RESEARCH ARTICLE

WILEY

Association between musculoskeletal function and postural balance in patients with long-lasting dizziness. A cross-sectional study

Linda Haukanes[1] | Mari Kalland Knapstad[1,2] | Lene Kristiansen[1] | Liv Heide Magnussen[1]

[1]Department of Health and Function, Western Norway University of Applied Sciences, Bergen, Norway

[2]Department of Otorhinolaryngology & Head and Neck Surgery, Norwegian National Advisory Unit on Vestibular Disorders, Haukeland University Hospital, Bergen, Norway

Correspondence
Liv Heide Magnussen, Department of Health and Function, Western Norway University of Applied Sciences, Bergen, Norway.
Email: liv.magnussen@hvl.no

Abstract

Background and purpose: Reduced balance and musculoskeletal pain are frequently reported among patients with long-lasting dizziness. However, the association between musculoskeletal function and postural sway among these patients has not been examined. The objective of this study was to examine if there is an association between aspects of musculoskeletal function and postural balance in patients with long-lasting dizziness.

Methods: This was a cross-sectional study, using data of 105 outpatients with long-lasting dizziness. Aspects of musculoskeletal function was assessed by examining body flexibility, grip strength, preferred and fast walking speed, in addition to musculoskeletal pain. Musculoskeletal pain was evaluated using the Subjective Health Complaints questionnaire. Postural balance was assessed by path length of postural sway by using a balance platform on both firm and soft surfaces, with eyes open and closed. The association between musculoskeletal function and postural sway was assessed using linear regression analyses.

Results: When adjusting for age and gender we found that on a firm surface, there was an association between increased musculoskeletal pain and increased postural sway measured with eyes open ($p = 0.038$). In addition, there was an association between decreased body flexibility and decreased postural sway with eyes open ($p = 0.025$). On a soft surface, decreased fast walking speed was associated with increased postural sway with eyes open ($p = 0.027$). In addition, decreased grip strength was associated with increased postural sway on a soft surface with eyes closed ($p = 0.015$).

Discussion: The findings from this study imply that musculoskeletal function may associate with postural sway in patients with long-lasting dizziness, although the associations were weak.

1 | INTRODUCTION

Dizziness is one of the most frequently reported symptoms in primary care and affects adults of all ages (Neuhauser et al., 2008). Dizziness is often followed by other symptoms such as psychiatric comorbidity and musculoskeletal pain (Kvåle et al., 2008; Lahmann et al., 2015; Malmström et al., 2020) and reduced function such as balance deficits (Herssens et al., 2020; Söhsten et al., 2016; Wilhelmsen & Kvåle, 2014) and decreased gait speed (Marchetti et al., 2008). However, little is known about whether or how aspects of musculoskeletal function and pain affect balance in this patient group. Previously, gait function has been linked to falls and balance in patients with vestibular disorders (Whitney et al., 2000) and grip strength has shown association to postural control in older adults (Strandkvist et al., 2021; Wiśniowska-Szurlej et al., 2019).

Persons with persistent dizziness may be prone to musculoskeletal pain and reduced function (Kvåle et al., 2008) as dizziness often is aggravated by head movements. The patients may attempt to minimize head motion during movement leading to avoidance behavior and "en bloc" movement of the head and trunk (locking the head on the trunk) causing a more rigid movement pattern. This may lead to muscular stiffness, pain, and reduced musculoskeletal function. To keep and maintain balance, we are dependent on a fine-tuned interaction between the visual, vestibular, and somatosensory systems (Kristjansson & Treleaven, 2009). Studies have implied that neck pain may disrupt afferent information from the cervical spine and thus influence balance (Knapstad et al., 2019; Treleaven, 2017). However, this relationship is not well explored in with musculoskeletal pain in general. It is possible to theorize that musculoskeletal ailments would influence balance, either through pain which may disturb the afferent proprioceptive information from the somatosensory system (Kristjansson & Treleaven, 2009) or through loss of function due to avoidance behavior. Compared to healthy controls, increased postural sway, a commonly used measure of postural balance, has been documented in persons with vestibular disorders (Allum et al., 2001), general musculoskeletal pain (Lihavainen et al., 2010), non-specific low back pain (Ruhe et al., 2011), idiopathic neck pain and whiplash-associated disorders (Silva & Cruz, 2013). Maintaining balance is critical to independence in daily life (Shumway-Cook & Woollacott, 2017, p. 153), and both dizziness and increased postural sway are strong predictors of falls, which can lead to further disability (Kollén et al., 2017). Knowledge about the potential associations between aspects of musculoskeletal function, pain and balance in a population prone to balanced disturbance is therefore valuable for practitioners treating this group. The aim of this study was to investigate possible associations between aspects of musculoskeletal function, such as gait, strength, flexibility and pain, and postural sway in persons with long-lasting dizziness.

2 | METHODS

2.1 | Study design

This cross-sectional study was carried out as part of the LODIP study (Kristiansen et al., 2019), a project examining the effect of vestibular rehabilitation combined with cognitive therapy in persons with long-lasting dizziness in primary care. The study was conducted at the Western Norway University of Applied Sciences (HVL), Bergen, Norway. The present study analyzed data from baseline assessments.

2.2 | Recruitment and sampling

Participants were recruited through general practitioners, physiotherapists, and otorhinolaryngology clinic, newspaper ads, and on social media from the region in and around the municipality of Bergen, Norway, between 2016 and 2019. In total, 229 potential participants were screened by telephone interview, and 86 of these were excluded. After the initial screening, 143 persons were invited to further assessment, and another 36 persons were excluded. In total, 107 participants who fulfilled the following criteria were included: age 18–70 years, acute onset of dizziness, symptoms lasting for more than three months, and dizziness aggravated by head movements. Exclusion criteria were non-vestibular causes of dizziness (e.g., neurological disorders), diseases with fluctuating vestibular function, patients who had had treatment for benign paroxysmal positional vertigo within one month of testing, diseases where fast head movements were contraindicated, severe/terminal pathology, inadequate verbal and written Norwegian language proficiency, or inability to attend test locations. The participants signed an informed consent and completed baseline assessments at HVL. Three experienced physiotherapists familiar with the testing procedures conducted the assessment.

2.2.1 | Sample size

This study uses the same study population as the main study (Kristiansen et al., 2019). The main study was designed as a randomized controlled trial comparing two intervention groups, with a

power sample calculation estimating at least 96 participants. To account for possible dropouts the goal was to include 125 participants; however, 107 participants were finally included, still within the sample size calculation (Kristiansen et al., 2019). As the sample size of this study was based on already collected data, a post hoc sample size calculation was not recommended (Lydersen, 2015).

2.3 | Measurements

Background variables included gender, age, dizziness symptoms, and duration of dizziness. Postural balance was assessed by postural sway, while aspects of musculoskeletal function were assessed by self-reported subjective health complaints, tests of body flexibility, grip strength, and walking speed. These tests were chosen as they were included as measures of musculoskeletal function in the main study (Kristiansen et al., 2019).

2.3.1 | Postural sway

Postural sway was used as a measure of balance and assessed by the Modified Clinical Test for Sensory Interaction and Balance (mCTSIB), using the balance trainer BTG4 (HUR health). The participants were standing with their arms crossed over the chest and with their Eyes Open on a firm surface (EOfirm), Eyes Closed on a firm surface (ECfirm), Eyes Open on a 6 cm balance cushion (EOsoft), and Eyes Closed on the balance cushion (ECsoft), for 30 s each time. In each test, postural sway was registered as path length in millimeters, which has been deemed reliable across different posturography devices (Clark et al., 2010).

2.3.2 | Musculoskeletal pain

To assess musculoskeletal pain during the last 30 days, the subscale musculoskeletal pain (SHCmusc) from the Subjective Health Complaints (SHC) questionnaire was used. SHCmusc contains eight items related to muscle pain (headache, pain in the neck, upper and lower back, shoulders, arms, migraine, and legs). Severity of pain was scored on an ordinal scale ranging from zero (no complaints) to three (serious complaints), giving a sum score from 0 to 24 points. The structural validity and reliability of the scale were found to be acceptable for use among the general population (Eriksen et al., 1999).

2.3.3 | Body flexibility

The Global Physiotherapy Examination (GPE) was used to evaluate bodily aberrations, and the subdomain bodily flexibility (GPEflex),

which includes testing of lumbo-sacral flexion, head-nod flexion, shoulder retraction, and elbow drop, was used. Each item was scored on a 15-step numbered scale ranging from −2.3 to +2.3. Optimal flexibility is defined as zero, while a higher score indicates less flexibility. The total sum score of the four tests was reported and included in the analysis. The GPEflex has demonstrated to be reliable and valid in patients with long-lasting musculoskeletal pain, and also, to discriminate between those with and without musculoskeletal pain (Kvåle et al., 2003).

2.3.4 | Grip strength

To assess musculoskeletal strength, the grip strength-test was administered using a handheld dynamometer (Mie medical research Myometer). The mean grip strength of two attempts in each hand was measured in kg. Grip strength is a reliable and valid test for musculoskeletal strength (Abizanda et al., 2012).

2.3.5 | Preferred and fast walking speed

The participants walked a 6-m pathway and were asked to walk at their preferred speed. To avoid the acceleration and deceleration phase, a 1-m start-up and slow-down at the start and end of the pathway were set. A stopwatch was used to measure the time in seconds. The mean preferred walking speed of two attempts was calculated in meters per second (m/s). The same protocol was used for fast walking, except that the participants were instructed to walk as fast as possible. The walking test protocols used in this study are considered to be valid and reliable (Hall & Herdman, 2006; Heitzman, 2013; Muhaidat et al., 2014).

2.3.6 | Dizziness symptoms

The Vertigo Symptom Scale-short form (VSS-sf) was used to assess self-perceived severity of dizziness. The scale consists of 15 items assessing symptoms during the past month. Each item is scored according to the frequency of symptoms on a five-point ordinal scale from 0 (never) to 4 (very often/almost every day), providing a total score ranging from 0 to 60 (Wilhelmsen & Kvåle, 2014). A score of <12 points has been demonstrated to indicate low severity, while ≥12 points indicate high severity of dizziness (Wilhelmsen & Kvåle, 2014).

2.4 | Statistical analysis

Distribution of variables was examined using histograms and scatter plots. Descriptive data are presented as frequencies (percentages), means and standard deviations (SD), or median and quartiles as

TABLE 1 Clinical characteristics of the 105 participants with long-lasting dizziness

Variable	n	
SHCmusc mean (SD)	105	7 (4.0)
GPEflex sumscore, mean (SD)	104	3.5 (2.0)
Grip strength, kg mean (SD)	105	26 (8.9)
Preferred walking speed, m/s mean (SD)	105	1.2 (0.2)
Fast walking speed, m/s mean (SD)	105	1.8 (0.3)
Eyes open firm, mm median (IQR)	100	137 (556)
Eyes closed firm, mm median (IQR)	98	319 (1061)
Eyes open soft, mm median (IQR)	98	246 (1088)
Eyes closed soft, mm median (IQR)	99	844 (2633)

Abbreviations: GPEflex, Global physiotherapeutic examination flexibility; IQR, interquartile range; mm, millimeter; n, sample size; SD, standard deviation; SHCmusc, Subjective health complaints musculoskeletal pain.

appropriate. Linear regression models were used to test the associations between postural sway (dependent variable) and aspects of musculoskeletal function and pain (independent variables). The different measures of musculoskeletal function (walking speed, grip strength, body flexibility, and pain) were analyzed separately in each condition of sway (EOfirm, ECfirm, EOsoft, and ECsoft), in univariate and adjusted models. Age and gender were used as adjustment variables as balance and muscular function can be influenced by both (Gribble et al., 2012). Since the four postural sway variables were significantly skewed, they were log-transformed so that the residuals approached normality. To facilitate interpretation of the regression coefficients, they were back-transformed after the regression. Analyses were two-tailed with a p-level of less than 0.05. Statistical analyses were performed using IBM SPSS Statistics version 26 (IBM Corp.).

3 | RESULTS

Two participants were excluded from further analyses due to extreme scores in the four postural sway tests. Thus, the analysis included 105 participants, of which 79 (75%) were women and mean age was 49 years (SD = 12.9). Mean score of VSS-sf was 21. Duration of dizziness ranged from 3 to 482 months, with a median of 72 months. Postural sway EOfirm showed the lowest values of sway with a median path length of 137 mm, while ECsoft showed the highest values of sway with a median path length of 844 mm (Table 1).

The adjusted models on a firm surface showed a statistically significant association between SHCmusc and postural sway in the EO condition, and a 1-point increase on the SHCmusc resulted in a 2% increase in sway. An inverse significant association was found between GPEflex and postural sway in the EO test (Table 2). A 1-point increase in the GPEflex resulted in a 6% reduction in sway with EO and a 5% reduction in sway with EC in the adjusted model.

In the adjusted models on a soft surface, there was a significant association between grip strength and postural sway in the EC condition, with a 1-point increase (kg) in grip strength resulted in a 2%

reduction in sway, and finally, a significant association between fast walking speed and postural sway in the EO condition, with a 1-point increase (m/s) in walking speed was associated with a 52% reduction sway (Table 3).

4 | DISCUSSION

4.1 | Main findings

The present study has demonstrated associations between musculoskeletal function, pain and postural sway in persons with long-lasting dizziness. Analyses with adjustments for age and gender showed that increased musculoskeletal pain, decreased fast walking speed, and decreased grip strength all were associated with increased sway. Surprisingly, decreased body flexibility was associated with decreased sway.

We found that increased self-reported musculoskeletal pain was associated with increased postural sway (EOfirm). These findings are in line with studies reporting that geriatric patients with general pain have increased postural sway (Lihavainen et al., 2010), and similar associations were found with localized pain in patients with low back pain (Ruhe et al., 2011). Since balance is dependent on somatosensory input from the musculoskeletal system (Lihavainen et al., 2010), pain may cause disturbances (Brumagne et al., 2000), leading to a greater reliance on visual and vestibular information to maintain postural control. Postural sway may therefore increase when sensory information is reduced. Surprisingly, no association was found between musculoskeletal pain and postural sway when visual input was removed, and somatosensory information disturbed (ECsoft). Previous studies have found associations between pain intensity in the neck and postural sway (Knapstad et al., 2019; Ruhe et al., 2013), and moderate to severe musculoskeletal pain has been found to associate with increased postural sway compared to patients with mild or no pain (Lihavainen et al., 2010). The mean SHCmusc score

TABLE 2 Linear regression between log-transformed path length on a firm surface and musculoskeletal and functional variables. Unadjusted and adjusted models (n = 105)

| | EOfirm | | | | | | ECfirm | | | | | |
| | Unadjusted | | | Adjusted (age, gender) | | | Unadjusted | | | Adjusted (age, gender) | | |
Variables	β (95% CI)	p	R²	β (95% CI)	p	R²	β (95% CI)	p	R²	β (95% CI)	p	R²
SHCmusc	**0.02 (0.00, 0.05)**	**0.038**	**0.043**	**0.02 (0.00, 0.05)**	**0.038**	**0.065**	0.01 (−0.02, 0.04)	0.619	0.003	0.01 (−0.02, 0.03)	0.630	0.039
GPEflex	−0.04 (−0.08, 0.01)	0.122	0.024	**−0.06 (−0.10, −0.01)**	**0.025**	**0.078**	−0.03 (−0.08, 0.02)	0.273	0.013	−0.05 (−0.05, −0.01)	0.062	0.068
Grip strength, kg	−0.00 (−0.01, 0.01)	0.842	0.000	−0.01 (−0.03, 0.00)	0.118	0.047	−0.00 (−0.01, 0.01)	0.479	0.005	−0.01 (−0.03, 0.01)	0.171	0.056
Preferred WS, m/s	0.007 (−0.42, 0.55)	0.789	0.001	0.03 (−0.46, 0.52)	0.893	0.023	−0.15 (−0.72, 0.42)	0.599	0.003	−0.17 (−0.74, 0.40)	0.550	0.040
Fast WS, m/s	−0.22 (−0.57, 0.13)	0.210	0.016	−0.29 (−0.66, 0.08)	0.122	0.047	−0.33 (−0.73, 0.07)	0.108	0.027	−0.34 (−0.76, 0.08)	0.115	0.062

Note: Bold indicate p < 0.05.

Abbreviations: Beta (β), unstandardized B; CI, confidence interval; EC, eyes closed; EO, eyes open; GPEflex, Global Physiotherapy Examination flexibility; n, sample size; p, p-value; R2, explained R-squared; SHCmusc, Subjective Health Complaints musculoskeletal pain; WS, walking speed.

TABLE 3 Linear regression between log-transformed path length on a soft surface and musculoskeletal and functional variables. Unadjusted and adjusted models (n = 105)

| | EOsoft | | | | | | ECsoft | | | | | |
| | Unadjusted | | | Adjusted (age, gender) | | | Unadjusted | | | Adjusted (age, gender) | | |
Variables	β (95% CI)	p	R²	β (95% CI)	p	R²	β (95% CI)	p	R²	β (95% CI)	p	R²
SHCmusc	0.02 (−0.00, 0.04)	0.102	0.028	0.02 (−0.00, 0.04)	0.108	0.032	0.02 (−0.00, 0.04)	0.064	0.035	0.02 (0.00, 0.04)	0.055	0.142
GPEflex	−0.02 (−0.06, 0.03)	0.488	0.005	−0.03 (−0.07, 0.02)	0.319	0.017	0.02 (−0.02, 0.06)	0.480	0.005	−0.01 (−0.06, 0.03)	0.604	0.117
Grip strength, kg	−0.00 (−0.01, 0.01)	0.443	0.006	−0.01 (−0.03, 0.00)	0.086	0.036	−0.01 (−0.02, 0.00)	0.170	0.019	**−0.02 (−0.03, −0.00)**	**0.015**	**0.162**
Preferred WS, m/s	−0.35 (−0.82, 0.13)	0.148	0.022	−0.37 (−0.85, 0.11)	0.134	0.028	−0.04 (−0.49, 0.42)	0.878	0.000	−0.06 (−0.50, 0.37)	0.770	0.109
Fast WS, m/s	**−0.35 (−0.70, −0.01)**	**0.045**	**0.041**	**−0.42 (−0.78, −0.05)**	**0.027**	**0.055**	−0.11 (−0.45, 0.22)	0.507	0.005	−0.06 (−0.40, 0.27)	0.709	0.109

Note: Bold indicate p < 0.05.

Abbreviations: Beta (β), unstandardized B; CI, confidence interval; EC, eyes closed; EO, eyes open; GPEflex, Global Physiotherapy Examination flexibility; n, sample size; p, p-value; R2, explained R-squared; SHCmusc, Subjective Health Complaints musculoskeletal pain; WS, walking speed.

in our participants was 7 (score ranges from 0 to 24), while the mean SHCmusc in the general population is reported to be 4.7 (Ihlebæk et al., 2002). This indicates that the participants in our study were only mildly affected by pain and that higher levels of pain could demonstrate associations also when vision and sensory input were disturbed. Even though visual dependency is common in persons with vestibular disturbances (Maire et al., 2017), the same is not established in patients with somatosensory disturbances, making the interpretation challenging. Another factor is that pain levels are a difficult construct to measure, highly influenced by both physiological and psychosocial factors (Sullivan, 2008). The SHCmusc is purely self-reported which may have influenced our results as other studies have attempted a more objective measure such as the pressure pain threshold (Knapstad et al., 2019). Another explanation may be that on uneven surfaces, other factors such as muscular strength may contribute to body stability. Grip strength has been considered an objective measure of muscle status (Alonso et al., 2018) and we found weaker grip strength to be associated with increased postural sway only in the most challenging test condition (ECsoft), which may be due to the increased demands of muscular strength and that standing steadiness with eyes open is quite robust in patients with vestibular and proprioceptive disorders (Fujimoto et al., 2009). In addition, grip strength has been associated with reduced balance (Alonso et al., 2018; Singh et al., 2015), supporting the results from our study.

Among patients with dizziness, restricted body flexibility has been described compared to healthy persons (Kvåle et al., 2008). Therefore, an association between reduced body flexibility and increased postural sway was expected, as flexibility is deemed beneficial for balance strategies. On the contrary, we found that reduced body flexibility was associated with decreased postural sway (EOfirm). An explanation for this unexpected finding may be that reduced flexibility acts as a compensatory mechanism to reduce sway on firm surfaces. Also, the total score was in this study was 3.5, which is somehow higher than what Kvåle et al. (2003) found among healthy participants (3), but lower compared to a previous study in patients with dizziness (4.4) and patients with dizziness and additional neck pain (4.8) (Knapstad et al., 2020).

In the fast walking condition, we found an association between walking speed and postural sway (EOsoft), indicating that a reduced ability to walk at a more rapid speed was associated with increased postural sway. This association is interesting, as walking speed can be used to detect persons at a higher risk of major health-related events (Cesari et al., 2005). It has been stated that persons reduce their walking speed to cope with increased risk of falling (England & Granata, 2007). In addition, patients with dizziness may be more reluctant to move at higher speeds due to a pre-existing sensory deficit, which may explain the association with increased postural sway.

Last, it could be argued that the included population was only mildly affected by musculoskeletal pain, with scores in the lower aspect of the normal range within their age group, in for instance walking speed (Fritz & Lusardi, 2009) and grip strength (Massy-Westropp et al., 2011). This may have influenced the results, and perhaps higher disability would have resulted in a stronger relationship with postural sway. However, the aim of this paper was merely to examine if an association existed between the different aspects of musculoskeletal function and postural sway, and not if their physical function.

4.2 | Strengths and limitations

A strength of our study is the use of reliable and valid measurement instruments, in addition to the fact that the participants are likely to be representative of persons with long-lasting dizziness in terms of age and gender (Kvåle et al., 2008). In addition, the VSS-sf was high (mean score 21), indicating a high severity of dizziness at inclusion. This and the large number of participants (n = 105), increases the external validity of the study. Despite this, there may be a selection bias as only the most motivated and least affected patients tend to volunteer for research studies (Rothwell, 2005). A participant pool of persons with reduced function and higher pain levels may have resulted in a stronger association between musculoskeletal function and postural sway.

It could be argued that walking speed is not a representative measure of musculoskeletal function. However, walking speed is a vital sign for overall health where a well-functioning musculoskeletal system is indeed important (Fritz & Lusardi, 2009). It is also considered as a strong predictor of ADL disability in community-dwelling older adults (Vermeulen et al., 2011). As neurological disorders were excluded from this study, we believe that gait speed is an important aspect of musculoskeletal function in the study population.

Four tests on a balance platform were used to examine postural sway as we wanted to include aspects of excessive reliance on vision and a possible reduction in proprioceptive input (Ruhe et al., 2011). In individuals with vestibular deficits, the Balance Evaluation Systems Test (Horak et al., 2009) has been described as valid to assess balance. There are disadvantages to using postural sway alone as a measure of balance, as it does not capture the myriad aspects of balance, and a combination of several balance tests may be preferable (Horak et al., 2009). Further, caution has been expressed about using postural sway during quiet standing, as some individuals use higher-frequency excursions of COP to gain information about their posture (Shumway-Cook & Woollacott, 2017, pp. 212–213), making it challenging to interpret increased sway as reduced balance. It is not inconceivable that other instruments could have given different answers. Having said that, we believe that the selected instruments are still well suited to answer the research question.

Finally, the associations were weak, and the low explanatory power (R^2) underscores that musculoskeletal function may have a limited effect on postural sway in persons with long-lasting dizziness. However, the aim of this study was merely to examine whether an association existed.

5 | IMPLICATION FOR PHYSIOTHERAPY PRACTICE

We found small but significant associations between postural sway and musculoskeletal function among patients with long-lasting dizziness. The results imply that reduced musculoskeletal function is to a certain degree associated with reduced balance, in persons with long-lasting dizziness. For clinicians treating these patients, the relationship may be of importance since balance is affected in patients with dizziness, and musculoskeletal issues may add to these balance issues. However, the detected associations were small, and the clinical significance is uncertain. Since altered postural control has a multitude of possible causes, these findings need to be corroborated in future studies.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

ETHICAL STATEMENT
This is a sub-study of a larger study and has been approved by the Regional Committee for Medical Research Ethics (REK West 2014-00921). The procedures followed the ethical guidelines described in the Helsinki declaration.

AUTHOR CONTRIBUTION
Linda Haukanes: Formal analyzis, Writing-Original Draft, Writing-Review & Visualization.

Mari Kalland Knapstad: Writing-Review & Visualization.

Lene Kristiansen: Resources, Data Curation, Writing-Review & Visualization.

Liv Heide Magnussen: Comceptualization, Resources, Data Curation, Writing-Review & Visualization, Supervision, Project administration.

DATA AVAILABILITY STATEMENT
Research data are not sheared because analyses of the main RCT study is still ongoing.

ORCID
Linda Haukanes https://orcid.org/0000-0001-6819-2975
Mari Kalland Knapstad https://orcid.org/0000-0002-0039-7154
Lene Kristiansen https://orcid.org/0000-0001-6662-9117
Liv Heide Magnussen https://orcid.org/0000-0001-8119-7922

REFERENCES
Abizanda, P., Navarro, J. L., García-Tomás, M. I., López-Jiménez, E., Martínez-Sánchez, E., & Paterna, G. (2012). Validity and usefulness of hand-held dynamometry for measuring muscle strength in community-dwelling older persons. *Archives of Gerontology and Geriatrics, 54*(1), 21–27. https://doi.org/10.1016/j.archger.2011.02.006

Allum, J. H. J., Adkin, A. L., Carpenter, M. G., Held-Ziolkowska, M., Honegger, F., & Pierchala, K. (2001). Trunk sway measures of postural stability during clinical balance tests: Effects of a unilateral vestibular deficit. *Gait & Posture, 14*(3), 227–237. https://doi.org/10.1016/S0966-6362(01)00132-1

Alonso, A. C., Ribeiro, S. M., Luna, N. M. S., Peterson, M. D., Bocalini, D. S., Serra, M. M., Brech, G. C., Greve J. M. D. A., Garcez-Leme L. E. (2018). Association between handgrip strength, balance, and knee flexion/extension strength in older adults. *PloS One, 13*(6), e0198185. https://doi.org/10.1371/journal.pone.0198185

Brumagne, S., Cordo, P., Lysens, R., Verschueren, S., & Swinnen, S. (2000). The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. *Spine, 25*(8), 989–994.

Cesari, M., Kritchevsky, S. B., Penninx, B. W. H. J., Nicklas, B. J., Simonsick, E. M., Newman, A. B., Tylavsky, F. A., Brach, J. S., Satterfield, S., Bauer, D. C., Visser, M., Rubin, S. M., Harris, T. B., & Pahor, M. (2005). Prognostic value of usual gait speed in well-functioning older people–Results from the Health, Aging and Body Composition Study. *Journal of the American Geriatrics Society, 53*(10), 1675–1680. https://doi.org/10.1111/j.1532-5415.2005.53501.x

Clark, R. A., Bryant, A. L., Pua, Y., McCrory, P., Bennell, K., & Hunt, M. (2010). Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. *Gait & Posture, 31*(3), 307–310. https://doi.org/10.1016/j.gaitpost.2009.11.012

England, S. A., & Granata, K. P. (2007). The influence of gait speed on local dynamic stability of walking. *Gait & Posture, 25*(2), 172–178. https://doi.org/10.1016/j.gaitpost.2006.03.003

Eriksen, H. R., Ihlebæk, C., & Ursin, H. (1999). A scoring system for subjective health complaints (SHC). *Scandinavian Journal of Public Health, 27*(1), 63-72. https://doi.org/10.1177/14034948990270010401

Fritz, S., & Lusardi, M. (2009). White paper: "Walking speed: The sixth vital sign". *Journal of Geriatric Physical Therapy, 32*(2), 2–5.

Fujimoto, C., Murofushi, T., Chihara, Y., Ushio, M., Sugasawa, K., Yamaguchi, T., Yamasoba, T., Iwasaki, S., & Iwasaki, S. (2009). Assessment of diagnostic accuracy of foam posturography for peripheral vestibular disorders: Analysis of parameters related to visual and somatosensory dependence. *Clinical Neurophysiology, 120*(7), 1408–1414. https://doi.org/10.1016/j.clinph.2009.05.002

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic Training, 47*(3), 339–357. https://doi.org/10.4085/1062-6050-47.3.08

Hall, C. D., & Herdman, S. J. (2006). Reliability of clinical measures used to with peripheral vestibular disorders. *Journal of Neurologic Physical Therapy, 30*(2), 74–81. https://doi.org/10.1097/01.NPT.0000282571.55673

Heitzman, J. (2013). *Gait Speed*. Retrieved from https://www.sralab.org/rehabilitation-measures/gait-speed

Herssens, N., Verbecque, E., McCrum, C., Meijer, K., van de Berg, R., Saeys, W., Vereeck, L., Van Rompaey, V., Hallemans, A., & Hallemans, A. (2020). A systematic review on balance performance in patients with bilateral vestibulopathy. *Physical Therapy, 100*(9), 1582–1594. https://doi.org/10.1093/ptj/pzaa083

Horak, F. B., Wrisley, D. M., & Frank, J. (2009). The balance evaluation systems test (BESTest) to differentiate balance deficits. *Physical Therapy, 89*(5), 484–498. https://doi.org/10.2522/ptj.2008007

Ihlebæk, C., Eriksen, H. R., & Ursin, H. (2002). Prevalence of subjective health complaints (SHC) in Norway. *Scandinavian Journal of Public Health, 30*(1), 20–29. https://doi.org/10.1177/14034948020300010701

Knapstad, M. K., Goplen, F. K., Ask, T., Skouen, J. S., & Nordahl, S. H. G. (2019). Associations between pressure pain threshold in the neck and postural control in patients with dizziness or neck pain– cross-sectional study. *BMC Musculoskeletal Disorders, 20*(1), 528. https://doi.org/10.1186/s12891-019-2922-4

Knapstad, M. K., Nordahl, S. H. G., Skouen, J. S., Ask, T., & Goplen, F. K. (2020). Neck pain associated with clinical symptoms in dizzy patients–A cross-sectional study. *Physiotherapy Research International, 25*(136), e1815. https://doi.org/10.1002/pri.1815

Kollén, L., Hörder, H., Möller, C., & Frändin, K. (2017). Physical functioning in older persons with dizziness: A population-based study. *Aging Clinical and Experimental Research, 29*(2), 197–205. https://doi.org/10.1007/s40520-016-0567-9

Kristiansen, L., Magnussen, L. H., Wilhelmsen, K. T., Mæland, S., Nordahl, S. H. G., Clendaniel, R., Hovland, A., & Juul-Kristensen, B. (2019). Efficacy of intergrating vestibular rehabilitation and cognitive behaviour therapy in persons with persistent dizziness in primary care- a study protocol for a randomised controlled trial. *Trials, 20*(575), 1–11. https://doi.org/10.1186/s13063-019-3660-5

Kristjansson, E., & Treleaven, J. (2009). Sensorimotor function and dizziness in neck pain: Implications for assessment and management. *Journal of Orthopaedic & Sports Physical Therapy, 39*(5), 364–377.

Kvåle, A., Ljunggren, A. E., & Johnsen, T. B. (2003). Examination of movement in patients with long-lasting musculoskeletal pain: Reliability and validity. *Physiotherapy Research International, 8*(1), 36–52. https://doi.org/10.1002/pri.270

Kvåle, A., Wilhelmsen, K., & Fiske, H. A. (2008). Physical findings in patients with dizziness undergoing a group exercise programme. *Physiotherapy Research International, 13*(3), 162–175. https://doi.org/10.1002/pri.402

Lahmann, C., Henningsen, P., Brandt, T., Strupp, M., Jahn, K., Dieterich, M., Eckhardt-Henn, A., Feuerecker, R., Dinkel, A., Schmid, G., & Schmid, G. (2015). Psychiatric comorbidity and psychosocial impairment among patients with vertigo and dizziness. *Journal of Neurology, Neurosurgery & Psychiatry, 86*(3), 302–308. https://doi.org/10.1136/jnnp-2014-307601

Lihavainen, K., Sipilä, S., Rantanen, T., Sihvonen, S., Sulkava, R., & Hartikainen, S. (2010). Contribution of musculoskeletal pain to postural balance in community-dwelling people aged 75 years and older. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 65A*(9), 990–996. https://doi.org/10.1093/gerona/glq052

Lydersen, S. (2015). Statistical review: Frequently given comments. *Annals of the Rheumatic Diseases, 74*, 323–325. https://doi.org/10.1136/annrheumdis-2014-206186

Maire, R., Mallinson, A., Ceyte, H., Caudron, S., Van Nechel, C., Bisdorff, A., Magnusson, M., Petersen, H., Kingma, H., Perrin, P., & Perrin, P. (2017). Discussion about visual dependence in balance control: European society for clinical evaluation of balance disorders. *Journal of International Advanced Otology, 13*(3), 404–406. https://doi.org/10.5152/iao.2017.4344

Malmström, E.-M., Magnusson, M., Holmberg, J., Karlberg, M., & Fransson, P.-A. (2020). Dizziness and localized pain are often concurrent in patients with balance or psychological disorders. *Scandinavian Journal of Pain, 20*(2), 353–362. https://doi.org/10.1515/sjpain-2019-0121

Marchetti, G. F., Whitney, S. L., Blatt, P. J., Morris, L. O., & Vance, J. M. (2008). Temporal and spatial characteristics of gait during performance of the dynamic gait index in people with and people without balance or vestibular disorders. *Physical Therapy, 88*(5), 640–651. https://doi.org/10.2522/ptj.20070130

Massy-Westropp, N. M., Gill, T. K., Taylor, A. W., Bohannon, R. W., & Hill, C. L. (2011). Hand grip strength: Age and gender stratified normative data in a population-based study. *BMC Research Notes, 4*(127), 1–5. https://doi.org/10.1186/1756-0500-4-127

Muhaidat, J., Kerr, A., Evans, J. J., Pilling, M., & Skelton, D. A. (2014). Validity of simple gait-related dual-task tests in predicting falls in community-dwelling older adults. *Archives of Physical Medicine and Rehabilitation, 95*(1), 58–64. https://doi.org/10.1016/j.apmr.2013.07.027

Neuhauser, H. K., Radtke, A., von Brevern, M., Lezius, F., Feldmann, M., & Lempert, T. (2008). Burden of dizziness and vertigo in the community. *Archives of Internal Medicine, 168*(19), 2118–2124. https://doi.org/10.1001/archinte.168.19.2118

Rothwell, P. M. (2005). External validity of randomised controlled trials: "To whom do the results of this trial apply?" *The Lancet, 365*(9453), 82–93. https://doi.org/10.1016/S0140-6736(04)17670-8

Ruhe, A., Fejer, R., & Walker, B. (2011). Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: A systematic review of the literature. *European Spine Journal, 20*(3), 358–368. https://doi.org/10.1007/s00586-010-1543-2

Ruhe, A., Fejer, R., & Walker, B. (2013). On the relationship between pain intensity and postural sway in patients with non-specific neck pain. *Journal of Back and Musculoskeletal Rehabilitation, 26*(4), 401–409. https://doi.org/10.3233/BMR-130399

Shumway-Cook, A., & Woollacott, M. H. (2017). *Motor control translating research into clinical practice* (5th ed.). Wolters Kluwer.

Silva, A. G., & Cruz, A. L. (2013). Standing balance in patients with whiplash-associated neck pain and idiopathic neck pain when compared with asymptomatic participants: A systematic review. *Physiotherapy Theory and Practice, 29*(1), 1–18. https://doi.org/10.3109/09593985.2012.677111

Singh, D. K. A., Pillai, S. G. K., Shahar, S., Tan, S. T., & Tai, C. C. (2015). Association between physiological falls risk and physical performance tests among community-dwelling older adults. *Clinical Interventions in Aging, 10*, 1319–1326. https://doi.org/10.2147/CIA.S79398

Söhsten, E., Bittar, R. S. M., & Staab, J. P. (2016). Posturographic profile of patients with persistent postural-perceptual dizziness on the sensory organization test. *Journal of Vestibular Research, 26*, 319–326. https://doi.org/10.3233/VES-160583

Strandkvist, V., Larsson, A., Pauelsen, M., Nyberg, L., Vikman, I., Lindberg, A., Gustafsson, T., Röijezon U. (2021). Hand grip strength is strongly associated with lower limb strength but only weakly with postural control in community-dwelling older adults. *Archives of Gerontology and Geriatrics, 94*, 104345. https://doi.org/10.1016/j.archger.2021.104345

Sullivan, M. J. L. (2008). Toward a biopsychomotor conceptualization of pain. *The Clinical Journal of Pain, 24*(4), 281–290. https://doi.org/10.1097/AJP.0b013e318164bb15

Treleaven, J. (2017). Dizziness, unsteadiness, visual disturbances, and sensorimotor control in traumatic neck pain. *Journal of Orthopaedic & Sports Physical Therapy, 47*(7), 492–502. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=28622488http://openurl.bibsys.no/openurl?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rfr_id=info:sid/Ovid:medl&rft.genre=article&rft_id=info:doi/10.2519%2Fjospt.2017.7052&rft_id=info:pmid/28622488&rft.issn=0190-6011&rft.volume=47&rft.issue=7&rft.spage=492&rft.pages=492-502&rft.date=2017&rft.jtitle=Journal+of+Orthopaedic+%26+Sports+Physical+Therapy&rft.atitle=Dizziness%2C+Unsteadiness%2C+Visual+Disturbances%2C+and+Sensorimotor+Control+in+Traumatic+Neck+Pain.&rft.aulast=Treleaven

Vermeulen, J., Neyens, J. C., van Rossum, E., Spreeuwenberg, M. D., & de Witte, L. P. (2011). Predicting ADL disability in community-dwelling elderly people using physical frailty indicators: A systematic review. *BMC Geriatrics, 11*(33). https://doi.org/10.1186/1471-2318-11-33

Whitney, S. L., Hudak, M. T., & Marchetti, G. F. (2000). The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *Journal of Vestibular Research, 10,* 99–105.

Wilhelmsen, K., & Kvåle, A. (2014). Examination and treatment of patients with unilateral vestibular damage, with focus on the musculoskeletal system: A case series. *Physical Therapy, 94*(7), 1024–1033. https://doi.org/10.2522/ptj.20130070

Wiśniowska-Szurlej, A., Ćwirlej-Sozańska, A., Wołoszyn, N., Sozański, B., & Wilmowska-Pietruszyńska, A. (2019). Association between handgrip strength, mobility, leg strength, flexibility, and postural balance in older adults under long-term care facilities. *BioMed Research International, 2019,* 1042834. https://doi.org/10.1155/2019/1042834