-third of all people over 65 years of age sustain a fall each year [3–5]. Injuries and fractures, particularly hip fractures among elderly people, often result in major changes in the lives of the sufferers, and even death and are costly for the community [6–8].

Different training methods have been used through the years in order to improve postural stability and decrease the rate of falls. There is weak evidence that some types of exercises are moderately efficient immediately after intervention. It is difficult to determine the most effective training program, as many trials report results from a mixture of different exercise regimes [9–11]. Considerable emphasis has been placed on increasing muscle strength and power in order to enhance functional performance and prevent falls in elderly people [12–14]. Progressive resistance training has not as an isolated intervention, consistently shown to improve balance performance in older adults [15], although there is some evidence for a relationship between muscle function and balance performance [16]. Steadman et al. [17] reported that both conventional and enhanced balance training improved functional balance and mobility in patients with balance problems independent of strategy. Comparatively limited knowledge exists about the effect of sensory training on balance performance. Training directed at facilitation of the sensory systems [18] as well as perturbation-based and multitask training has been reported to be beneficial for elderly people [19,20].

Control of human upright posture is the basis for locomotion and most functional activities. It involves coordinated muscle

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responses to control the position and movement of the body's centre of mass and alignment of body parts with reference to the gravitational forces and other environmental features. The muscular activity is dependent on sufficient and coherent mechanoreceptive, proprioceptive, vestibular, and visual information [21–24]. The multisensory input is synchronized at several levels within the central nervous system. Appropriate motor patterns are then selected for postural adjustments and movements, based on past experiences [25]. Postural control can be looked at as a feedback mechanism consisting of two semicircles, sensory information and execution of movements, where both semicircles are of fundamental importance for the control of posture and movements [26].

Age-related degenerative changes affect all domains involved in postural control. Kristinsdottir et al. [27,28] found that elderly individuals with decreased vibration sensation in lower limbs have increased vibration-induced postural sway and unfavourable postural strategies compared with those with good vibration sensation. Their sway gradually decreased during vibration, lasting only 200 s. These results lead to the idea that specific sensory training might improve the use of mechano- and proprioceptive impulses resulting in more efficient control of posture.

Age-related degenerative changes in vestibular organs significantly affect control of posture, especially if these occur with an asymmetry. An asymmetrical vestibular function has been found amongst 37% of healthy elderly people who had not sustained a fall. In contrast, it was found in 68% of hip fracture subjects and 76% of wrist fracture subjects [29,30]. Vestibular asymmetry disturbs fall-prevention movements which become smaller or distorted leading to increased danger of falling and imbalance in connection with head movements increases [31,32]. The association of vestibular asymmetry with falls and fractures initiated the idea that vestibular and fall-prevention training could be beneficial for postural control and decrease the danger of falling.

On the basis of the above mentioned research a new specific multisensory training method to improve postural control and prevent falls was initiated at the Department of Geriatrics at Landspitali National University Hospital (LNUH), Reykjavik, Iceland. To our knowledge such a training method has not been described before.

The aim of this pilot study was to evaluate effects of combined mechano- and proprioceptive, vestibular and fall-prevention training on postural control, functional ability, confidence in activities of daily living (ADL) and falls among unsteady elderly people.

Methods

Subjects

Over a 15 months period, 200 consecutive outpatients attending physiotherapy at the Department of Geriatrics, (LNUH) were screened for participation in the study.

Inclusion criteria

- Having sustained a fall/falls
- Complaining of unsteadiness and/or fear of falling in an interview
- Able to stand unsupported for 2 min
- Able to walk 30 m unsupported or with an aid of a stick/crutch
- Scoring more than 21 on the Mini Mental State Examination scale [33].

Fifty-one patients met the inclusion criteria, five of those became ill and nine did not complete the treatment protocol, leaving 37 (32 females, five males) individuals completing the study (Figure 1).

Subjects signed an informed consent prior to participation in the study, which was approved by the Bioethics Committee of LNUH and reported to The Data Protection Authority of Iceland.

Evaluation

Vibration perception was tested with a tuning fork (128 Hz) in order to assess sensory status in the lower limbs. It was graded from 1 to 3, as described below [28].
Sensation 1: vibration detected at base of first metatarsal bone, medial malleolus and tibial tuberosity
Sensation 2: vibration detected at medial malleolus and tibial tuberosity
Sensation 3: vibration only detected at tibial tuberosity

Stepping test was used as an indicator for vestibular asymmetry. The subjects walked 50 steps in place in bare feet, arms elevated forwards and eyes closed [34]. Angular deviation was noted.

These tests are easy to perform and readily available in most clinical settings. They were only used for baseline measurements on sensory status to support emphasis in treatment. The tests were not repeated after treatment.

Self-reported falls

The subjects were asked about number of falls during 1 year period prior to the study and asked to keep a diary of falls during the treatment period and the following 6 months.

Measurements

Sensory Organization Test in the Smart Balance Master® (NeuroCom, Clackamas, OR) was utilized to measure control of posture. The test evaluates the subjects' ability to make effective use of somatosensory, visual and vestibular inputs and suppress

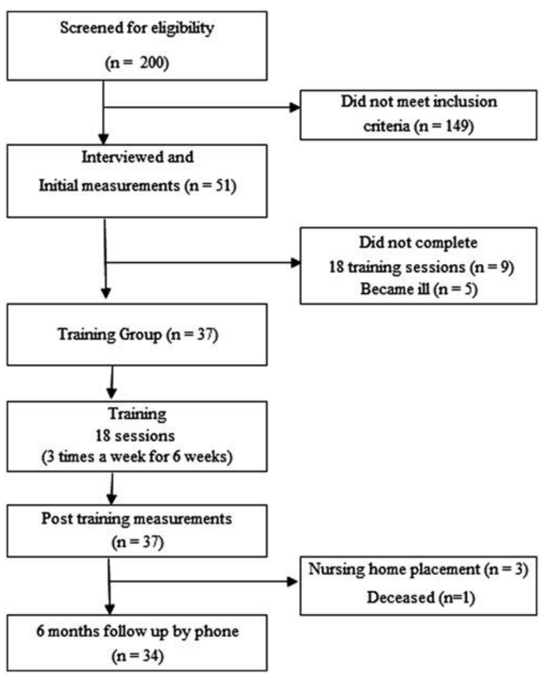

Figure 1. Study flow chart.

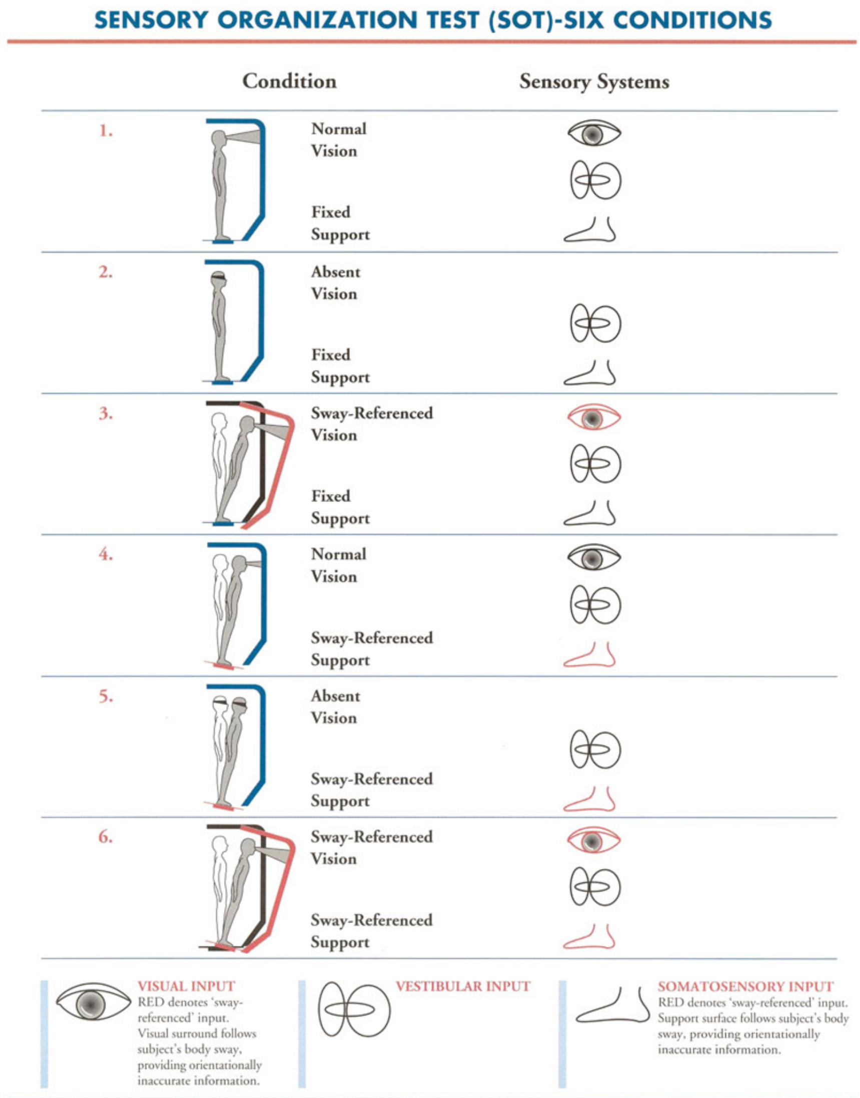

Figure 2. ''Image courtesy of Natus Medical Incorporated''.

inappropriate sensory information. Composite scores of postural sway from the six different sensory conditions were used for analysis. Further description of the Sensory Organization Test and the measuring procedure has previously been published [35,36]. Computerized dynamic platform posturography such as the Sensory Organization Test has gained wide acceptance as a method of measuring postural control [37,38]. The test has fulfilled most criteria that are required of a reliable and valid test of postural stability [39,40] (Figure 2).

Functional tests

Five-Times-Sit-to-Stand Test was used to evaluate functional ability and strength in the lower limbs. The test has displayed discriminative and concurrent validity properties and reproducibility and is therefore suitable for comparing lower extremity strength in patients from one visit to the next [41,42].

Normal and fast 30-m walk with a turn was timed in order to assess the key elements in walking and safety during turning. The test is reliable and easy to perform in clinical settings [43,44].

Ascending–descending 11 steps was timed to test the ability and confidence during this important activity for many people. The test has shown to have good inter-rater reliability [45].

Activities-specific Balance Confidence Scale was utilized, where the subjects rated their own confidence in 16 ADL on a percentile scale from 0 to 100 [46]. The Scale has demonstrated strong internal-consistency reliability and validity when self-administered [47].

Training procedure

Multi-sensory training according to the ''Reykjavik model''

The subjects attended 18 individual training sessions, lasting approximately 45 min, 3 times a week. Each session started with a

15 min warming-up period walking at a comfortable speed on a treadmill, wearing shoes and holding onto the bars for stability, followed by stretching of the muscles in the lower limbs.

Then they underwent the multi-sensory training program consisting of:

- proprioceptive training, mainly for the lower limbs
- vestibular and eye control training
- facilitation and integration of proprioceptive and vestibular impulses
- fall-prevention movements

The exercises were performed barefooted on firm and soft surfaces, during quiet stance and movements. During exercises, subjects were encouraged to pay attention to and control weight distribution on the soles of the feet and movements of the body. They were discouraged to use hands or the body for external support. Control of posture was practised during fixation of gaze and movements of the head in different directions, head kept still and eyes moved, as well as head moved with eyes closed. The subjects were taught how to react to sudden disturbances by taking a step to hinder falling and use stepping reactions when their stability was challenged by manual push in different directions. The exercises were chosen from a list (see Appendix 1) according to the main weaknesses of each subject, tailored close to the limits of their capability and progressed continuously according to their improvements. Each training session was thoroughly recorded. The training demanded the physiotherapist to be well aware of each individual's capabilities. For safety, waist harness was used in order to prevent falling or accidents during training sessions. If necessary, exercises were performed close to a wall, in a corner of a room or in a parallel bar.

The same physiotherapist was responsible for all training sessions. In order to avoid bias, another physiotherapist performed all measurements. The outcome of measurements before training was not available when measurements were repeated.

Statistical analysis

The outcomes from different tests were compared before and after training. Wilcoxon signed-rank test was used to compare measurements before and after training as the values were not normally distributed. Effect sizes were calculated using Choen's d statistic. In this study, Choen's d is the difference between before training means and the after training means divided by a standard deviation of the difference between the two time measurement moments. Large magnitude of effect is considered to be $d \leq 0.8$, medium sized effects 0.5–0.8 and small effects <0.5 [48]. SPSS software (version 11) was used for all analysis and $p \leq 0.05$ considered significant.

Results

The subjects were between 70 and 92 years of age with a mean age of 80.8 years with considerable medical histories (Table 1). All the fractures among the subjects were sustained more than 3 months prior to the study. All the subjects except two of them were on different types of medications: tranquilizers, anti-depressives, anti-hypertensive/arrhythmic and analgesics. There were no changes in medication made during the training period. Decreased vibration sensation, as measured with a tuning fork, was frequently observed as well as vestibular dysfunction, according to performance on the stepping test (Table 2). As can be seen in Table 3, 34 subjects reported falls during 1 year period prior to the study. Six subjects sustained a fall during the training period and seven during the following 6 months. At follow-up, one of the subjects had died and three admitted to nursing homes because of serious illnesses.

Table 1. Medical history.

Medical findings	($n = 37$)
Compression fracture of spine	10
Fracture of rib	1
Fracture of pelvis	1
Fracture of hip	4
Fracture of patella	1
Fracture of ankle	2
Fracture of humerus	2
Fracture of wrist	18
Rupture of quadriceps tendon	1
Hip or knee replacements	5
Osteoarthritis	10
Discus prolaps (treated)	2
Rheumatoic arthritis	2
Spinal stenosis	1
Dizziness	19
Lung complaints	8
Hypertension (treated)	13
Hypotension (treated)	5
Coronary arterio-sclerosis	6
Irregular heartbeat (treated)	2
Pacemaker implantation	1
Heart-valve operation	2
Intermittent claudication	2
Diabetes (treated)	4
Periferal neuropathy	1
Recovered stroke	4
Parkinsons disease	1
Cerebellar degeneration	1
Oesophageal tumour	1
Brain tumour	1
Glandular tumour	1

Table 2. Vibration sensation and performance on the stepping test.

Sensation	$n = 37$		Stepping test	$n = 37$	
1	6	16%	No rotation	5	13%
2	6	16%	Rotation	25	68%
3	25	68%	Incapable	7	19%

Incapable = Unable to perform the test because of falling tendencies.

Table 3. Self-reported falls.

	Subjects (n/N)	Falls (N)
Prior	34/37	159
During	6/37	7
After	7/34	17

Prior = 1 year prior to training. During = 6 weeks training period. After = 6 months after completion of training.

Figure 3 presents outcome measures before and after training. The means, range, standard deviations, p values, and effect sizes are presented in Table 4. The subjects performed significantly better in all the tests as indicated by the p values (<0.001). The improvements are also displayed by medium effect sizes for all the tests except for the FTSST showing a small effect size. One subject declined to answer the ABC questionnaire and one outlier on the SOT test was not included in the statistical analysis.

Discussion

The results of this pilot study show that specific multisensory and fall-prevention training is an effective intervention to enhance postural control, functional ability and confidence in daily activities among unsteady elderly outpatients. The training also appears to decrease the rate of falling.

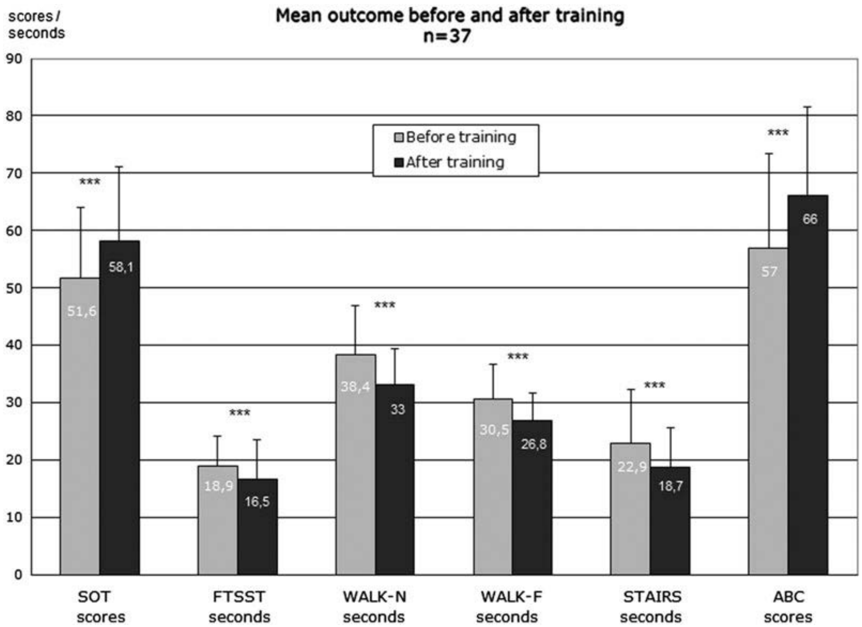

Figure 3. SOT, sensory organization test; FTSST, five-times-sit-to-stand test; WALK-N, 30-m walk with a turn at normal speed; WALK-F, 30-m fast walk with a turn, STAIRS, ascending and descending 11 steps, ABC, activities-specific balance confidence scale. ***$p<0.001$.

Table 4. Means, range, standard deviations, *p* values and effect sizes before and after training.

	Before			After				
	Mean	Range	SD	Mean	Range	SD	*p*	ES
SOT	51.61	20–75	12.33	58.14	25–78	13.02	0.000	0.52
FTSST	18.87	11–31	5.19	16.50	10–52	7.00	0.000	0.38
WALK–N	38.40	24–58	8.44	33.04	23–52	6.30	0.000	0.71
WALK–F	30.51	18–45	6.14	26.81	18–38	4.80	0.000	0.67
STAIRS	22.90	12–51	9.45	18.74	11–47	6.84	0.000	0.50
ABC	57.04	20–90	16.41	66.00	33–90	15.51	0.000	0.54

SOT, Sensory Organization Test (composite scores); FTSST, Five-Times-Sit-to-Stand Test (seconds); WALK-N, 30-m walk with a turn at normal speed (seconds); WALK-F, 30 m fast walk with a turn (seconds); STAIRS, ascending and descending 11 steps (seconds); ABC, activities-specific balance confidence scale (scores); SD, standard deviation; *p*, values; Wilcoxon signed-rank test; ES, effect size.

The subjects were elderly individuals, attending physiotherapy at a geriatric unit because of unsteadiness and falls. Besides old age and instability many of them suffered from numerous comorbidities. They had decreased sensation in the lower limbs, vestibular dysfunction and multiple falls and fractures. Six months after completion of the training, one subject was deceased and three had been admitted to nursing homes, which reflect the severity of the subjects' medical conditions.

Different types of interventions have been utilized in order to enhance postural control and prevent falls in older people living in the community [49,50]. Gauchard et al. [51] reported that regular physical activity maintains the efficiency of the reflexes involved in postural control which stimulates central integration and more appropriate motor responses. The training procedure in this study was aimed at stimulating the subjects to utilize more efficiently sensory information from the different sensory organs, as age-related degenerative changes affect all domains involved in postural control [26]. Decreased mechano- and proprioceptive sensation in connection with aging tends to change the postural control patterns. The control strategy moves from the ankles to the hips and subsequently postural sway increases in amplitude and velocity [27,52]. The subjects were taught to be aware of their postural control pattern and change it to the more favourable ankle strategy. In order to utilize better the mechano-receptive impulses and stimulate proprioceptive adaptation the subjects performed the exercises in bare feet [53].

Vestibular rehabilitation has shown to be beneficial for individuals with vestibular disorders [54–56]. In this program, vestibular training was performed during stance and movements and simultaneously the subjects were encouraged to keep their attention on weight distribution on the soles of the feet. With increasing age there is a decline in both the optokinetic and vestibulo-occular reflexes [57]. As a consequence, it becomes more difficult to visualize and follow a moving object and imbalance in connection with head movements increases [58,59]. Therefore, the program also included exercises for eye control during stance and movements. Stepping reactions to prevent falls were practiced since fall-prevention movements become smaller or distorted in connection with age-related vestibular decline [32,60]. By training the different sensory systems separately and combined, the subjects learned to rely on the most appropriate sensory information and suppress those which are more undependable. In this manner, proprioceptive adaptation and sensory-motor coupling mechanism were stimulated.

The different tests in this study were chosen in order to get comprehensive information with regards to function of the different sensory systems as well as functional capability in daily activities. All the tests are well known and have been used in several studies and in clinical practise. Recordings of the forces actuated by a subjects feet on the supporting surface can objectively measure postural performance. Assessment of quiet stance is not considered sensitive enough to always identify instability, therefore, perturbing the different sensory systems as provided in the Sensory Organization Test should give a more comprehensive assessment of postural control [61].

Comparison of our results with previously published data is difficult as the majority of studies were carried out on considerably younger people without so many serious medical diagnoses.

Thirty-two subjects showed vestibular dysfunction on the stepping test, which indicates impaired control of posture. Whitney et al. [62] found a relationship between composite SOT scores and reported falls among people with balance and vestibular disorders. They reported a mean composite SOT score of 55 for none-fallers and 52 for one-time fallers. Our subjects had a mean SOT score of 51.6 prior to training which is close to the mean score of Whitney's et al. for one-time fallers. After the training period, our subjects showed a significant improvement in postural control with a mean SOT score of 58.1, which is slightly higher than the mean score for Whitney's et al. non-fallers. These improvements observed on the SOT test indicate that the multi-sensory training program enhances central integration of the different sensory impulses.

Apart from the improvement on the SOT test, there was a considerable reduction in incidence of falls. At first attendance 34 of our subjects reported a total of 159 falls in the preceding year. This information is unreliable as it was based on the subjects' memory but not collected in a systematic manner. On the other hand, it indicates that our subjects had sustained a great number of falls prior to training. The reported falls during training and the following 6 months are more trustworthy as the subjects kept a diary on falls. Only 13 subjects reported falls during those periods. Thus, it is reasonable to assume that this training method can reduce number of falls among unsteady elderly people.

Falls and consequences of falling can have a great effect on elderly people. Those, having experienced a fall or fall-related trauma are likely to reduce their physical activity because of fear of a new fall. Their confidence in daily activity decreases which can be quantified by using the ABC scale [46]. The subjects in this study had a mean score of 57 before training similar to reported scores for elderly people with previous hip fractures [1,2]. After training, the subjects scored 64, which is slightly higher than Whitney et al. [62] reported for elderly none-fallers. The significant improvement in confidence can be of major importance. Increased self-assurance can break up the vicious circle of fear of falling and avoidance of physical activity which can lead to increased disability and risk of further falls.

The subjects also showed significant improvement in all functional tests, although their performance did not reach the same level as has been reported among considerably younger healthier elderly people [12,13,45,54]. Improvements in the Sit-to-Stand test and Ascending–Descending stairs indicate increased functional strength in lower limbs, even though the multisensory training did not include specific strengthening exercises.

This pilot study has some limitations. Outcomes of current study cannot be compared with other training methods as no comparison group was included. Measuring vibration perception with a tuning fork and assessment of vestibular function with a stepping test are not precise instruments. Due to the coarse scale of the measurements, they were not repeated after training and therefore no information was gathered on post training sensory status. Another potential limitation is the small group size and the single hospital setting which limits the generalisation of the findings.

Based on the results of this pilot study, further research on the efficiency of the ''Reykjavik Model'' is now in progress in a randomized controlled trial. In this project, a thorough scientific evaluation of the sensory training regime will be conducted. The evaluation will be based on measurements quantifying functions of the key sensory systems, using more sensitive and modern assessment techniques to explore how this treatment impacts the functions of the sensory systems.

Clinical practice implications and conclusion

Combined vestibular, proprioceptive and fall-prevention training improves postural control, functional ability, confidence in ADL and might even decrease the risk of falling among elderly people. Hence, systematic stimulation of the sensory systems is of utmost importance when improving postural control among elderly individuals.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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Appendix 1

Reykjavik Model Sample of Exercises

Exercises performed with bare feet

Focus is on weight distribution on the soles of the feet

Proprioceptive training

Standing

Exercises performed with eyes open and then closed:

(1) Sensing weight distribution on the sole of feet
(2) Weight shift from side to side
(3) Weight shift forwards and backwards
(4) Moving arms in different directions
(5) Stamping feet on the spot

Standing on a balance cushion, foam or trampoline

Exercises 1–4

Walking

(6) Paying attention to weight distribution on the feet
(7) Stamping feet
(8) Walking on uneven surfaces and surfaces with different textures

Vestibular and eye control training

Sitting

(9) Head kept still, eyes moved in all directions or following a moving target
(10) Eyes kept still during movements of the head in all directions
(11) Moving the head in all directions, eyes following head movements
(12) Moving the head in all directions with eyes closed
(13) Quick rotation of the head with fixed gaze
(14) Quick rotation of the head, eyes following head movements
(15) Quick rotation of the head with eyes closed

Sitting on a rotational chair

(16) Chair rotated irregularly in both directions with eyes open and closed

Standing

Exercises 9–15

Standing on a turning disc

(17) Disc rotated irregularly in both directions with eyes open and closed

On trampoline

(18) Walking and bouncing

Combined proprioceptive and vestibular training

Standing on a balance cushion, foam or trampoline

Exercises 9–15

(19) Reaching for an object in different directions
(20) Catching and throwing a ball
(21) Keeping a balloon in the air

Walking

Exercises 20–21

(22) Moving head in all directions, fixing gaze on surrounding objects
(23) Quick right and left turns

Sitting on a rotational chair or standing on a turning disc

(24) Chair/disc rotated irregularly in both directions while reading text

Fall reaction training

Standing

(25) Practising quick stepping actions in different directions to prevent a fall
(26) Subjects pushed in different directions with and without prior warning

Walking

(27) Subject pushed irregularly in different directions with and without prior warning

Training method instigated by:
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ORIGINAL REPORT

SENSORY IMPAIRMENTS AND WRIST FRACTURE: A CASE-CONTROL STUDY

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Objectives: **To investigate vestibular function, foot sensation, postural control and functional abilities, and to evaluate whether these variables are associated with fall-related wrist fracture.**

Methods: **A case-control study was conducted with 98 subjects, age range 50–75 years, who had sustained a fall-related wrist fracture. Forty-eight sex-, age- and physical activity-matched individuals, with no previous history of wrist fracture, served as controls. Measurements included: head-shake test (HST), tuning fork, biothesiometer, Semmes-Weinstein monofilaments (MF), Sensory Organization Test (SOT), Five-Times-Sit-to-Stand Test (FTSTS), 10-m walk test (10MWT), Activities-specific Balance Confidence (ABC), and the Dizziness Handicap Inventory (DHI) scales. Logistic regression models were used to determine associations of variables with a fall-related wrist fracture.**

Results: **Vestibular asymmetry was apparent in 82% of wrist fracture subjects and 63% of controls ($p = 0.012$). Plantar pressure sensation ($p < 0.001$), SOT composite scores ($p < 0.001$), 10MWT ($p < 0.001$), FTSTS ($p < 0.001$), ABC ($p < 0.001$) and DHI ($p < 0.005$) were significantly poorer among cases than controls. A positive HST (odds ratio (OR) 5.424; $p = 0.008$) and monofilament sensation (OR 3.886; $p = 0.014$) showed the strongest associations with having a fall-related wrist fracture.**

Conclusion: **Asymmetrical vestibular function and reduced plantar pressure sensation are associated with fall-related wrist fractures among the ageing population. These factors are potential targets for future interventions.**

Key words: wrist fracture; vestibular-asymmetry; plantar sensation; postural control; functional ability.

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Falls and fractures in older adults are a major health issue and socioeconomic challenge for Western societies. Each year approximately one-third of people over 65 years of age sustain a fall (1), which can result in a fracture. Wrist fracture (distal forearm fracture) is the most common first fracture among Icelandic women, with a sharp increase in incidence between 45 and 60 years of age, and is the third most common first fracture among men (2). Wrist fracture is a strong predictor of future fracture risk (3) and is often a precursor to the more serious hip fracture (4), which can result in decreased quality of life, death, and increased health cost (5).

Our upright posture is unstable from a biomechanical point of view. In order to control it, coordinated muscular activity, dependent on sufficient and coherent mechanoreceptive, proprioceptive, vestibular and visual information, is needed (6). Multisensory input is synchronized at several levels within the central nervous system (CNS). Appropriate motor patterns are then selected for postural adjustments and movements (7). Age-related degenerative changes affect all domains involved in postural control and become apparent between the ages of 40 and 50 years (8). Decreased vibration sensation in the lower limbs has been associated with increased postural sway among healthy older adults (9). An association of vestibular asymmetry with falls and wrist fractures (10, 11), as well as hip fractures (12), has been reported. Body-orienting reflexes, muscle strength and tone, and step length and height all decline with age, and impair the ability to avoid a fall after an unexpected trip or slip (13).

Fear of falling has been recognized as an important psychological factor associated with falls (14). Fear of falling can lead to decreased confidence in daily activities and a vicious circle of increased disability and risk of further falls. In addition, fear of falling has been shown to be an independent predictor of decline in physical function (15). The prevalence of dizziness among older adults is substantial (16) and has been identified as a risk factor for falls (17).

Limited research has been performed into mechanoreceptive sensation in the lower limbs among people who have sustained a wrist fracture, and the prevalence of asymmetrical vestibular function among this group has not been compared with matched controls. In addition, the associations between postural control, vestibular function, mechanoreceptive sensation in the lower limbs, functional ability, perceived dizziness, fear of falling, and wrist fractures are not clear.

The aim of this case-control study was to investigate vestibular function, mechanoreceptive sensation in the lower limbs, postural control, functional abilities, perceived dizziness and confidence in individuals in the age range 50–75 years with and without fall-related wrist fractures. The associations between sensory and physical dysfunction and age were examined. In addition, multivariate models were used to determine whether vestibular, mechanoreceptive and physical functions are independently associated with being in the wrist fracture group.

MATERIALS AND METHODS

Subjects

A total of 146 persons agreed to participate in this case-controlled study. Of these, 98 (85 women, 13 men) had sustained a fall-related wrist fracture (mean age (standard deviation; SD): 61.9 (7.1) years; range 50–75). They were identified from medical records at the emergency department of Landspitali, University Hospital in Iceland and recruited for the study 2–5 months after the fracture. They were screened for eligibility from a total of 440 consecutive patients during a 12-month period. Exclusion criteria were a confirmed diagnosis of degenerative CNS disease, such as Parkinson's disease, Alzheimer's disease, and other diseases that impair mobility and cognitive function. Half of the patients ($n=219$) did not fulfil the inclusion criteria, thus 221 patients were invited to take part in the study. The participation rate of eligible patients was 44%. The enrolled subjects were healthy, although some were taking medication for hypertension ($n=29$), high cholesterol ($n=14$), diabetes type 2 ($n=2$) and vitamin B12 deficiency ($n=1$). Fourteen subjects had a previous history of benign positional postural vertigo (BPPV). A comparison group was comprised of a convenience sample of 48 healthy individuals (38 women, 10 men) without previous history of fall-related wrist fractures, matched according to age, sex and weekly physical activity level during the previous 12 months. The control group was identified through a network of colleagues, friends and family members. Reported duration of physical activity was divided into 3 groups: <1 h/week, 1–3 h/week, and >3 h/week. The size of the control group was determined as 1:2 in relation to the size of the fracture group due to homogeneity among control subjects. The study was approved by the Icelandic National Bioethics Committee (VSNb2013110036/03.11) and performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All persons gave their informed written consent prior to inclusion in the study.

Questionnaires

Participants answered questions regarding their general health, including medication, previous falls and fractures, and level of weekly physical activity (h/week) during the previous 12 months. They were also questioned about the circumstances of the fall that had caused the distal forearm fracture.

Activities-specific Balance Confidence Scale (ABC). Participants rated their level of confidence while performing 16 activities of daily living, on a percentile scale from zero (no confidence) to 100 (complete confidence) (18). Individual items ranged in difficulty, from walking on level surfaces inside the home to walking outdoors on icy pavements.

Dizziness Handicap Inventory Scale (DHI). The DHI was utilized to assess the individual's handicap because of his/her dizziness and/or unsteadiness. The scale comprises 25 items relating to physical, emotional and functional domains. The range of possible scores on the DHI is 0–100; the higher the score, the greater the level of self-perceived handicap (19). If participants perceived themselves as dizzy they were assessed with the Dix-Hallpike manoeuvre to exclude BPPV (20).

Mechanoreceptive sensation

Each of the measurements shown below was conducted once per participant.

Vibration perception. A tuning fork (128 Hz) was used to assess vibration perception in the lower limbs. The sensation was graded from 1 to 3 according to the following criteria: Sensation 1: vibration detected at the base of first metatarsal bone, medial malleolus and tibial tuberosity. Sensation 2: vibration detected at the medial malleolus and tibial tuberosity. Sensation 3: vibration detected only at the tibial tuberosity. This method was used in accordance with other studies, on estimation of vibration sensation in the lower limbs among elderly subjects (9, 12, 21).

Biothesiometer electronic device. A biothesiometer (Model EG electronic BioThesiometer, Newbury, OH, USA) that generated a 120 Hz vibration of varying amplitude (in µm) was used to measure vibration perception on the plantar surface of the foot. Vibration was applied to the plantar surface of the first metatarsal bone (the base of the big toe), the fifth metatarsal bone (the base of the little toe) and the centre of the plantar surface of the heel. Subjects were asked to indicate to the examiner whether they were able to feel the vibration (yes/no) (22). Vibration was applied once in ascending intensity until the subject could feel the vibration and then in descending intensity until the subject could no longer feel the vibration. Vibration was applied again in ascending intensity until the subject could feel the vibration, which was registered as the perception threshold, in line with operational instructions from the manufacturer of the biothesiometer.

Tactile sensitivity. Semmes-Weinstein pressure aesthesiometer (Semmes-Weinstein Mono-filaments, San Jose, CA, USA) was used to measure tactile sensitivity. The aesthesiometer is composed of 20 nylon filaments of equal length, with varying diameters. The filaments were applied to the plantar surface of the same 3 points as the biothesiometer, and participants were instructed to report whether they felt it on the "heel", "at the big toe", or "at the little toe". The tactile sensation threshold was determined by presenting suprathreshold filaments initially, then applying thinner and thinner filaments until the subject could no longer detect them (23). The examiner then applied thicker filaments until the subject could detect them, which was determined as the touch threshold and presented as pressure (in g).

Vestibular function

A head-shake test (HST) was used to assess vestibular function. Goggles, equipped with an infrared-charged device camera (no visual cues), were used to record eye movements. Participants were exposed to a passive head shaking test (~2 Hz/20 s) in the supine position with the head in 30° of neck flexion with the eyes closed. After an abrupt halt of the head shaking, the eyes were immediately opened and eye movements were recorded (24). A specialist in neuro-otology experienced in nystagmoscopy, blinded to whether the recordings were from wrist fracture subjects or controls, evaluated the eye movements from the recordings. The test is considered positive for vestibular asymmetry when eye deviation occurs with 3 or more interposed fast phases, i.e.

nystagmus (25). An eye deviation of more than one interposed fast phase is considered a sign of weak asymmetry, especially if it prevails on repeated testing (10). In this study we used 2 or more fast eye beats as being a positive test as has been used in previous studies (10, 12). The HST was preferred to caloric irrigation as it is a functional test depending on both labyrinths simultaneously in the high frequency range. Furthermore, the HST was chosen to be able to compare results with previously published studies (10, 11).

Posturography

Sensory Organization Test in the Smart Balance Master (SOT); (Neurocom Inc., Clackamas, OR, USA) was utilized to measure postural control. The test evaluates the subject's ability to make effective use of somatosensory, visual and vestibular inputs and suppress inappropriate sensory information. Composite scores of postural sway from the 6 different sensory conditions were used for analysis. Further description of the SOT and the measuring procedure has been published previously (26).

Physical function

Five-Times-Sit-To-Stand Test (FTSTS). Functional lower limb muscle strength was measured with the FTSTS. The participants were instructed to rise from a chair with a seat height of 43 cm, as fast as possible, 5 times, with their hands crossed on their chest. The time (in s) was recorded (27).

10-m walk test (10MWT). Gait speed was measured with the 10MWT to assess locomotion as a part of balance control. A 20-m straight path was used, with 5 m for acceleration, 10 m for steady-state walking, and 5 m for deceleration. Markers were placed at the 5- and 15-m positions along the path. Participants began to walk at one end of the 20-m path and continued walking until they reached the other end. Timing started at the first marker and stopped when the participants crossed the second marker. The test was performed at their preferred walking speed and repeated at the subject's fastest speed. Gait speed was calculated (in m/s) as the distance covered divided by the time it took the individual to walk the distance (28).

Statistical analysis

Statistical analysis was conducted using SPSS for Windows version 24.0 (SPSS, Chicago, IL, USA) and the level of significance was set at $p < 0.05$. Data were checked for normality using the Kolmogorov–Smirnov test and are shown as median and ranges for not normally distributed variables and as mean (SD) for normally distributed variables. Comparisons between groups were made using the Mann–Whitney *U* test (not normally distributed variables) or independent samples *t*-test (normally distributed variables). Correlations between variables were calculated using Spearman's rho.

The Kruskal–Wallis test (not normally distributed variables) and one-way ANOVA, including Fisher's least significant difference (LSD) *post hoc* test (normally distributed variables), were used to find characteristics of variables by age group, each covering approximately one-third of the age range in the present study (group 1: 50–58 years, group 2: 59–66 years, group 3: 67–75 years). Logistic regression models were used to find associations of variables with having obtained a fall-related wrist fracture (see Table IV). Model 1 included mechanoreceptive sensation and vestibular function; model 2 additionally included postural control; model 3 additionally included perceived dizziness handicap and confidence; and model 4 additionally included walking speed and strength in the lower limbs.

RESULTS

Characteristics of participants and differences between the wrist fracture and the control groups are shown in Table I. There were significant differences between the groups for most of the variables, indicating poorer plantar pressure sensation and poorer vestibular and

Table I. Characteristics of participants categorized by group

Characteristics	Fracture group (*n*=98)	Control (*n*=48)	*p*-value*
	Median (25^{th}–75^{th} percentile)	Median (25^{th}–75^{th} percentile)	
Age, years	62 (56–67)	61 (55–67)	0.440
Falls previous 12 months (*n*)	1 (1–3)	0 (0–1)	**<0.001**
Physical activity previous 12 months (h/week)	2 (2–3)	2 (2–3)	0.735
Total fractures over lifespan (*n*)	2 (1–2)	0 (0–1)	**<0.001**
Body mass index (kg/m^2)	28 (25–31)	25 (23–29)	**0.002**
10-m walk comfortable speed (m/s)	1.4 (1.3–1.5)	1.5 (1.4–1.6)	**<0.001**
Monofilament (g)	1.15[a] (0.76–2.21)	0.66 (0.41–1.13)	**<0.001**
Biothesiometer (μm)	1.38 (0.74–2.80)	1.48 (0.72–2.89)	0.935
Tuning fork (score)	1 (1–2)	1 (1–2)	0.506
Sensory Organization Test composite (score)	74[a] (69–78)	79 (75–82)	**<0.001**
Activities-specific Balance Confidence Scale (score)	92 (82–97)	97 (94–99)	**<0.001**
Dizziness Handicap Inventory (score)	2 (0–16)	0 (0–4)	**0.005**
Head-shake test (% positive)[b]	82%	63%	**0.012**
	Mean (SD)	Mean (SD)	
10-m walk fast speed (m/s)	1.9 (0.3)	2.1 (0.3)	**<0.001**
Five-Times-Sit-to-Stand-Test (s)	12 (2.5)	9 (1.4)	**<0.001**

Differences between groups according to Mann–Whitney *U* test (not normally distributed variables) and independent samples *t*-test (normally distributed variables).
Monofilament and Biothesiometer; mean values measured on centre of heel, basis big toe and little toe, left and right.
[a]Number of participants with missing data for the variable.
Monofilaments: 2; SOT: 15.
[b]Positive head-shake test: ≥ 2 fast eye beats.
Significant values are shown in bold.

Table II. Spearman's rho correlations for monofilaments, tuning fork, biothesiometer, head-shake test (HST), 10-m walk test (10MWT) and 5-Times-Sit-To-Stand (FTSTS) compared using the Sensory Organization Test (SOT), Activities-specific Balance Confidence Scale (ABC) and Dizziness Handicap Inventory (DHI). (All subjects included, *n*=146)

Variables	Spearman's rho	*p*-value
Monofilaments (g)		
SOT	−0.199	**0.024**
ABC	−0.295	**<0.001**
DHI	0.174	**0.037**
Tuning fork (score)		
SOT	−0.143	0.103
ABC	−0.187	**0.024**
DHI	0.150	0.071
Biothesiometer (µm)		
SOT	−0.145	0.098
ABC	−0.156	0.060
DHI	0.105	0.206
HST (number of fast eye beats)		
SOT	−0.153	0.082
ABC	−0.092	0.272
DHI	0.083	0.321
10MWT, comfortable speed (m/s)		
SOT	0.342	**<0.001**
ABC	0.395	**<0.001**
DHI	−0.265	**0.001**
FTSTS (s)		
SOT	−0.447	**<0.001**
ABC	−0.466	**<0.001**
DHI	0.253	**0.002**

Significant values are shown in bold.

physical function in the wrist fracture group. Vestibular asymmetry was apparent in 82% of the wrist fracture subjects, but in only 64% of the controls ($p=0.012$). Vibration sensation did not differ between the groups. The fracture group used, in mean, 1.7 medications (range 0–9) and the control group 1.1 (range 0–6).

Tripping was the most frequently reported reason for the fall, accounting for 41% of subjects, followed by 36% slipping on an icy surface, 14% slipping on a wet surface, 6% during sport activities, and 3% associated with sudden head movements.

Table II shows correlations of sensation (monofilaments, tuning fork, biothesiometer and HST) and physical function (10MWT and FTSTS) with postural control, perceived dizziness handicap and confidence. Walking speed and lower extremity strength (FTSTS) had a weak to moderate correlation with the SOT (R=0.342/–0.506), ABC (R=0.395/–0.497) and DHI (R=–0.265/0.310) and monofilaments had a weak correlation with ABC (R=–0.295).

Characteristics of the participants categorized by age group are shown in Table III. Vibration sensation, i.e. biothesiometer ($p \leq 0.001$) and tuning fork ($p=0.02$), walking speed; comfortable walking speed ($p=0.001$), fast speed ($p \leq 0.001$) and lower limb functional muscle strength ($p=0.038$) were the only variables that were significantly different between age groups.

Multivariate linear models in Table IV show that mechanoreceptive sensation; biothesiometer (OR 0.843; 95% confidence interval (95% CI) 0.737–0.965) and monofilament (OR 5.643; 95% CI 2.363–13.473), a positive HST (OR 3.874; 95% CI 1.544–9.724), SOT (OR 0.899; 95% CI 0.835–0.968) and FTSTS (OR 2.040; 95% CI 1.389–2.997]) were associated with being in the wrist fracture group, but not walking speed, perceived dizziness handicap and confidence.

The association between SOT and a fall-related wrist fracture was partly explained by perceived dizziness handicap and confidence, although the SOT composite score remained significant (OR 0.921; 95% CI 0.850–0.998). The association between the SOT and a fall-related wrist fracture disappeared when corrected for walking speed and functional strength in the lower

Table III. Characteristics of the participants categorized by age group. (All subjects included, *n*=146)

	Age group 1 Age 50–58 years (*n*=51)	Age group 2 Age 59–66 years (*n*=59)	Age group 3 Age 67–75 years (*n*=36)	*p*-value
	Median (range)	Median (range)	Median (range)	
Physical activity previous 12 months (h/week)	2.0 (1–4)	2.0 (1–4)	2.0 (1–4)	0.83
Total fractures over lifespan (*n*)	1.0 (0–5)	2.0 (0–8)	1.0 (0–7)	0.36
Body mass index (kg/m^2)	27.4 (20–59)	27.3 (19–35)	26.3 (17–38)	0.91
10-m walk, comfortable speed (m/s)	1.5 (1.1–1.9)	1.4 (0.7–1.9)	1.3 (0.7–1.7)	**0.001**[a]
Monofilament (g)	0.9 (0.16–7.67)	0.9 (0.21–4.37)	1.3 (0.03–4.67)	0.09
Biothesiometer (µm)	0.9 (0.29–20.00)	1.6 (0.29–14.77)	3.2 (0.52–25.5)	**<0.001**[b]
Tuning fork (score)	1.0 (1–4)	1.0 (1–4)	1.5 (1–4)	**0.020**[c]
Sensory Organization Test composite score	78.0 (52–87)	75.5 (50–87)	76.0 (50–86)	0.41
Activities-specific Balance Confidence Scale (score)	95.1 (40–100)	93.8 (43–100)	92.6 (57–100)	0.18
The Dizziness Handicap Inventory (score)	2.0 (0–66)	0.0 (0–62)	2.0 (0–60)	0.50
Head-shake test (% positive)	71%	80%	75%	0.55
	Mean (SD)	Mean (SD)	Mean (SD)	
10-m walk, fast speed (m/s)	2.0 (0.3)	1.9 (0.2)	1.8 (0.3)	**<0.001**[d]
Five Times Sit to Stand Test (s)	10 (2.2)	10.6 (2.6)	11.4 (2.96)	**0.038**[e]

p-values based on Kruskal–Wallis test (not normally distributed variables) and one-way analysis of variance (ANOVA) (normally distributed variables). *Post hoc* test: LSD. t1: age group 1; t2: age group 2; t3: age group 3: [a]t1 vs t2 $p=0.044$; t2 vs t3 $p=0.033$; t1 vs t3:$p<0.001$. [b]t1 vs t2 $p=0.013$; t2 vs t3 $p=0.002$; t1 vs t3 $p<0.001$. [c]t2 vs t3 $p=0.48$; t1 vs t3: $p=0.006$. [d]t1 vs t2 $p=0.044$; t2 vs t3 $p=0.18$; t1 vs t3: $p<0.001$. [e]t1 vs t3: $p=0.011$.
Positive Head-Shake Test: ≤2 fast eye beats.
Significant values are shown in bold.

Table IV. Logistic regression models for a fall-related wrist fracture

	Model 1		Model 2		Model 3		Model 4	
	Function of sensory systems		Aditional: postural control		Additional: dizziness and confidence		Additional: functional ability	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Biothesiometer (μm)	0.843 (0.737–0.965)	**0.013**	0.860 (0.748–0.989)	**0.034**	0.849 (0.732–0.986)	**0.032**	0.818 (0.696–0.962)	**0.015**
Monofilament (g)	5.643 (2.363–13.473)	**< 0.001**	4.640 (1.900–11.332)	**0.001**	4.663 (1.806–12.041)	**0.001**	3.886 (1.318–11.457)	**0.014**
HST[a]	3.874 (1.544–9.724)	**0.004**	3.603 (1.337–9.709)	**0.011**	4.430 (1.502–13.061)	**0.007**	5.424 (1.570–18.740)	**0.008**
SOT (score)			0.899 (0.835–0.968)	**0.005**	0.921 (0.850–0.998)	**0.045**	0.971 (0.891–1.059)	0.508
ABC (score)					0.934 (0.862–1.013)	0.101	0.970 (0.883–1.066)	0.529
DHI (score)					1.021 (0.963–1.083)	0.488	1.035 (0.974–1.099)	0.266
10MWT (m/s)							4.574 (0.167–125.288)	0.368
FTSTS (s)							2.040 (1.389–2.997)	**< 0.001**

[a]HST ≥ 2 fast eye beat.
HST: head-shake test; SOT: Sensory Organization Test; ABC: Activities-specific Balance Confidence Scale; DHI: Dizziness Handicap Inventory; 10WT: 10-m walk test; FTSTS: Five-Times-Sit-to-Stand Test; OR: odds ratio: 95% CI: 95% confidence interval. Significant values are shown in bold.

limbs. In the final model a positive HST (OR 5.424; 95% CI 1.570–18.740) and monofilaments sensation (OR 3.886; 95% CI 1.318–11.457) showed the strongest associations with having obtained a fall-related wrist fracture.

DISCUSSION

The results of this case-control study show that individuals aged 50–75 years with fall-related wrist fractures have a higher incidence of asymmetrical vestibular function, decreased plantar pressure sensation and poorer postural control compared with matched controls. They also have slower walking speed and reduced strength in their lower limbs. In addition, wrist fracture subjects perceived more dizziness handicap and less confidence during daily activities and they had sustained a higher number of previous falls and fractures than controls. According to multivariate analysis, a positive HST and decreased plantar pressure sensation had the strongest associations with being in the wrist fracture group.

Subjects were recruited 2–5 months after the fracture, and during that time some of the subjects had been referred to physical therapy, consisting of exercises to improve movement and strength in the wrist and decrease pain. These exercises were conducted in a sitting position and therefore it is unlikely that they had an impact on the variables being analysed in the study.

The individuals in the wrist fracture group and comparison group were matched according to age, sex and amount of physical activity level (h/week). Physical activity is known to stimulate the function of both the sensory and motor systems and, by matching this with sex and age, comparison of the fracture group and the control group became more meaningful. The definition of physical activity was fairly broad and encompassed strenuous activities of daily living and recreation. With regard to possible impact of retirement on level of physical activity, information about this was not collected. However employment is high in the age range 50–66 years in Iceland and the most common retirement period is in the age range 67–70 years. After the age of 70 years retirement is nearly 100%. In light of this, the level of employment was considered comparable between the 2 groups.

The vestibular organs play a major role in coordinating head and eye movements and modifying muscle tone for postural adjustments (29). They also contribute to the estimation of the internal representation of body vertical and the subject's mental representation of position in space (30). Nystagmus after head shaking is generally considered pathological (31) and demonstrates asymmetry of the vestibular system (32). A previous study by Kristinsdottir et al. (10) found a high prevalence of asymmetrical vestibular function (76%) among patients with fall-related wrist fractures, similar to that found in our study. Ekvall Hansson et al. (11) found a somewhat lower incidence of vestibular asymmetry (65%) in a similar patient group; however, they used ≥3 fast eye beats as a threshold value for a positive HST which may explain observed differences between studies.

Vestibular asymmetry appears to be frequent in older adults as the control group also displayed a high prevalence of a positive HST in our study. However, as the prevalence of vestibular asymmetry was significantly higher in persons after wrist fracture than in controls, our findings indicate a possible association between vestibular asymmetry and fall-related wrist fractures. In our group of participants, the occurrence of nystagmus was seen, yet the subjects were asymptomatic, physically active, and not complaining of dizziness or unsteadiness, as demonstrated by the low DHI score. There also was no relationship between perceived dizziness handicap, confidence and postural control scores on the SOT among the participants.

Previous studies have reported a correlation between decreased vibration sensation (9, 33, 34) and tactile sensitivity (35) with increased postural sway among the older adults. In our study we did not find correlations between mechanoreceptive sensation, i.e. tuning fork, biothesiometer, monofilaments and SOT. Monofilament sensation was correlated with ABC scores, possibly indicating the importance of detecting weight distribution on the soles of the feet to feel confident during daily activities. As measurements of vibration perception (tuning fork and biothesiometer) were mostly in the normal range in our participants, this could explain the lack of significant associations between these variables and the SOT composite scores. According to data provided by the manufacturer, almost all our participants had diminished light touch and some participants in the fracture group had diminished protective sensation. Rinkel et al. recently reported normative data for cutaneous threshold in the feet among 196 healthy adults (36). Our findings indicate that tactile sensitivity (monofilament) in the control group were within the normal range, whereas, some participants in the fracture group had diminished sensitivity, as defined by Rinkel et al.

According to previous studies, sensation, strength and physical function decrease with age (36–39). However, it is not clear whether clinically relevant changes occur between the ages of 50 and 75 years. Our study shows that age was related to a lower vibration sensation, slower walking speed, and poorer functional muscle strength in the lower limbs in our participants. This is in accordance with the results of other studies (9, 27, 38). However, there were no differences between age groups in SOT, DHI and ABC, possibly indicating that relevant changes in these variables occur later in life. There were no differences in monofilament sensation between age groups, which is in contrast to findings by Rinkel et al, who reported age-related changes in monofilament sensation among healthy individuals in the age range 20.8–89.8 years, arranged into 7 groups, each with a 10-year span (36). The apparent discrepancy in monofilament sensation and age could possibly be explained by the use of different test locations in the 2 studies. Rinkel et al. used 5 locations: the pulp of the first and fifth toes, medial heel, first web, and lateral foot, chosen in concordance with the nerve distribution of the foot. In the present study 3 locations were used; plantar surface of the first metatarsal bone, the fifth metatarsal bone and the centre of the plantar surface of the heel, chosen as points playing a role in detecting weight distribution on the soles of the feet.

According to multivariate logistic regression models, by having 2 or more fast eye beats on the HST, the risk of a wrist fracture increased 5 times. With each additional g needed to sense plantar pressure the risk of being in the wrist fracture group increased almost 4 times, and with each additional μm needed to sense plantar vibration the likelihood increased 18%. These associations were independent of postural control, perceived dizziness handicap and confidence, walking speed or lower limb muscle strength. We also found a positive association between lower limb functional muscle strength and fall-related wrist fracture. With each additional second on the FTSTS the likelihood of being in the fracture group increased 2 times.

Given the importance of prevention of falls and wrist fractures, these variables represent potential targets for future interventions. In the current emergency care settings in Iceland, people aged 50–75 years, who have sustained a fall-related wrist fracture, receive treatment for the fracture. Postural control, vestibular function, sensation in the feet and lower-limb strength are usually not evaluated. Future studies are necessary to investigate whether training that facilitates the vestibular, somatosensory and physical functions can decrease the incidence of recurrent falls and fractures.

Strength and limitations

To the best of our knowledge, no previous studies have compared the function of the sensory systems, postural control and functional abilities between individuals with and without a fall-related wrist fracture, matched according to age, sex and weekly physical activity level.

However, it should be noted that an observed association in a case-control study does not necessarily imply causality. Future epidemiological studies with a longitudinal design or intervention studies are needed to confirm these findings.

Conclusion

People with wrist fracture have a higher incidence of asymmetrical vestibular function, reduced plantar pressure sensation and poorer standing and dynamic postural control compared with matched controls. Asymmetrical vestibular function and reduced plantar pressure sensation could be important contributing factors to falls and subsequent wrist fractures among the ageing population.

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Paper III

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ORIGINAL ARTICLE

Multi-sensory training and wrist fractures: a randomized, controlled trial

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Abstract

Background Asymmetric vestibular function, decreased plantar sensation, postural control and functional ability have been associated with fall-related wrist fractures.

Objective To investigate whether multi-sensory training (MST) improves postural control, vestibular function, foot sensation and functional ability among people with fall-related wrist fractures compared to wrist stabilization training (WT).

Methods This was an assessor-blinded, randomized controlled trial. Ninety-eight participants, age 50–75 years, were randomized to MST or WT. Pre- and post-training measurements: Head Shake Test (HST), Video-Head Impulse Test (vHIT), Semmes–Weinstein Monofilaments (SWF), Biothesiometer (BT), Sensory Organization Test (SOT), 10-m Walk Test (10MWT), Five Times Sit to Stand Test (FTSTS), Activities-Specific Balance Confidence (ABC) and Dizziness Handicap Inventory Scales (DHI). The training period was 12 weeks, with six supervised sessions by a physical therapist and daily home exercises for both groups.

Results There were significant endpoint differences in SOT ($p=0.01$) between the two groups, in favor of the MST group, but no changes were seen in other outcome variables. Subgroup analysis with participants below normal baseline SOT composite scores indicated that the MST was more effective in improving 10MWT fast ($p=0.04$), FTSTS ($p=0.04$), SWF ($p=0.04$) and SOT scores ($p=0.04$) than the WT.

Conclusions MST improves postural control among people with a fall-related wrist fracture. The results further suggest that the program is more effective for those with SOT balance scores below age-related norms.

Keywords Fracture · Rehabilitation · Wrist · Sensation · Exercise

Introduction

Postural instability and falls are one of the major health concerns associated with increasing age. About one-third of people aged 65 and over fall each year and the incidence of falls doubles every 5 years thereafter [1]. Injuries and fractures are common consequences of falls. Wrist fracture (distal forearm fracture) has been reported as the most common injury in people between 65 and 74 years of age, attending an orthopedic emergency clinic after a fall [2]. Wrist fractures have also been shown to be a strong predictor of future fracture risk [3] and are often a precursor to hip fractures [4], which results in increased health costs, decreased quality of life and even death [5].

The most common profile of a patients affected by a wrist fracture is a functionally independent woman younger than 75 years of age [6]. Although the majority of wrist fracture

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subjects are apparently healthy, many of them exhibit risk factors for new falls and fractures. These can be regular medications [7], functional decline [6], history of previous falls and fractures [7], as well as asymmetric vestibular function [8, 9]. In a recently published case–control study, postural control, plantar sensation, vestibular and physical functions were significantly worse among subjects having sustained a wrist fracture than healthy controls [10]. Furthermore, asymmetric vestibular function and decreased plantar pressure sensation showed the strongest associations with a fall-related wrist fracture [10]. Some of these variables, such as vestibular function, postural control and physical function, can be enhanced by rehabilitation.

Group sessions with vestibular rehabilitation have reduced the incident of vestibular asymmetry among elderly people with wrist fracture [11]. Vestibular rehabilitation consists of balance exercises and the incorporation of head movements that may provoke dizziness. Symptoms are generated by using exercises comprising a sequence of eye, head and body movements of increasing difficulty [12, 13]. Multi-sensory exercises are characteristically defined as exercises that selectively stimulate and manipulate all the three afferent sensory systems including vestibular, visual and somatosensory pathways [14–18]. Hu and Wollacott, reported that multi-sensory balance training designed to improve intersensory interaction, improved balance performance in healthy older adults [14] and optimized the muscle and movement characteristics among the participants [15]. Multi-sensory training directed at improving function of the sensory systems has improved functional mobility [16] and reduced body sway in older adults living in the community [17]. A pilot study on the efficacy of a new multi-sensory balance training, "The Reykjavik model", consisting of combined mechano- and proprioceptive, vestibular and fall-prevention training, demonstrated that post-training, postural control, functional ability and confidence during daily activities improved among frail old people with a history of multiple falls [18].

Ongoing problems after a wrist fracture can encompass stiffness, pain and muscle weakness, which can lead to difficulties completing everyday functional tasks [19]. Physiotherapy usually consists of exercises for range of motion (ROM) and muscle strength to improve pain, range of motion, grip strength and activity in this population [20]. In the current emergency care settings in Iceland, people who have sustained a fall-related wrist fracture receive treatment for the fracture. When the cast has been removed (~ 5–6 weeks post-fracture), they are offered to participate in group training sessions with the aim to improve movement and strength in the wrist. Patients are referred to individual physical therapy sessions if their condition (range of motion restrictions and/or complex regional pain syndrome) requires further intervention. However, they are not routinely screened for falls and fracture risk nor offered an exercise program to improve or maintain balance control to reduce the risk of future falls.

The aim of the present study was to investigate whether, multi-sensory training (MST) "The Reykjavik model" improves postural control, vestibular function, foot sensation and functional ability among people with fall-related wrist fractures compared with those receiving wrist stabilization training (WT). Additionally, we wanted to investigate whether potential changes are affected by baseline balance control.

Methods

Design overview

This study was a randomized, controlled trial. All participants underwent baseline measurements within a week before intervention started. They were randomly assigned to one of two study arms: (1) intervention group = MST, and (2) control group = WT. Participants in both groups attended six treatment sessions (30 min each) during a 3-month period, which were supervised by a physical therapist (PT). In the first two training sessions, additional 30 min were allocated to the participants in both groups, so they could familiarize themselves with the proposed exercises. Participants in both groups further received a written exercise program that was to be performed daily at home. Duration of home exercises was a minimum of 15 min, without upper time limits in both groups. The participants kept a home exercise diary during the training period. Outcome measurements were repeated within a week after the last training session.

Setting and participants

Ninety-eight individuals (mean age 61.9 ± 7.1; range 50–75; females = 85, males = 13), who had previously sustained a fall-related wrist fracture, participated in this trial. They were identified from medical records at the Emergency Department of the Landspitali University Hospital in Reykjavik, Iceland and screened for eligibility from a total of 440 consecutive patients during a 12-month period. Enrolment commenced in May 2015 and ceased in May 2016. Subjects were recruited for the study 2–5 months after the fracture by an invitation letter, followed up by a phone call. Exclusion criteria were diagnosis of a degenerative CNS disease, such as Parkinson's, Alzheimer's or other diseases possibly impairing mobility or cognitive function. The study received permission from the Icelandic National Bioethics Committee (VSNb2013110036/03.11) and was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The subjects provided informed written consent before participation in the study. A flow chart of study participants is shown in Fig. 1.

Sample size

The recruitment target was 90 participants. Sample size calculations were based on previous work by Herbert et al. [21], where they used composite scores from the sensory organization test as the primary outcome measure. With a power of 80% and significance level of 5%, 36 people were required in each group in order to detect a mean difference of 10 SOT composite score assuming a standard deviation of 15. The sample size was increased to 47 participants per group to allow for a 30% loss due to dropouts.

Randomization and interventions

After recruitment and baseline measurements, participants were randomized using a computer-created random number list and sealed envelopes.

Intervention: multi-sensory training (MST), "the Reykjavik model"

The exercises were performed barefoot on firm and soft surfaces, during quiet stance and movements. Throughout all the exercises, the subjects' attention was directed at weight distribution on the soles of the feet to recognize and control the position and movements of the body. They were also encouraged to be aware of their postural control pattern and

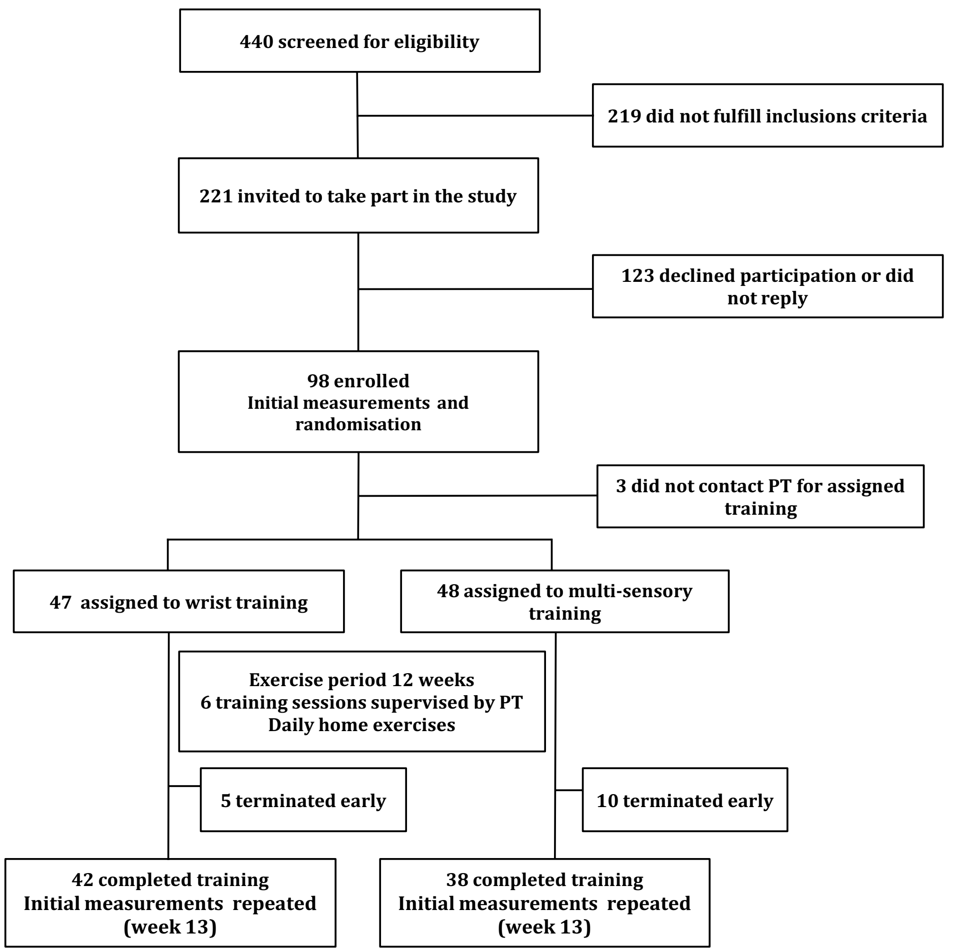

Fig. 1 Study flow chart

taught to readjust their posture with slow smooth corrective motions at the ankles and avoid using high-frequency movements at the hips and upper body. The participants were discouraged to use their hands or body for external support. Control of posture was practiced during head movements in different directions, with eyes open, closed and during fixation of gaze. The subjects were taught how to react to sudden balance disturbances by taking a step to hinder falling and use stepping reactions when their stability was challenged by a manual push in different directions. Exercises were chosen from a list (Appendix 1) according to the main balance weaknesses of each subject, tailored close to the limits of capability, and progressed in the supervised sessions according to their improvements. The participants were instructed to perform the home exercises as well in barefoot, focus on weight distribution on the soles of the feet in all the exercises and performed the exercises until symptoms of dizziness and/or unsteadiness were provoked; then to take a short break to let the symptoms subside and then continue with the home exercise program. Examples of the MST home exercises performed in the present study can be viewed at: https://vimeo.com/252733777/c6eef955ad.

A detailed description of the training has previously been published [18] and the exercise program is demonstrated at: https://vimeo.com/album/4948077.

Control group: wrist stabilization training (WT)

The WT comprised a set of strengthening and coordination exercises for the fractured wrist. The WT exercise set was developed by a physical therapist experienced in the treatment of people with wrist fractures and the exercise set had not been used previously. Post-wrist fracture, muscle weakness and instability of the fractured wrist does often persist and can affect every day function [22]. It was therefore thought likely that this type of exercises could motivate people who had sustained a wrist fracture to participate in the study and adhere to the prescribed exercises. Additionally, we wanted the WT group to receive the same attention from a PT as the MST group, therefore the number and duration of supervised sessions were identical in both groups. The WT was conducted using Inimove training equipment (Inimove ApS, Albertslund, Denmark) in supervised training session. Red elastic resistance bands (TheraBand, Akron. OH), a sponge ball and a ball on a plate were used for the home and supervised exercise sessions. All exercises were performed in a sitting position, in order not to stimulate the control of posture simultaneously (Appendix 2). Examples of the WT exercises performed in the present study can be viewed at: https://vimeo.com/252677340/f0bc12ac32.

The training was supervised by two experienced physiotherapists, who were unaware of the results of the subject's baseline measurements.

Outcome measures

All measurements were conducted at baseline and endpoint of the study by the same blinded physiotherapist. The measurements used in the present study are widely accepted, frequently used and validated. The participants were not informed of the assessment results until completion of the training and all measurements. Questionnaires were completed by participants before and after the training.

Primary outcome measure

Posturography

The Sensory Organization Test in the Smart Balance Master (SOT) (Neurocom Inc., Clackamas, OR) was used to measure postural control. The test evaluates the subject's ability to make effective use of somato-sensory, visual and vestibular inputs and suppress inappropriate sensory information. Composite scores of postural sway from the six different sensory conditions were used for analysis. Age-related normative values for the SOT composite scores have been described, ranging from 64 to 70 [23]. Further description of the SOT and the measuring procedure has previously been published [24]. The test has shown moderate-to-good test–retest reliability in older adults [25] and has been validated among people with vestibular disorders [26].

Secondary outcome measures

Physical function

Five Times Sit to Stand Test (FTSTS) Functional lower limb muscle strength was measured with the FTSTS [27]. Normative performance values for this test across ages have been reported [28]. The test has displayed discriminative validity, concurrent validity and has been shown to be reliable for comparing lower extremity strength in patients from one visit to the next [29].

10-m Walk Test (10MWT) Gait speed was assessed with the 10MWT. The test was performed at preferred walking speed and repeated at the subject´s fastest speed [30]. This test has shown excellent test–retest reliability for comfortable and fastest gait speeds among healthy adults [31].

Sensation in feet

A biothesiometer electronic device (Model EG electronic BioThesiometer, Newbury, OH, USA) that generated a 120-Hz vibration of varying amplitude (in μm) was used to measure vibration perception of the plantar surface of the feet. It was applied to the plantar surface of the caput of the first and fifth metatarsal bones as well as on the center of the plantar surface of the heel. The biothesiometer has shown excellent reliability in testing vibration perception threshold (VPT) within mild-to-moderate neuropathy [32].

The Semmes–Weinstein pressure aesthesiometer (Semmes–Weinstein Monofilaments, San Jose, USA) (SWM) was used to measure tactile sensitivity. The aesthesiometer comprised 20 nylon filaments of equal length, with varying diameters. The filaments were applied to the plantar surface of the same three points as the biothesiometer. Touch threshold is presented as pressure in grams. Normative values of plantar cutaneous SWM threshold have been described and ranges from 0.4 to 4.0 g, depending on testing sites and age [33]. The SWM test is considered the golden standard to screen for loss of protective sensation [34], which is defined as a level of sensory deficit where a patient can sustain an injury without recognizing a trauma [35]. The test has demonstrated acceptable interrater and intra-rater reliability among healthy adults [36].

For statistical analyses mean values of monofilament and biothesiometer were calculated from individual values measured on plantar surface of heel, caput of the first and fifth metatarsal bones, left and right.

Vestibular function

Head Shake Test The Head Shake Test was used to assess symmetry of vestibular function. Eye movements were recorded in the supine position with infrared video goggles in place. Based on the recordings, the occurrence of nystagmus and the number of fast eye beats was calculated by a specialist in neurotology. Greater than two or more beats of nystagmus post head shaking was considered positive for vestibular asymmetry [8–10]. The neurotologist was blinded to all recordings both pre- and post-training. The HST, has shown good specificity (82%) but less sensitivity (45%) in pooled analysis [37].

Description of the procedures of all the above tests have previously been described [10].

Video-Head Impulse Test (vHIT) vHIT was used to assess the function of the horizontal semi-circular canals by measuring the eye rotation response to an abrupt head rotation in the plane of the lateral semi-circular canals. The main measure of canal adequacy is the ratio of the eye movement response to the head movement stimulus, i.e., the gain of the vestibulo-ocular reflex (VOR). The measurement of the horizontal VOR by the vHIT has previously been described in detail [38]. The vHIT test was performed with a set of ICS impulse video goggles (GN Otometrics, Taastrup, Denmark), with a camera speed of 250 frames, recording motion of the right eye. Subjects were seated and tested in a well-lit room with an eye-level target at a distance of 1 m. Twenty passive horizontal head turns, both in the right and left directions were performed. The vHIT test has been demonstrated to be a valid clinical tool for testing the function of the horizontal semi-circular canals and simple to use [38, 39].

Anthropometrics

Body weight and height were measured and body mass index (BMI) was calculated as kg/m^2.

Questionnaires

Activities-Specific Balance Confidence Scale (ABC) The participants rated their own confidence in 16 activities of daily living on a percentile scale from 0 (no confidence) to 100 (complete confidence) [40]. The scale has demonstrated strong internal-consistency, reliability, and validity when self-administered [41].

Dizziness Handicap Inventory Scale (DHI) Self-perceived handicap resulting from dizziness was assessed with the DHI scale. The scale contains 25 items relating to physical, emotional and functional domains. The range of possible scores on the DHI is 0–100. The higher the score, the greater the level of self-perceived handicap resulting from dizziness [42]. It has been shown to demonstrate change over the course of rehabilitation [43].

Demographics of the participants were obtained using a questionnaire. They were also asked about the level of weekly physical activity, 12 months prior to participation in the study as well as during the training period. They were not instructed to limit their physical activity in any way during participation in the study.

Data analysis

Statistical analyses were conducted using SPSS for Windows version 24.0 (SPSS, Chicago, IL, USA) and the level of significance was set at $p < 0.05$. Data were checked for normality using the Kolmogorov–Smirnov test. Results are shown as means, standard deviation (SD), median and range. The Mann–Whitney U test was used to compare groups at baseline for not normally distributed variables and independent samples t test for the normally distributed ones.

Improvements over time were calculated using the Wilcoxon test for the not normally or paired samples t test for the normally distributed variables. This was done for each of the training group separately. Effect sizes were calculated according to method described by Cohen for non-parametric variables; effect size $(r) = z$ divided by square root of total number of observations [44]. Large magnitude of effect is considered to be: $r \leq 0.50$, medium-sized effects 0.3–0.5 and small effects 0.1–0.3.

Univariate general linear models with statistical adjustment for baseline values, gender and age were used to compare endpoint differences between the two training groups.

Results

Baseline

The baseline characteristics of participants are shown in Table 1. The groups were largely comparable, besides vibration sensation, which was significantly poorer in the MST group at baseline ($p = 0.02$).

Drop-out

In the present study, drop-out rate was 10.6% ($n = 5$) in the WT group, and 20.8% ($n = 10$) in the MST group. There were no differences in baseline characteristics between participants who withdrew from the training and those who completed the training in both groups, except that those who stopped in the WT group were older, with a mean age of 70.4 years versus 60.5 years in the MST group.

Participants did not have to provide an explanation for discontinuing training, so data about the reasons for dropping out of the study are limited. However, in the MST group, four dropped out because they felt their balance was fine, three decided to drop out because they did not adhere to the home exercises, two did not arrive for their first training session and one quit because of personal reasons. There was no difference in reporting between the two groups of their exercise adherence.

Intervention

Table 2 shows within-group mean changes in postural control, foot sensation, vestibular function, perceived dizziness, balance confidence and functional abilities after the intervention. There were significant improvements in both training groups in lower limb muscle strength and SOT. Additionally, there were significant improvements in DHI in the MST group only. The observed effect sizes of significant variables were medium in both groups (MST; SOT: $r = -0.34$, FTSTS: $r = -0.52$, DHI: $r = -0.30$/WT; SOT: $r = -0.41$, FTSTS: $r = -0.34$).

Table 1 Baseline characteristics of the participants categorized by groups

Variable	Wrist training ($n = 42$)			Multi-sensory training ($n = 38$)			p value*
	Mean ± SD	Median	Range	Mean ± SD	Median	Range	
Age (years)	60.8 ± 6.7	61	50–75	62.7 ± 7.9	63	50–75	0.38
Sex; females/males (n)	36/6			33/5			
BMI (kg/m^2)	28.5 ± 6.0	27	19–59	28.4 ± 6.2	28	19–57	0.97
Phys act prev 12 months (h/week)	2 ± 0.8	2	1–3	2 ± 0.6	2.0	1–3	0.36
Falls previous 12 months (n)	2 ± 1.3	1	1–5	2 ± 1.3	1.0	1–6	0.26
Total fractures over lifespan (n)	2 ± 1.2	2	1–6	2 ± 1.6	2.0	1–8	0.52
10MWT comfort speed (m/s)	1.4 ± 0.19	1.4	1.0-1.8	1.4 ± 0.19	1.4	0.7–1.7	0.93
10MWT fast speed (m/s)	1.9 ± 0.3	1.8	1.4–2.7	1.8 ± 0.30	1.8	1.1–2.5	0.42
FTSTS (s)	11.4 ± 2.41	11.2	5.9–15.9	11.70 ± 2.61	11.9	6.8–19.1	0.50
Monofilament (g)	1.6 ± 1.6	1.1	0.3–7.7	1.6 ± 1.1	1.3	0.4–4.3	0.46
Biothesiometer (µm)	2.5 ± 3.8	1.1	0.3–20.0	3.6 ± 4.9	1.8	0.6–25.5	**0.02***
Head Shake Test (% positive)†	76.2%			89.5%			0.12
vHIT left (gain)	0.9 ± 0.1	0.9	0.8–1.1	0.9 ± 0.1	0.9	0.7–1.2	0.35
vHIT right (gain)	1 ± 0.1	1.0	0.9–1.3	1.0 ± 0.2	1.0	0.8–1.6	0.99
SOT composite (score)	72 ± 7.4	73	50–81	74 ± 7.8	76	52–86	0.11
DHI (score)	9 ± 14.9	1	0–62	13.0 ± 19.6	4	0–66	0.33
ABC (%)	88 ± 13.1	93	43–100	87.0 ± 13.3	90	40–100	0.59

Monofilament and biothesiometer; mean values measured on plantar surface of: heel, caput of the first and fifth metatarsal bones, left and right

Significant values are shown in bold

BMI, body mass index, *10MWT* 10 m Walk Test, *FTSTS* Five Times Sit to Stand Test, *vHIT* Video Head Impulse Test, *SOT* Sensory Organization Test, *DHI* The Dizziness Handicap Inventory, *ABC* Activities-Specific Balance Confidence Scale

*Difference between groups according to Mann–Whitney *U* test (not normally distributed variables) and independent samples *t* test (normally distributed variables)

†Positive HST: ≥ 2 fast eye beats

Table 2 Within-group changes in functional ability, postural control, sensation, perceived dizziness and confidence after the interventions

Outcome measure	Wrist training (*n* = 42)				Multi-sensory training (*n* = 38)			
	Δ	95% CI		*p* value*	Δ	95% CI		*p* value*
SOT composite (score)	3.6	1.363	5.813	< **0.01***	4.2	1.495	6.943	< **0.01***
Monofilament (g)	− 0.2	− 0.465	− 0.012	0.14	− 0.1	− 0.360	0.222	0.08
Biothesiometer (µm)	− 0.3	− 0.697	0.133	0.11	− 0.2	− 0.629	0.179	0.38
Head Shake Test positive[a] (%)	0.0	− 0.195	0.195	1.0	− 15.8	− 0.320	0.005	0.06
vHIT left (gain)	0.01	− 0.012	0.037	0.30	0.0	− 0.011	0.045	0.23
vHIT right (gain)	0.0	− 0.042	0.005	0.15	0.0	− 0.066	0.027	0.41
10MWT comfort speed (m/s)	0.0	− 0.025	0.063	0.39	0.0	− 0.032	0.064	0.51
10MWT fast speed (m/s)	0.0	− 0.037	0.082	0.45	0.1	− 0.002	0.094	0.06
FTSTS (s)	− 1.0	− 1.537	− 0.444	< **0.01***	− 1.5	− 1.964	− 0.996	< **0.001***
DHI (score)	− 2.3	− 5.673	1.088	0.21	− 4.7	− 8.283	− 1.086	**0.01***
ABC (score)	0.9	− 1.152	2.935	0.98	2.3	− 0.141	4.743	0.69

Monofilament and biothesiometer; mean values measured on plantar surface of: heel, caput of the first and fifth metatarsal bones, left and right

Significant values are shown in bold

Δ mean change, *SOT* Sensory Organization Test, *10MWT* 10 m Walk Test, *FTSTS* Five Times Sit to Stand Test, *DHI* The Dizziness Handicap Inventory, *ABC* Activities-Specific Balance Confidence Scale, *vHIT* Video Head Impulse Test

*Baseline − endpoint differences: Wilcoxon non-parametric test and paired samples *t* test

[a]Positive HST: ≥ 2 fast eye beats

Weekly physical activity level during the training period, decreased by 0.02 h/week in the WT group and increased by 0.2 h/week in the MST group, compared to physical activity level 12 months prior to participation in the study. According to Mann–Whitney *U* test, baseline − endpoint differences in physical activity levels between the groups, were not significantly different ($p = 0.11$).

According to linear models, correcting for baseline values, age and gender (Table 3), there was a significant in between group difference in endpoint SOT (MST + 3.1, $p = 0.01$), but not in other outcome variables.

Table 3 Endpoint differences between groups in functional ability, sensation, postural control, perceived dizziness and confidence

Outcome measure	*B*	95% CI		*p* value
SOT composite (score)	3.095	0.797	5.393	**0.01***
Monofilament (g)	0.134	− 0.158	0.426	0.36
Biothesiometer (µm)	0.250	− 0.139	0.639	0.20
Number fast eye beats	0.135	0.382	0.950	0.88
vHIT left (gain)	0.006	− 0.025	0.037	0.71
vHIT right (gain)	0.002	− 0.037	0.040	0.93
10MWT comfort speed (m/s)	0.002	− 0.056	0.060	0.94
10MWT fast speed (m/s)	0.012	− 0.056	0.081	0.73
FTSTS (s)	− 0.463	− 1.184	0.258	0.20
DHI (score)	− 0.571	− 4.079	2.938	0.75
ABC (score)	1.303	− 1.318	3.924	0.33

Monofilament; mean values measured on plantar surface of: heel, caput of the first and fifth metatarsal bones, left and right

Significant values are shown in bold

SOT Sensory Organization Test, *10MWT* 10 m Walk Test, *FTSTS* Five Times Sit to Stand Test, *DHI* The Dizziness Handicap Inventory, *ABC* Activities-Specific Balance Confidence Scale, *vHIT* Video-Head Impulse Test

*Results show MST compared to WT based on univariate general linear models which corrected for base line values, age and gender

Participants with poor baseline SOT

When looking at within-group changes in participants who had SOT baseline composite scores below age norms, we found that more outcome measures improved in the MST than in the WT group. The observed effect sizes of significant variables in the MST were large ($r = -0.64$) for all the variables. However, the number of cases was small (MST: $n = 5$, WT: $n = 8$) and statistical power was limited (Table 4). In a separate comparison between groups, using linear regression corrected for baseline values (not shown in a table), we found that the MST had a higher endpoint SOT than the WT group (+ 7.4, $p = 0.012$).

There were a few outliers in the data set; seven people had 5–6 falls within the previous 12 months, four had DHI scores of > 54 [42] and two had ABC scores of < 50 [45]. The analysis of data was also conducted without the outliers in the analyses, but their removal did not make a difference in the results of the study (data not shown).

Table 4 Within-group changes in functional ability, pressure plantar sensation and postural control after the intervention, among participants with SOT baseline values below age norms

Outcome measures	Wrist training ($n=8$)				Multi-sensory training ($n=5$)			
	Δ	95% CI		*p* value*	Δ	95% CI		*p* value*
SOT composite (score)	9.5	5	14	**0.01***	16.8	12.1	21.5	**0.04***
Monofilament (g)	0.1	−0.2	0.4	0.31	−0.4	−1.2	0.4	**0.04***
10MWT fast speed (m/s)	0.0	0.0	0.1	0.12	0.1	0.0	0.2	**0.04***
FTSTS (s)	−1.1	−3.0	0.8	0.16	−2.9	−4.7	−1.1	**0.04***

Monofilament; mean values measured on plantar surface of: heel, caput of the first and fifth metatarsal bones, left and right

Significant values are shown in bold

SOT composite age norms (scores): 20–59 years: ≥ 70; 60–69 years: ≥ 68; 70–79 years: ≥ 64

Δ mean change, *SOT* Sensory Organization Test composite scores, *10MWT* 10 m Walk Test, *FTSTS* Five Times Sit to Stand Test

*Baseline − endpoint differences: Wilcoxon non-parametric test

Discussion

The aim of the present study was to investigate whether MST improves postural control, vestibular function, tactile sensation and functional ability among people with fall-related wrist fractures compared to those receiving WT. In a direct comparison, we found that the MST group displayed significantly higher scores on the SOT at the end of the study than WT. Considering within-group changes during the intervention, a significant improvement on DHI was only observed in the MST group but not the WT group. However, significant improvements in both groups were observed for the FTSTS and SOT. According to our results, poor balance control at baseline was associated with a better improvement in postural control during the intervention.

These modest findings were somewhat unexpected, because in a previous pilot study [18], MST resulted in greater improvements in postural control, functional ability and confidence in activities of daily living. This difference in outcomes can possibly be explained by different study populations. The participants in the pilot study were older, between 70 and 92 years, had sustained multiple falls and fractures, most of them had decreased sensation in their lower limbs and they had numerous comorbidities. They were physically weaker, more unstable and less confident during daily activities, as demonstrated by their poorer performance in the different tests and questionnaire (ABC scale) at baseline. The participants in the present study were younger, 50–75 years of age and retrospectively quite healthy and well-functioning. Although, the prevalence of vestibular asymmetry was high (83%) among the wrist fracture participants and 35% of them had reduced plantar sensitivity [33], they were physically active and not complaining of dizziness or unsteadiness as demonstrated by their low DHI and high ABC scores. The balance performance for 84% of them was within normal age range, as measured by the SOT [23]. Walking speed [46] and lower limb functional muscle strength [47] were within normal age-related ranges for healthy individuals among all of the participants and vibration sense [48] was within the normal range for 89% of them. As the participants in the present study were healthy and generally in good physical condition, this might have made it more difficult to achieve improvements with the MST training. Subgroup analysis with wrist fracture participants (WT $n=8$; MST $n=5$) with below normal baseline SOT composite scores support this. Reduced postural control at baseline was associated with a better improvement in postural control during the intervention. Additionally, the effects of the intervention among participants with reduced postural control at baseline demonstrated that the MST resulted in significant better outcomes than the WT for these participants. The WT group showed a mean change of 9.5 composite scores on the SOT, which is close to a learning effect (8 scores) due to repeated measurements [49]. However, the MST group exceeded that with mean change of 16.8 scores. Fast walking speed increased by 0.1 m/s post-training among the MST participants, which is regarded clinically meaningful [50], but no change was observed in the WT group. Tactile sensitivity improved as well only in the MST group. Although minimal clinically important differences in tactile sensitivity have not been reported, it has been shown that reduced tactile sensitivity is associated with fall-related wrist fractures [10]. Additionally, a clinically meaningful change of 2.9 s was reached in the FTSTS [51] in the MST group. These results imply that the MST was more effective than the WT among people with reduced postural control. However, as the number of participants with reduced postural control at baseline was very small, these findings need to be confirmed using a larger sample size before firm conclusions can be drawn.

Furthermore, the study protocols in the pilot study and the present study were different which can as well explain the limited improvements observed in the present study. The number of training sessions in the pilot study was dictated by the Icelandic social security reimbursement rules. Each referral included 20 reimbursed sessions, of which two were used for pre- and post-assessments and the remaining 18 for training. The frequency of supervised training sessions in the present study was lower than in the pilot study, consisting of only six supervised sessions and prescribed home exercises. This reduction in supervised sessions was based on clinical experience, where six supervised sessions of the MST and daily home exercises have led to decreased dizziness and improved postural stability among people with unilateral and bilateral peripheral vestibular hypofunction. This approach is as well in line with the clinical practice guidelines from the American Physical Therapy Association for vestibular rehabilitation for peripheral vestibular hypofunction [13]. According to these guidelines, based on expert opinion, persons with chronic unilateral vestibular hypofunction may need supervised sessions once a week for 4–6 weeks, together with daily home exercises.

The drop-out rate in the present study was 11% in the WT group, and 21% in the MST group, which can be considered acceptable in a randomized controlled trial [52].

One variable of interest in this study was asymmetric vestibular function, which has been shown to be associated with falls and wrist fractures [8, 10]. Post-training, there were no significant changes observed on the vHIT in the training groups. The gain of the vestibulo-ocular reflex (VOR) as measured with the vHIT, was within normative values [53] at baseline among the participants so there was most likely a ceiling effect. Conversely, there was a 16% borderline significant ($p = 0.06$) reduction of vestibular asymmetry in the MST group as measured by the Head Shake Test but no change was observed in the group receiving the WT. Previously, Hanson et al. found an 18.5% reduction of vestibular asymmetry after 9 weeks of group sessions two times/week of vestibular rehabilitation among persons post wrist fracture [11]. The reduction in vestibular asymmetry post-training in our study indicates that the MST can positively affect asymmetric vestibular function. This is of importance with regards to fall prevention, as vestibular asymmetry disturbs fall-prevention movements which become smaller or distorted leading to increased danger of falling and imbalance [54]. However, as our findings did not reach statistical significance, no firm conclusions on the effect of the MST on vestibular asymmetry can be drawn from this study.

Strength and limitations

To the best of our knowledge, no previous studies have investigated the effect of MST among people with fall-related wrist fractures compared to WT. However, it is a limitation that the participants were healthy and well-functioning in accordance with relatively young age thus potentially masking the true potential of the MST.

As in every intervention study, compliance is important. Even though the participants did complete an exercise diary, their adherence to the home exercises cannot be verified.

Conclusion

MST improves postural control among people who have sustained a fall-related wrist fracture. The results of the study further suggest that the program is more effective for those with balance scores below age-related norms on the sensory organization test.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflicts of interest.

Statement of human and animal rights This study received permission from the Icelandic National Bioethics Committee (VSNb2013110036/03.11). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix 1: Multi-sensory training

Duration of home exercises: minimum 15 min, 5–7 times each week.

Exercises are performed with bare feet.

Two sets of each exercise are performed. Rest interval between sets, 10–15 s, or until symptoms of dizziness or unsteadiness have subsided.

Throughout all the exercises, focus is on weight distribution on the soles of the feet in order to recognize and control the position and movements of the body.

Proprioceptive training

Standing. Exercises performed with eyes open and then closed:

1. Weight shift from side to side, 4–6 times in each direction.
2. Weight shift forwards and backwards, 4–6 times in each direction.

Perform exercise (1) and (2) slowly, using smooth corrective motions at the ankles and avoid high-frequency movements at the hips and upper body.

3. Stamping feet on the spot, 7–10 times.

Standing on a balance cushion, foam or trampoline.

Exercises 1–3 repeated.

Walking (preferred walking speed). 2 min for each exercise.

4. Paying attention to weight distribution on the feet.
5. Stamping feet.
6. Walking on uneven surfaces and surfaces with different textures.

Vestibular and eye control training

Each of exercises 7–21 are performed until symptoms of dizziness and/or unsteadiness are provoked.

Standing.

7. Eyes kept still during movements of the head in all directions.
8. Moving the head in all directions, eyes following head movements.
9. Moving the head in all directions with eyes closed.
10. Quick movement of the head in all directions with fixed gaze.
11. Quick movement of the head in all directions, eyes following head movements.
12. Quick movement of the head in all directions with eyes closed.

Sitting on a rotational chair.

13. Chair rotated irregularly in both directions with eyes open and closed.

Standing on one foot or on a turning disc.

14. Quick right and left turns, eyes open and closed.

On trampoline.

15. Walking and bouncing.

Combined proprioceptive and vestibular training

Standing on a balance cushion, foam or trampoline.

Exercises 7–12.

16. Reaching for an object in different directions.
17. Catching and throwing a ball.
18. Keeping a balloon in the air.

Walking (preferred walking speed).

Exercises 17–18

19. Moving head in all directions, fixing gaze on surrounding objects.
20. Quick right and left turns.

Sitting on a rotational chair or standing on a turning disc.

21. Chair/disc rotated irregularly in both directions while reading text.

Fall reaction training

Each of exercises 22–24 are performed 4–6 times in each direction.

Standing.

22. Practicing quick stepping actions in different directions to prevent a fall.

23. Subjects pushed in different directions with and without prior warning.

Walking (preferred walking speed).

24. Subject pushed irregularly in different directions with and without prior warning.

Training method instigated by:
Dr. Ella K. Kristinsdottir, PT, PhD
Bergthora Baldursdottir, PT, MSc

Appendix 2: Wrist stabilization training

Duration of home exercises: minimum 15 min, 5–7 times each week.

All exercises are performed in the sitting position.

Exercises using a golf ball on a plate (5 min)

1. Try to keep the golf ball steady in the center of the plate.
2. Try to move the ball slightly without touching the rim of the plate.
3. Move the forearm away from your body while keeping the ball steady in the middle of the cup.

Exercises using a red elastic band (5 min)

Grab the elastic band using both hands, elbows against the side of the body.

1. Elbows flexed to 90°. Pull the elastic band to the side using the fractured arm resist the pull with the non-fractured arm.
2. One elbow is flexing and the opposite elbow is extending. Pull the elastic band using the fractured forearm by bending the elbow upwards and stabilizing with the non-fractured forearm against the thigh and then resist the forces in the opposite direction.

It is important to maintain the wrist in neutral or slightly extended throughout the exercises.

Exercises using a sponge ball (5 min)

Squeeze a sponge ball as tightly as possible, count to three and relax, repeat ten times. Rest for a moment (10–15 s) and fully extend the fingers. Repeat the exercise set three times.

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Appendices

Appendix 1

Health questionnaire

Spurningalisti um heilsufar

Spurningalisti um heilsufar

Númer þátttakanda________

1. Hversu oft hefur þú dottið eða hlotið byltu síðustu 12 mánuði?
   Ef þú ert ekki viss reyndu þá að meta það eftir bestu getu.
   _____ aldrei
   _____ 1 sinni
   _____ 2 til 3 sinnum
   _____ 4 til 5 sinnum
   _____ 6 sinnum eða oftar

2. Hversu oft hefur þú brotnað eða brákast á úlnlið eða framhandlegg?
   _____ aldrei
   _____ 1 sinni
   _____ 2 sinnum
   _____ 3 sinnum eða oftar

3. Hver var ástæða/örsök brotsins núna?
   _____ Rann í hálku
   _____ Rann í bleytu
   _____ Rak fótinn í
   _____ Leið yfir mig
   _____ Datt ofan af tröppu, kolli, stól, úr stiga
   _____ Íþróttaiðkun
   _____ Annað____
   ______Veit ekki

4. Ert þú með beinþynningu (stökkbein)?
   _____ Já _____ Nei _____ Veit ekki

5. Hefur þú brotnað eða brákast á eftirtöldum stöðum:
   _____ hryggjarliðum? Hversu oft? _____
   _____ rifbeini, bringubeini? Hversu oft? _____
   _____ viðbeini? Hversu oft? _____
   _____ upphandlegg? Hversu oft? _____
   _____ hendi? Hversu oft? _____
   _____ mjaðmargrind? Hversu oft? _____
   _____ lærlegg? Hversu oft? _____
   _____ ökkla, fæti ? Hversu oft? _____

6. Hefur þú greinst með slagæðasjúkdóm í neðri útlimum (læri, kálfi, fótur) eða stíflu í slagæðum neðri útlima?
   _____ Já _____ Nei _____ Veit ekki

7. Hefurðu farið í skurðaðgerð eða æðavíkkun á slagæðum neðri útlima?
   _____ Já _____ Nei _____ Veit ekki

8. Ertu með sykursýki?
   _____ Já _____ Nei _____ Veit ekki

9. Hefur þú verið með hjartsláttartruflanir?
   _____ Já _____ Nei _____ Veit ekki

10. Hefur þú greinst með krabbamein?
    _____ Já ______ Nei

    Hvar? _______________________________________
    Fékkstu: Lyfjameðferð? ______ Geislun? ______

11. Hefur læknir eða annar heilbrigðisstarfsmaður einhvern tíma sagt þér að þú værir með einkenni frá jafnvægiskerfi innra eyra s.s.:
    _____ Bólgu í jafnvægistaug (Vestibular Neuritis)?
    _____ Meniére´s sjúkdóm?
    _____ Stöðusteinaflakk eða góðkynja stöðusvima?
    _____ Annað? _____ Nei _____ Veit ekki

12. Hversu oft síðustu 12 mánuði stundaðir þú hóflega eða kröftuga líkamsþjálfun?
    Dæmi um hóflega eða kröftuga líkamsþjálfun: Badminton, golf, hjólreiðar, sund, erfið garðvinna, lyftingar, langar gönguferðir/fjallgöngur, hröð ganga, hraður dans, erfið húsverk, þvo og bóna bílinn, þolfimi, skíði, skokk eða hlaup.
    _____ minna en 1 klst í viku
    _____ 1-3 klst í viku _____ 4 klst í viku eða meira

13. Tekur þú lyf?
    ______ Nei
    _____ Já

    Skráðu heiti lyfja ____

Appendix 2

Activities-specific Balance Confidence Scale (ABC)

A-Ö jafnvægiskvarðinn

A-Ö jafnvægiskvarðinn

Númer þátttakanda: __________

Veldu viðeigandi tölur, af þessum prósentukvarða, sem lýsa sjálfsöryggi þínu í eftirfarandi athöfnum.

0% 10 20 30 40 50 60 70 80 90 100%

Ekkert öryggi	**Fullkomlega örugg/ur**

"Hversu örugg(ur) ert þú um að halda jafnvægi og vera stöðug(ur) þegar þú..."

1. gengur um húsið?________%
2. gengur upp eða niður stiga? ________%
3. beygir þig niður og tekur upp inniskó sem liggur fremst á botninum inni í fataskáp? ________%
4. teygir þig eftir lítilli niðursuðudós á hillu í augnhæð? ________%
5. stendur á tám og teygir þig eftir einhverju fyrir ofan höfuð? _____%
6. stendur á stól og teygir þig eftir einhverju? ________%
7. sópar gólfið? ________%
8. gengur út að bíl sem er lagt í innkeyrsluna? ________%
9. ferð inní eða útúr bíl? ________%
10. gengur þvert yfir bílastæði í áttina að verslunarmiðstöð eða búð? ________%
11. gengur upp eða niður halla? ________%
12. gengur um troðfulla verslunarmiðstöð þar sem fólk gengur hratt framhjá þér? ________%
13. lendir í því að fólk rekur sig utan í þig á göngu um verslunarmiðstöðina? ________%
14. ferð í eða úr rúllustiga og heldur í handrið? ________%
15. ferð í eða úr rúllustiga, með fangið fullt af varningi, þannig að þú getur ekki haldið í handrið? ________%
16. gengur úti á ísilagðri gangstétt? ________%

Samtals úr spurningum 1-16 = _________ Stig.

Samtals stig / 16 = ___________ ABC stig

Appendix 3

Dizziness handicap Inventory Scale (DHI)

DHI Svimakvarði

HÁSKÓLI ÍSLANDS
LÆKNADEILD

**Upplýsingar vegna vísindarannsóknar
Jafnvægisstjórnun hjá einstaklingum sem hlotið hafa úlnliðsbrot í kjölfar byltu og áhrif skynþjálfunar**

LANDSPÍTALI
HÁSKÓLASJÚKRAHÚS

DHI Svimakvarði Númer þátttakanda:__________

Tilgangur þessa kvarða er að greina óþægindi sem þú getur fundið fyrir vegna svima eða óstöðugleika.
Vinsamlegast merktu „já“, „stundum“ eða „nei“ við hverja spurningu.
Svaraðu hverri spurningu einungis með tilliti til svima eða óstöðugleika.

P1. Aukast óþægindin við að horfa upp?	☐ já ☐ stundum ☐ nei
E2. Verður þú óróleg/ur vegna óþægindanna?	☐ já ☐ stundum ☐ nei
F3. Minnkar þú vinnu- eða tómstundaferðir vegna óþægindanna?	☐ já ☐ stundum ☐ nei
P4. Aukast óþægindin þegar þú gengur á milli rekka í stórmarkaði?	☐ já ☐ stundum ☐ nei
F5. Áttu í erfiðleikum með að fara upp í eða fram úr rúmi vegna óþægindanna?	☐ já ☐ stundum ☐ nei
F6. Koma óþægindin í veg fyrir að þú getir tekið þátt í félagslegum athöfnum eins og að fara út að borða, fara í bíó, dansa, fara í samkvæmi?	☐ já ☐ stundum ☐ nei
F7. Áttu í erfiðleikum með að lesa vegna óþægindanna?	☐ já ☐ stundum ☐ nei
P8. Aukast óþægindin þegar þú sinnir meira krefjandi verkefnum svo sem íþróttaiðkun, dansi, heimilisstörfum (sópa gólf, ganga frá diskum)?	☐ já ☐ stundum ☐ nei
E9. Ertu hrædd/ur við að fara út án fylgdar vegna óþægindanna?	☐ já ☐ stundum ☐ nei
E10. Hefur þú verið vandræðaleg/ur frammi fyrir fólki vegna óþægindanna?	☐ já ☐ stundum ☐ nei
P11. Aukast óþægindin við snöggar höfuðhreyfingar?	☐ já ☐ stundum ☐ nei
F12. Forðastu hæð vegna óþægindanna?	☐ já ☐ stundum ☐ nei
P13. Aukast óþægindin þegar þú snýrð þér í rúminu?	☐ já

	☐ stundum ☐ nei
F14. Áttu í erfiðleikum með að sinna erfiðum heimilisstörfum eða garðvinnu vegna óþægindanna?	☐ já ☐ stundum ☐ nei
E15. Óttastu að fólk telji þig undir áhrifum vegna óþægindanna?	☐ já ☐ stundum ☐ nei
F16. Áttu erfitt með að fara ein/n út að ganga vegna óþægindanna?	☐ já ☐ stundum ☐ nei
P17. Aukast óþægindin við að ganga niður gangstétt sem hallar?	☐ já ☐ stundum ☐ nei
E18. Áttu erfitt með að einbeita þér vegna óþægindanna?	☐ já ☐ stundum ☐ nei
F19. Áttu erfitt með að ganga um í húsinu/ íbúðinni í myrkri vegna óþægindanna?	☐ já ☐ stundum ☐ nei
E20. Ertu hrædd/ur við að vera ein/n heima vegna óþægindanna?	☐ já ☐ stundum ☐ nei
E21. Finnst þér óþægindin vera hindrun?	☐ já ☐ stundum ☐ nei
E22. Hafa óþægindin valdið erfiðleikum í samskiptum við fjölskyldu eða vini?	☐ já ☐ stundum ☐ nei
E23. Ertu þunglynd/ur vegna óþægindanna?	☐ já ☐ stundum ☐ nei
F24. Hafa óþægindin áhrif á skyldur þínar í starfi eða á heimilinu?	☐ já ☐ stundum ☐ nei
P25. Aukast óþægindin þegar þú beygir þig fram?	☐ já ☐ stundum ☐ nei

Appendix 4

Multi-Sensory Training – the “Reykjavik Model”

Skynörvandi jafnvægisþjálfun – Æfingalisti

LANDSPÍTALI
UNIVERSITY HOSPITAL

SENSORY TRAINING – SAMPLE OF EXERCISES

Exercises performed with bare feet
Focus is on weight distribution on the soles of the feet

Proprioceptive training

Standing

Exercises performed with eyes open and then closed:

1. Sensing weight distribution on the sole of feet
2. Weight shift from side to side
3. Weight shift forwards and backwards
4. Moving arms in different directions
5. Stamping feet on the spot

Standing on a balance cushion, foam or trampoline

Exercises 1-4

Walking

6. Paying attention to weight distribution on the feet
7. Stamping feet
8. Walking on uneven surfaces and surfaces with different textures

Vestibular and eye control training

Sitting

9. Head kept still, eyes moved in all directions or following a moving target
10. Eyes kept still during movements of the head in all directions
11. Moving the head in all directions, eyes following head movements
12. Moving the head in all directions with eyes closed
13. Quick rotation of the head with fixed gaze
14. Quick rotation of the head, eyes following head movements
15. Quick rotation of the head with eyes closed

Sitting on a rotational chair

16. Chair rotated irregularly in both directions with eyes open and closed

Standing

Exercises 9 -15

Standing on a turning disc

17. Disc rotated irregularly in both directions with eyes open and closed

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On trampoline

18. Walking and bouncing

Combined proprioceptive and vestibular training

Standing on a balance cushion, foam or trampoline

Exercises 9-15

19. Reaching for an object in different directions
20. Catching and throwing a ball
21. Keeping a balloon in the air

Walking

Exercises 20-21

22. Moving head in all directions, fixing gaze on surrounding objects
23. Quick right and left turns

Sitting on a rotational chair or standing on a turning disc

24. Chair/disc rotated irregularly in both directions while reading text

Fall reaction training

Standing

25. Practising quick stepping actions in different directions to prevent a fall
26. Subjects pushed in different directions with and without prior warning

Walking

27. Subject pushed irregularly in different directions with and without prior warning

Training method instigated by:

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Bergþóra Baldursdóttir, PT, MSc, bergbald@landspitali.is

SKYNÞJÁLFUN - ÆFINGALISTI

Æfingar framkvæmdar á berum fótum og athygli beint að þungadreifingu á iljar

Stöðuskynsþjálfun

Standandi

Æfingar framkvæmdar með augun opin og síðan lokuð:

1. Finna hvar þungi kemur á fætur
2. Þyngdarflutningur frá hlið til hliðar
3. Þyngdarflutningur fram og aftur
4. Hreyfa handleggi í mismunandi stefnur
5. Stappa fótum á staðnum

Standandi á jafnvægispúða, svampi eða trampólíni

Æfingar 1-5

Gangandi

6. Beina athygli að þungadreifingu á fætur
7. Stappa fótum
8. Ganga á ójöfnu undirlagi og fjölbreytilegri áferð

Þjálfun jafnvægiskerfis innra eyra og stjórnun augnhreyfinga

Sitjandi

9. Höfuð kyrrt, augu hreyfð í allar áttir eða látin fylgja eftir hlut á hreyfingu
10. Halda augum kyrrum á meðan höfuð er hreyft í allar áttir
11. Hreyfa höfuð í allar áttir, augu fylgja hreyfingu höfuðs
12. Hreyfa höfuð í allar áttir með augu lokuð
13. Snöggur snúningur á höfði í báðar áttir, augu kyrr
14. Snöggur snúningur á höfði í báðar áttir, augu fylgja hreyfingu höfuðs
15. Snöggur snúningur á höfði með augu lokuð

Sitjandi á snúanlegum stól

16. Stól snúið óreglubundið í báðar áttir, augu opin og lokuð

Standandi

Æfingar 9-15

Standandi á snúningsdiski

17. Disknum snúið óreglubundið í báðar áttir, augu opin og lokuð

Á trampólíni

18. Ganga, hoppa og hoppa með snúningum

<u>Þjálfun samþættingar skynupplýsinga</u>

Standandi á jafnvægispúða, svampi eða trampólíni

Æfingar 9-15

19. Teygja sig eftir hlut í mismunandi stefnur
20. Grípa og kasta bolta úr og í mismunandi áttir
21. Halda blöðru á lofti

Á hreyfingu

Æfingar 20-21

Gangandi

22. Hreyfa höfuð í allar áttir, festa sjón á því sem fyrir augu ber
23. Snúa sér við óreglubundið í báðar áttir

Sitjandi á snúanlegum stól eða staðið á snúningsdiski

24. Stól/diski snúið óreglubundið í báðar áttir, texti lesinn samtímis

<u>Þjálfun fallviðbragða</u>

Standandi

25. Bera fyrir sig fót í allar áttir til að forðast byltu
26. Einstaklingi ýtt í mismunandi áttir með og án viðvörunar

Á hreyfingu

27. Einstaklingi ýtt óreglubundið í mismunandi áttir, með og án viðvörunar

Höfundar þjálfunaraðferðar:

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Bergþóra Baldursdóttir, sjúkraþjálfari MSc, bergbald@landspitali.is

Appendix 5

Wrist Stabilisation Training

Stöðugleikaþjálfun fyrir úlnlið – Æfingalisti

LANDSPÍTALI
UNIVERSITY HOSPITAL

WRIST STABILIZATION TRAINING - SAMPLE OF EXERCISES

Duration of home exercises: Minimum 15 min, 5-7 times each week

All exercises are performed in the sitting position

Exercises using a golf ball on a plate

1. Try to keep the golf ball steady in the center of the plate
2. Try to move the ball slightly without touching the rim of the plate
3. Move the forearm away from your body while keeping the ball steady in the middle of the cup

Exercises using a red elastic band

Grab the elastic band using both hands, elbows against the side of the body

1. Elbows flexed to 90°. Pull the elastic band to the side using the fractured arm resist the pull with the non-fractured arm
2. One elbow is flexing and the opposite elbow is extending. Pull the elastic band using the fractured forearm by bending the elbow upwards and stabilizing with the non-fractured forearm against the thigh and then resist the forces in the opposite direction

It is important to maintain the wrist in neutral or slightly extended throughout the exercises

Exercises using a sponge ball

Squeeze a sponge ball as tightly as possible, count to three and relax, repeat 10 times. Rest for a moment and fully extend the fingers. Repeat the exercise set three times

STÖÐUGLEIKAÞJÁLFUN FYRIR ÚLNLIÐ - ÆFINGALISTI

Tímalengd æfinga: Lágmark 15 mínútur, 5 til 7 sinnum í viku

Allar æfingar eru gerðar sitjandi

Æfingar með kúlu á diski

1. Reyna að halda kúlunni kyrri í miðjunni
2. Reyna að láta kúluna hreyfast örlítið en án þess að hún fari út í kantinn
3. Færa höndina hægt fram en reyna að halda kúlunni kyrri

Æfingar með teygju, halda um teygjuna með báðum höndum.
Olnbogar upp að síðunni

1. Toga teygjuna með brotnu hendinni út til hliðar, halda á móti með þeirri óbrotnu
2. Toga teygjuna með brotnu hendinni upp með því að beygja olnbogann
3. Toga teygjuna eins en með óbrotnu hendinni og halda á móti með hinni

Mikilvægt er að halda úlnliðum kyrrum og aðeins sveigðum aftur

Gripæfing

Kreista svampbolta eins fast og hægt er, telja upp að þremum og slaka, 10 sinnum í röð. Endurtaka þetta þrisvar en hvíla aðeins á milli lota og rétta vel úr fingrum

Appendix 6

Multi-Sensory Training – Exercise Diary

Skynörvandi jafnvægisþjálfun – Æfingadagbók

Jafnvægisstjórnun hjá einstaklingum sem hlotið hafa úlnliðsbrot við byltu og áhrif skynþjálfunar

Æfingadagbók þátttakanda

____

Númer þátttakanda

____

Upphafsstafir þátttakanda

Þjálfunarstaður: Sjúkraþjálfun Styrkur
Höfðabakka 9 - 110 Reykjavík

Símanúmer: 845 5559

Sjúkraþjálfari: Hólmfríður H. Sigurðardóttir
Netfang: frida@styrkurehf.is

Það er áríðandi að geyma dagbókina vel.
Mundu að koma með hana í næsta þjálfunartíma.

LEIÐBEININGAR UM FÆRSLU DAGBÓKAR

Æfðu þig að lágmarki í 15 mínútur, 5 til 7 sinnum í viku.

Skráðu daglegar æfingar með því að merkja „X“ í reit fyrir viðkomandi dag og viku. Skráðu heildarfjölda byltna í lok hverrar viku.

	Sunnu-dagur	Mánu-dagur	Þriðju-dagur	Miðviku-dagur	Fimmtu-dagur	Föstu-dagur	Laugar-dagur	Byltur
Vika 1								
Vika 2								
Vika 3								
Vika 4								
Vika 5								
Vika 6								
Vika 7								
Vika 8								
Vika 9								
Vika 10								
Vika 11								
Vika 12								
Vika 13								

Næsti þjálfunartími:

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Endurmat í Læknagarði:

Dags.______________ Kl._______________

JAFNVÆGISÞJÁLFUN - ÆFINGALISTI

Tímalengd æfinga: Lágmark 15 mínútur, 5 til 7 sinnum í viku

Æfingar framkvæmdar á berum fótum og athygli beint að þungadreifingu á iljar

Stöðuskynsþjálfun

Standandi

Æfingar framkvæmdar með augun opin og síðan lokuð:

1. Finna hvar þungi kemur á fætur
2. Þyngdarflutningur frá hlið til hliðar
3. Þyngdarflutningur fram og aftur
4. Stappa fótum á staðnum

Standandi á jafnvægispúða, dýnu eða trampólíni

Æfingar 1-4 endurteknar

Gangandi

6. Beina athygli að þungadreifingu á fætur
7. Stappa fótum
8. Ganga á ójöfnu undirlagi og fjölbreytilegri áferð

Þjálfun jafnvægiskerfis innra eyra og stjórnun augnhreyfinga

Sitjandi

9. Höfuð kyrrt, augu hreyfð í allar áttir eða látin fylgja eftir hlut á hreyfingu
10. Halda augum kyrrum á meðan höfuð er hreyft í allar áttir
11. Hreyfa höfuð í allar áttir, augu fylgja hreyfingu höfuðs
12. Hreyfa höfuð í allar áttir með augu lokuð
13. Snögg hreyfing á höfði í allar áttir, augu kyrr
14. Snögg hreyfing á höfði í allar áttir, augu fylgja hreyfingu höfuðs
15. Snögg hreyfing á höfði í allar áttir með augu lokuð

Sitjandi á snúanlegum stól

16. Stól snúið óreglubundið í báðar áttir, augu opin og lokuð

Standandi

Æfingar 9-15

Standandi á öðrum fæti

17. Snúa sér óreglubundið í báðar áttir, augu opin og lokuð

Á trampólíni

18. Ganga, hoppa og hoppa með snúningum

Þjálfun samþættingar skynupplýsinga

Standandi á jafnvægispúða, dýnu eða trampólíni

Æfingar 9-15

19. Teygja sig eftir hlut í mismunandi stefnur
20. Grípa og kasta bolta úr og í mismunandi áttir
21. Halda blöðru á lofti

Á hreyfingu

Æfingar 20-21

Gangandi á mismunandi undirlagi

22. Hreyfa höfuð í allar áttir, festa sjón á því sem fyrir augu ber
23. Halda augum kyrrum á meðan höfuð er hreyft í allar áttir
24. Snúa sér við óreglubundið í báðar áttir

Sitjandi á snúanlegum stól

25. Stól/diski snúið óreglubundið í báðar áttir, texti lesinn samtímis

Þjálfun fallviðbragða

Standandi og í göngu

26. Bera fyrir sig fót í allar áttir til að forðast byltu

Prentgripur
Vistvæn prentun - GuðjónÓ

Appendix 7

Wrist Stabilisation Training – Exercise Diary

Stöðugleikaþjálfun fyrir úlnlið – Æfingadagbók

HÁSKÓLI ÍSLANDS
LÆKNADEILD

LANDSPÍTALI
HÁSKÓLASJÚKRAHÚS

Jafnvægisstjórnun hjá einstaklingum sem hlotið hafa úlnliðsbrot við byltu

Æfingadagbók þátttakanda

____

Númer þátttakanda

____

Upphafsstafir þátttakanda

Þjálfunarstaður: Sjúkraþjálfun Landspítala Fossvogi

Símanúmer: 543 9134

Sjúkraþjálfari: Anne Melén
Netfang: annemel@landspitali.is

Það er áríðandi að geyma dagbókina vel.
Mundu að koma með hana í næsta þjálfunartíma.

LEIÐBEININGAR UM FÆRSLU DAGBÓKAR

Æfðu þig að lágmarki í 15 mínútur, 5 til 7 sinnum í viku.

Skráðu daglegar æfingar með því að merkja „X" í reit fyrir viðkomandi dag og viku. Skráðu heildarfjölda byltna í lok hverrar viku.

	Sunnu-dagur	Mánu-dagur	Þriðju-dagur	Miðviku-dagur	Fimmtu-dagur	Föstu-dagur	Laugar-dagur	Byltur
Vika 1								
Vika 2								
Vika 3								
Vika 4								
Vika 5								
Vika 6								
Vika 7								
Vika 8								
Vika 9								
Vika 10								
Vika 11								
Vika 12								
Vika 13								

Næsti þjálfunartími:

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Dags.______________ Kl._______________

Endurmat í Læknagarði:

Dags.______________ Kl._______________

STÖÐUGLEIKAÞJÁLFUN FYRIR ÚLNLIÐ ÆFINGALISTI

Tímalengd æfinga: Lágmark 15 mínútur, 5 til 7 sinnum í viku

Allar æfingar eru gerðar sitjandi

Æfingar með kúlu á diski

1. Reyna að halda kúlunni kyrri í miðjunni
2. Reyna að láta kúluna hreyfast örlítið en án þess að hún fari út í kantinn
3. Færa höndina hægt fram en reyna að halda kúlunni kyrri

Æfingar með teygju, halda um teygjuna með báðum höndum
Olnbogar upp að síðunni

1. Toga teygjuna með brotnu hendinni út til hliðar, halda á móti með þeirri óbrotnu
2. Toga teygjuna með brotnu hendinni upp með því að beygja olnbogann
3. Toga teygjuna eins en með óbrotnu hendinni og halda á móti með hinni

Mikilvægt er að halda úlnliðum kyrrum og aðeins sveigðum aftur

Gripæfing

Kreista svampbolta eins fast og hægt er, telja upp að þremur og slaka, 10 sinnum í röð. Endurtaka þetta þrisvar en hvíla aðeins á milli lota og rétta vel úr fingrum

Til minnis

UMHVERFISMERKI
141 381
Prentgripur
Vistvæn prentun - GuðjónÓ