Original Article

Standing and Walking Balance in Patients with Chronic Shoulder Pain: A Case–control Study

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Abstract

Background: Patients with shoulder pain may have proprioceptive and balance deficits. However, studies on balance in patients with shoulder pain are scarce.

Objective: This study aims to investigate if patients with chronic shoulder pain demonstrate deficits in standing and walking balance and to study the relationship between outcome measures of balance and age and body mass index (BMI).

Materials and Methods: This case–control study was conducted at Dammam Medical Complex, Dammam, Saudi Arabia, between March and November 2018. The study recruited patients (n = 15) with chronic shoulder pain (>4 months) and healthy controls (n = 15) matched for age, gender and BMI. Standing balance was tested using a Challenge Disc test, the Romberg test and timed unipedal stance test (UPST). Walking balance was assessed using the timed up and go (TUG) test, stance phase duration and center of pressure (COP) deviation. Independent t-tests were used to investigate the differences between the two groups in demographic data and all the outcome measurements. Pearson correlation coefficients were used for correlation analysis.

Results: No statistically significant differences were found between the two groups in any outcome of the standing balance ($P \geq 0.095$) or walking balance ($P \geq 0.160$). However, medium effect sizes were found for the UPST (η^2: ≥0.06), Challenge Disc (η^2: 0.06), TUG (Cohen's d: 0.54) and COP deviation (Cohen's d: 0.53). There was a moderate correlation between BMI and Challenge Disc ($P = 0.025$) and between age and Challenge Disc ($P = 0.012$) in both the groups.

Conclusion: Patients with chronic shoulder pain had lower balance measurements compared with healthy people, although this difference was not statistically significant.

Keywords: Balance ability, pain, postural stability, sensorimotor system, shoulder

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INTRODUCTION

Musculoskeletal pain can affect muscles, tendons, ligaments and bones, can present at localized, regional or widespread areas,[1] and may result in physical, functional and psychological impairments.[2] It is the fourth leading cause of years lived with disability according to the 2010 Global Burden of Disease study, with a global point prevalence

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of 8%.[3] Shoulder pain, which is the fourth most common musculoskeletal condition after lower back, knee and neck pain,[2,4] can have a significant effect on a person's quality of life and activities of daily living.[2]

Body control can be achieved by the information provided from somatosensory, visual and vestibular input. Somatosensation encompasses all the mechanoreceptive, thermoreceptive and pain information arising from the periphery. Proprioception describes afferent information that contributes to postural control (balance), joint stability (segmental posture) and conscious peripheral sensations (muscle senses).[5] Postural balance can be altered by pain.

Research has demonstrated that both chronicity and severity of musculoskeletal pain in the upper and lower quadrant are crucial risk factors for falls.[6,7] For example, neck pain was associated with significant changes in standing balance,[8] and severe low back pain increased the risk of falling.[8] In addition, motor control can be negatively affected by pain in the lower limbs and spine, which can alter proprioception in affected areas.[9] A somatosensory dysfunction in one area of the body can be the cause of shoulder proprioception deficit.[10] Pain may cause balance disorders, as pain processing, balance control circuit, muscle inhibition caused by pain and changes of the proprioceptive feedback in painful structures share the same pathways of the central nervous system. Shoulder pain may alter these pathways, consequently impacting the overall balance/postural control.[11]

To the best of the authors' knowledge, only one trial has examined balance in patients with shoulder pain. Baierle *et al*.[11] measured postural stability, balance ability and symmetry index using the S3-Check system. They found that patients with shoulder pain had balance and posture deficits compared with healthy control participants. These authors investigated balance during standing but not while walking. Balance while walking is important in terms of maintaining independence and safety.[12] In addition, balance disturbance may affect the functional capability of individuals.[13] Owing to the paucity of knowledge in this domain, the primary aim of the current study was to investigate balance both while standing and walking in patients with chronic shoulder pain. Our hypothesis was that the patients with shoulder pain would have deficits in standing and walking balance compared with healthy participants. The secondary aim was to determine any possible relationship between outcome measures of standing/walking balance and age and body mass index (BMI). The results of this study may provide additional insights into the examination and treatment of patients with chronic shoulder pain.

MATERIALS AND METHODS

Design and setting

This is a case–control study that was conducted at the Physical Therapy Department in Dammam Medical Complex, Dammam, Saudi Arabia, from March to November 2018. The study was approved by the institutional review boards at Imam Abdulrahman Bin Faisal University and Dammam Medical Complex. The study followed ethical principles required for human research in accordance with the Declaration of Helsinki, 2013. The manuscript was prepared considering the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. The study participants comprised two groups: a chronic shoulder pain group and a control group.

Sample size calculation

The sample size was calculated using G*Power 3.1.9.4 (Franz Faul, Universität Kiel, Germany) based on stability index data from a previous study[11] with the following combination: one-tailed *t*-test for difference between two independent means; estimated mean 1 of 55,000 with standard deviation (SD) of 6000 and mean 2 of 48,500 with SD of 7125; effect size of 0.99; alpha level (α) of 0.05; power ($1-\beta$) of 80%; and allocation ratio N2/N1 of 1. The sample size calculation resulted in 14 participants per group. An extra 10% was added to each group in case of dropouts, resulting in a total of 15 participants per group.

Participants

Patients with unilateral shoulder pain were enrolled if they were 25–60 years of age, had pain for 4 months or longer, had pain intensity of 5 or greater on the Numeric Pain Rating Scale within the past week of screening, complained of pain at rest during the study session,[11] and were able to walk independently without aids or assistive devices.[14] Patients with any of the following were excluded from this study: history of major surgery in the lower limbs, trauma to the lower limbs in the past 6 months that affected function, pain in the spine or lower limbs during the study session, neurological diseases, any type of headache during the study, cardiovascular diseases, acute and chronic dizziness, diseases of the inner ear, disorders of the peripheral circulation such as claudication,[14] balance training in the past 6 months and recent use of any medication that affects the central nervous system.[11] Age-, gender- and BMI-matched participants were recruited to the control group. Convenience sampling was applied to recruit the participants.

Outcome measures

Standing balance

The Challenge Disc 2.0 (MFT, TST Trendsport, Grosshöflein, Austria), a primary outcome, is a device with a multiaxial electrical platform that includes motion sensors and, with a Bluetooth module, facilitates wireless communication with a smartphone over an application. The installed application has an option to assess the degree of standing balance. The device gives a score of up to 5, with a lower score indicating better balance. This device is valid and demonstrated moderate reliability (intraclass correlation coefficient [ICC]: 0.688) to assess standing balance [Figure 1a].[15] No established minimal detectable change (MDC) value for the Challenge Disc has been found in the literature. The primary investigator stood in front of the participant to hold the smartphone screen that shows the application. The participant stood on the disc barefooted to avoid the effect of shoe types on the results.[16] Then, the test started with a 10-s preparation instruction, followed by standing for 20 s with both legs in the center of the disc and arms by their sides while holding their balance. The device provided constant feedback to keep the ball in the center, as steady as possible [Figure 1b]. The device has an anti-slip coating surface that provides the necessary safety. The test was stopped if there is a loss of balance.[15] The test was performed three times, and the mean was used for analysis.

The timed unipedal stance test (UPST) (also referred to as the unipedal balance test or one-leg standing balance) is a valid test of balance and has excellent inter-rater reliability for eyes open (ICC: 0.994) and eyes closed (ICC: 0.998).[17] The MDC ranged from 5.5 to 16 s.[18] Decreased time of UPST indicates a decrease in balance.[19] The participant was instructed to stand on the tested leg (barefooted) and to place the arms across the chest with the hands touching their shoulders and the lower limbs not touching each other. Then, the participant was asked to look forward with their eyes open and concentrate on an object approximately 3 feet in front of them. A digital stopwatch was used to time the test. The test was stopped at a maximum of 60 s or as soon as the limbs touched each other, the feet moved on the floor due to severe balance disturbance, the lifted foot touched the floor or the upper limbs moved from their starting position.[17] The test was performed once.

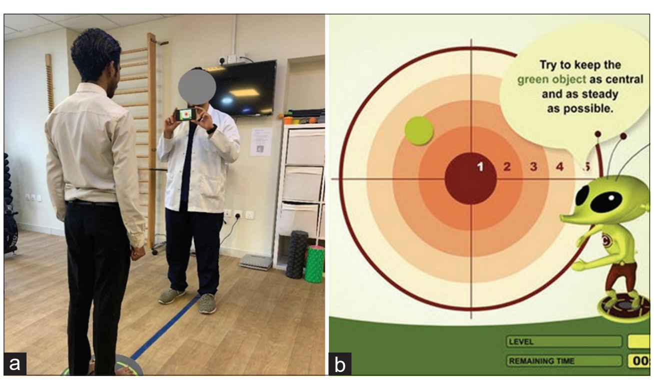

Figure 1: Testing standing balance using (a) the challenge disc (b) while the investigator is providing feedback through the device application

The Romberg test was used to assess balance in a standing position. It is highly reliable (ICC: 0.840–0.860) and accurately detects balance dysfunction.[20] There has been no consensus on the MDC value for the Romberg test, as it is more of qualitative (positive or negative) than quantitative test. The participant was asked to remove their shoes and stand with both feet together. The arms were held next to the body. Then, the primary investigator asked the participant to stand quietly with eyes open and then with eyes closed. The participant tried to maintain balance. The Romberg test was scored by calculating the seconds of standing with eyes closed. The test was considered positive if the participant was unable to maintain balance with the eyes closed for at least 60 s.[21] The test was performed once.

All the aforementioned measures of standing balance were used for the same construct (standing balance) because they probably assess different balance systems using eyes open (UPST) and closed (Romberg test) and visual feedback (Challenge Disc) with different floor stability.

Walking balance

Center of pressure (COP) mediolateral deviation,[22] a primary outcome and stance phase duration[23] were used to test walking balance using the Tekscan MatScan system (Tekscan, Mobile Mat, EH-2 Boston, MA, USA). Stance phase duration is the time elapsed between touchdown and liftoff of the same foot in a gait cycle.[23] Stance phase duration test has a moderate reliability (ICC: 0.56–0.74) and an MDC value of 0.018–0.028 s.[24]

The COP mediolateral deviation was calculated by the system, taking the maximum sway of the COP from a straight line that connects the first and last points of a curve. This test has a good reliability (ICC: 0.70) and root mean square error of 0.56 cm.[25] The participant was instructed to be barefooted to avoid the effect of shoe types on the results.[16] Then, they practiced determining the appropriate distance that requires walking for three steps, during which the third step strikes the mat until it is completely clear of the mat. With the predetermined starting place, the participant walked at a comfortable speed and focused on a picture on the front wall to ensure that the gait was as normal as possible. Three measurements were recorded, and the mean of the three measurements was used for analysis.[26]

The timed up and go (TUG) test is a test for basic functional mobility (walking).[27] It is a valid and moderately reliable (ICC: 0.510–0.780) tool to screen balance deficiency that may increase the risk of fall.[28] The MDC value has not been established in the risk of falls or in disorders affecting the upper quadrant. However, the MDC value for lower quadrant musculoskeletal conditions such as hip and knee osteoarthritis is 2.49 s.[29] The participant stood on the investigator's command from a chair with armrests, walked 3 meters and returned to the chair and sat down. The time in seconds was measured at the end of the task as soon as the participant sat on the chair. The test was performed three times, and the mean of the three trials was used for analysis.

Procedure

At the outpatient rehabilitation clinic in Dammam Medical Complex, patients who were diagnosed with musculoskeletal shoulder pain were referred for our study. The control participants, who fulfilled the inclusion and matching criteria, were invited by personal communication from the hospital staff, friends and family. If the participant agreed to participate, a written consent form was obtained. The primary investigator screened each participant for eligibility. Once eligible, this investigator explained the study to the patient. Initially, demographic data were collected. Then, the outcome measures were tested in the following order: TUG, Romberg test, UPST, Challenge Disc, stance phase duration and COP deviation. This order was standardized for all participants to minimize any possible effect of a test on another. The testing procedure took approximately 1 h.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) software for Windows (IBM SPSS version 20.0, New York, NY, USA). Means and SDs were calculated as descriptive statistics for quantitative variables. The Shapiro–Wilk test was used to evaluate the normality of data distribution. To investigate the differences between the two groups, independent *t*-tests were used for normally distributed data, whereas Mann–Whitney *U*-tests were performed for ordinal data and nonnormally distributed data. Chi-square tests were used for categorical data. In addition to the mean difference and 95% confidence interval (CI), Cohen's *d* and η^2 were calculated as another parameter for effect size on data from independent *t*-tests and Mann–Whitney test, respectively. The ranges of effect size using Cohen's *d* were 0.20–0.49 (small), 0.50–0.79 (medium) and ≥0.80 (large), whereas the ranges for η^2 were 0.01–0.05 (small), 0.06–0.13 (medium) and ≥0.14 (large).[30] The criterion for statistical significance was set at $P < 0.05$, with a 95% CI. Pearson correlation coefficient was used to find the correlation between BMI and age and these measurements with the two groups' data pooled together.

RESULTS

A total of 47 patients were screened for eligibility. Thirty-one patients did not fulfill the inclusion criteria and one patient refused to continue before data collection commenced. Twenty-four healthy participants were screened for the control group; nine of them did not meet the matching criteria. There were no statistically significant differences in the demographic data between the shoulder pathology group and the control group [Table 1]. A total of 15 patients had the following shoulder pathologies: adhesive capsulitis ($n = 4$), rotator cuff tendonitis (6), fracture of humerus (2), superior labral tear from anterior to posterior (SLAP lesion) (1), avascular necrosis (1) and dislocation (1).

No significant differences were found in any outcome of the standing and walking balance between the shoulder pain group and the control group. These differences did not reach the MDC for all outcome measures. However, there were trends that both standing and walking balance is lower in the shoulder pain group compared to the control group. This was demonstrated by the medium effect size for UPST (η^2: 0.06–0.09), Challenge Disc (η^2: 0.09), TUG (Cohen's *d*: 0.54) and right COP deviation (Cohen's *d*: 0.53) [Table 2].

The Pearson correlation coefficients found statistically moderate negative correlations between BMI and the TUG test ($r = -0.424$, $P = 0.020$), between BMI and the Challenge Disc test ($r = -0.408$, $P = 0.025$) and between age and the Challenge Disc test ($r = -0.453$, $P = 0.012$) in both the groups. These findings indicate that the higher the BMI and age, the more disturbance in balance [Table 3].

DISCUSSION

This study did not identify any statistically significant differences in the walking and standing balance between healthy individuals and patients with chronic shoulder pain. However, there were some trends that both standing and walking balance was lower in those with shoulder pain, as demonstrated by medium effect sizes. In both the groups, there were statistically moderate negative correlations

Table 1: Demographic data of both groups at baseline

Variables	Shoulder pain group (*n*=15)	Control group (*n*=15)	Mean/mean rank difference	95% CI	Significance (statistic; *P*)
Age (years)*	43.7±11.1	43.4±10.3	0.27	−7.8-8.3	*t*=0.070; 0.945
BMI (kg/m²)$	27.3 (26.1-27.4)	27.4 (24.7-30.8)	−0.4	−2.7-2.7	*U*=109.5; 0.901
Occupation (clerk/others)	7/8	9/6	-	-	Chi-square test=0.536; 0.464
Sports¥	6	5	-	-	Chi-square test=0.144; 0.705
Diabetics	4	3	-	-	Chi-square test=0.186; 0.666
Dominance (right/left)	13/2	14/1	-	-	Chi-square test=0.370; 0.543
NPRS during session (cm)	2.5±1.4	-	-	-	-
Maximum NPRS last 7 days (cm)	6.5±0.8	-	-	-	-
Pain duration (months)	10.9±6.5	-	-	-	-
Affected shoulder (right/left)	5\10	-	-	-	-
DASH	40.6±13.3	-	-	-	-

*Data are expressed as mean±SD, $Data are expressed as median (IQR), ¥Participants who practice regular exercise ≥2 times per week. BMI – Body mass index; NPRS – Numeric Pain Rating Scale; DASH –Disabilities of the arm, shoulder and hand; *t* – Independent *t*-test; SD – Standard deviation; CI – Confidence interval; IQR – Interquartile range

Table 2: Result of balance during standing and walking

Variables	Shapiro-Wilk test (statistic; *P*)	Shoulder pain group (*n*=15)	Control group (*n*=15)	Between-group differences			
				Mean/mean rank difference	95% CI	Eta²/ Cohen's *d*	Significance (statistic; *P*)
Standing balance							
Challenge Disc (0–5)*	0.881; 0.003	4.6 (4.5-4.8)	4.6 (4.2-4.7)	5.14	−0.06-0.39	0.09	*U*=74.0; 0.110
Right UPST (s)*	0.729; <0.001	51.0 (34.0-60.0)	60.0 (60.0-60.0)	−4.74	−25.20-0.00	0.09	*U*=−77.0; 0.104
Romberg (+\−)	0.275; <0.001	2/13	0/15				Chi-square test=2.14; 0.143
Walking balance							
Right COPd (cm)$	0.976; 0.709	2.71±0.98	3.16±0.88	0.44	−1.15-0.25	0.53	*t*=−1.31; 0.201
Left COPd (cm)$	0.972; 0.605	2.34±0.51	2.38±1.05	0.04	−0.67-0.58	0.05	*t*=−1.54; 0.879
Right stance phase duration (s)*	0.925; 0.037	0.8 (0.8-0.8)	0.8 (0.8-0.9)	−1.86	−0.06-0.04	0.01	*U*=98.5; 0.561
Left stance phase duration (s)$	0.986; 0.947	0.80±0.07	0.81±0.07	0.00	−0.06-0.05	0.10	*t*=1.89; P=0.847
TUG (s)$	0.963; 0.374	10.3±0.91	9.81±0.92	0.48	−0.20-1.16	0.54	*t*=1.44; 0.160

*Mann-Whitney *U*-test (*U*) used and data are expressed as median (IQR), $Independent *t*-test (*t*) and data are expressed as mean±SD. ¥Chi-square test and data are expressed as frequency. COPd – Center of pressure deviation; SD – Standard deviation; TUG – Timed up and go; UPST – Unipedal stance test; CI – Confidence interval; IQR – Interquartile range

Table 3: Relationship between body mass index and age and standing and walking balance

Outcome measure	Pearson correlation (*r*)			*P*		
	Shoulder pain group (*n*=15)	Control group (*n*=15)	Both groups	Shoulder pain group (*n*=15)	Control group (*n*=15)	Both groups
BMI versus						
Challenge Disc test	0.070	0.675	−0.408	0.805	−0.006	0.025*
Right UPST	0.314	−0.279	0.054	0.255	0.314	0.777
Left UPST	−0.091	−0.272	−0.151	0.747	0.326	0.427
Right COPd	−0.007	−0.506	−0.234	0.981	0.054	0.214
Right stance phase duration	0.416	0.284	0.349	0.123	0.305	0.059
Left stance phase duration	0.310	0.100	0.201	0.261	0.723	0.287
TUG	0.375	0.505	−0.424	0.169	0.055	0.020*
Age versus						
Challenge Disc test	−0.590	0.428	−0.453	0.021	0.111	0.012*
Right UPST	−0.240	−0.446	−0.315	0.389	0.096	0.090
Left UPST	−0.072	−0.020	−0.039	0.798	0.943	0.836
Right COPd	0.358	−0.102	0.141	0.190	0.717	0.457
Left COPd	−0.078	−0.316	−0.218	0.782	0.252	0.247
Right stance phase duration	0.278	0.114	0.196	0.316	0.687	0.299
Left stance phase duration	−0.211	−0.144	−0.177	0.451	0.609	0.350
TUG	0.375	0.198	0.282	0.168	0.480	0.130

*Significant correlation. UPST – Unipedal stance test; TUG – Timed up and go; COPd – Center of pressure deviation; NPRS – Numeric Pain Rating Scale; BMI – Body mass index

between BMI and the TUG test, between BMI and the Challenge Disc test and between age and the Challenge Disc test.

Standing balance was affected in patients with chronic shoulder pain compared with the controls in a previous study.[11] This effect of pain on balance may be explained by the fact that balance control and pain processing are both controlled by the same central nervous system pathways.[31,32] If a patient experiences shoulder pain, an indirect effect on balance may occur as a result of the pain influencing the central system pathways shared between pain processing and balance control. This explanation of the effect of pain on body control was discussed for cases of low back pain.[33]

Our participants did not show any differences in either standing or walking balance, which disagreed with the findings of Baierle *et al*.,[11] who examined the standing balance but not the walking balance. A possible explanation for this difference between the studies may be because, in their study, the patients were asked to hold their balance without receiving any visual feedback from the monitor, whereas the patients in our study were looking at the feedback screen to maintain their balance. It should be noted that the outcome measures of standing balance differed in both studies, which provides another explanation for the difference. Body balance is maintained by collaborative action of the visual, vestibular and somatosensory systems. Any deficiency in one of these systems is compensated for by the other systems. In our study, some or all these systems were not ruled out.

A negative correlation between BMI and the Challenge Disc for standing balance and between BMI and the TUG test for walking balance was demonstrated in our study, in agreement with a previous study.[34] In addition, our results found a negative correlation between age and standing balance as measured by the Challenge Disc, which was supported by the findings of another study.[35] Although the likelihood of falls and balance impairment are more common in the elderly, particularly over the age of 65, postural control and balance can also be negatively affected in middle-aged adults aged <65 years.[36]

Study strengths and limitations

The results of this study are reasonably valid, as a narrow inclusion criterion was used and an appropriate sample size was estimated before the start of the study. A limitation of the current study was that the researcher was not blinded to the tests or study groups, which could possibly have resulted in bias. Another limitation is that all the participants were men; nonetheless, Hageman *et al*.[37] had not found differences in balance between male and female patients in different age groups. The Romberg test and UPST test were only performed once, as previous research has not clarified the number of trials required for this test.[38,39] The UPST was also performed once, but this was because a previous study found higher ICC for one trial (0.994 for eyes open and 0.994 for eyes closed) compared with the mean of three trials (0.951 for eyes open and 0.832 for eyes closed).[17] The wide variation in shoulder pathology within the patient group might have affected the study results. The exploratory nature of research may have disadvantages such as difficulty of accurate interpretation of the results for a generalized population. However, this study was carried out because the topic needs to be understood in depth, especially that it has not been studied sufficiently before.

CONCLUSION

Our study showed that patients with mild-to-moderate chronic shoulder pain did not demonstrate statistically significant differences in standing and walking balance compared with healthy controls. However, there were trends that balance was lower in the shoulder pain group, as demonstrated by medium effect sizes for some standing and walking balance outcomes. In addition, negative correlations were found between BMI and the Challenge Disc of standing balance and between age and the Challenge Disc in both the groups. Thus, testing balance should be justified in the rehabilitation program for this group of patients. Future research may consider blinding the examiner to the test measurements and the inclusion of patients with high scores of pain intensity and functional disabilities.

Ethical statement

The study protocol was approved by the institutional review boards at Imam Abdulrahman Bin Faisal University (Ref no.: IRB-PGS-2017-03-182; date: October 1, 2017) and Dammam Medical Complex (Ref no.: RAC-034; March 19, 2018). The study followed ethical principles required for human research in accordance with the Declaration of Helsinki, 2013. A written informed consent was obtained from each patient.

Peer review

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Carli G, Suman AL, Biasi G, Marcolongo R. Reactivity to superficial and deep stimuli in patients with chronic musculoskeletal pain. Pain 2002;100:259-69.

2. Hill CL, Gill TK, Shanahan EM, Taylor AW. Prevalence and correlates of shoulder pain and stiffness in a population-based study: The North West Adelaide Health Study. Int J Rheum Dis 2010;13:215-22.
3. Smith E, Hoy DG, Cross M, Vos T, Naghavi M, Buchbinder R, *et al*. The global burden of other musculoskeletal disorders: Estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis 2014;73:1462-9.
4. Picavet HS, Schouten JS. Musculoskeletal pain in the Netherlands: Prevalences, consequences and risk groups, the DMC (3)-study. Pain 2003;102:167-78.
5. Riemann BL, Lephart SM. The sensorimotor system, part I: The physiologic basis of functional joint stability. J Athl Train 2002;37:71-9.
6. Leveille SG, Jones RN, Kiely DK, Hausdorff JM, Shmerling RH, Guralnik JM, *et al*. Chronic musculoskeletal pain and the occurrence of falls in an older population. JAMA 2009;302:2214-21.
7. Stubbs B, Binnekade T, Eggermont L, Sepehry AA, Patchay S, Schofield P. Pain and the risk for falls in community-dwelling older adults: Systematic review and meta-analysis. Arch Phys Med Rehabil 2014;95:175-87.
8. Kendall JC, Hvid LG, Hartvigsen J, Fazalbhoy A, Azari MF, Skjødt M, *et al*. Impact of musculoskeletal pain on balance and concerns of falling in mobility-limited, community-dwelling Danes over 75 years of age: A cross-sectional study. Aging Clin Exp Res 2018;30:969-75.
9. Ruhe A, Fejer R, Walker B. Pain relief is associated with decreasing postural sway in patients with non-specific low back pain. BMC Musculoskelet Disord 2012;13:39.
10. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Med 2006;36:189-98.
11. Baierle T, Kromer T, Petermann C, Magosch P, Luomajoki H. Balance ability and postural stability among patients with painful shoulder disorders and healthy controls. BMC Musculoskelet Disord 2013;14:282.
12. Howe TE, Rochester L, Neil F, Skelton DA, Ballinger C. Exercise for improving balance in older people. Cochrane Database Syst Rev 2011;11:CD004963.
13. Lin HW, Bhattacharyya N. Balance disorders in the elderly: Epidemiology and functional impact. Laryngoscope 2012;122:1858-61.
14. Dudek K, Drużbicki M, Przysada G, Śpiewak D. Assessment of standing balance in patients after ankle fractures. Acta Bioeng Biomech 2014;16:59-65.
15. Hildebrandt C, Müller L, Zisch B, Huber R, Fink C, Raschner C. Erratum to: Functional assessments for decision-making regarding return to sports following ACL reconstruction. Part I: Development of a new test battery. Knee Surg Sports Traumatol Arthrosc 2015;23:1282.
16. Kim MK, Kong BS, Yoo KT. The effect of shoe type on static and dynamic balance during treadmill walking in young healthy women. J Phys Ther Sci 2017;29:1653-7.
17. Springer BA, Marin R, Cyhan T, Roberts H, Gill NW. Normative values for the unipedal stance test with eyes open and closed. J Geriatr Phys Ther 2007;30:8-15.
18. Bohannon RW. Responsiveness of the single-limb stance test. Gait Posture 2012;35:173.
19. Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ. One-leg balance is an important predictor of injurious falls in older persons. J Am Geriatr Soc 1997;45:735-8.
20. Murray N, Salvatore A, Powell D, Reed-Jones R. Reliability and validity evidence of multiple balance assessments in athletes with a concussion. J Athl Train 2014;49:540-9.
21. Khasnis A, Gokula RM. Romberg's test. J Postgrad Med 2003;49:169-72.
22. Lugade V, Kaufman K. Center of pressure trajectory during gait: A comparison of four foot positions. Gait Posture 2014;40:719-22.
23. Saucedo F, Yang F. Effects of visual deprivation on stability among young and older adults during treadmill walking. Gait Posture 2017;54:106-11.
24. Almarwani M, Perera S, VanSwearingen JM, Sparto PJ, Brach JS. The test-retest reliability and minimal detectable change of spatial and temporal gait variability during usual over-ground walking for younger and older adults. Gait Posture 2016;44:94-9.
25. Chesnin KJ, Selby-Silverstein L, Besser MP. Comparison of an in-shoe pressure measurement device to a force plate: Concurrent validity of center of pressure measurements. Gait Posture 2000;12:128-33.
26. Zammit GV, Menz HB, Munteanu SE. Reliability of the TekScan MatScan (R) system for the measurement of plantar forces and pressures during barefoot level walking in healthy adults. J Foot Ankle Res 2010;3:11.
27. Podsiadlo D, Richardson S. The timed "Up & Go": A test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991;39:142-8.
28. Nightingale CJ, Mitchell SN, Butterfield SA. Validation of the timed up and go test for assessing balance variables in adults aged 65 and older. J Aging Phys Act 2019;27:230-3.
29. Kennedy DM, Stratford PW, Wessel J, Gollish JD, Penney D. Assessing stability and change of four performance measures: A longitudinal study evaluating outcome following total hip and knee arthroplasty. BMC Musculoskelet Disord 2005;6:3.
30. Cohen J. Statistical Power Analysis for the Behavioral Sciences. New York: Routledge Academic; 1988.
31. Treede RD, Apkarian VA, Bromm B, Greenspan JD, Lenz FA. Cortical representation of pain: functional characterization of nociceptive areas near the lateral sulcus. Pain 2000;87:113-9.
32. Sullivan EV, Rose J, Rohlfing T, Pfefferbaum A. Postural sway reduction in aging men and women: Relation to brain structure, cognitive status, and stabilizing factors. Neurobiol Aging 2009;30:793-807.
33. Crombez G, Eccleston C, Baeyens F, Eelen P. The disruptive nature of pain: An experimental investigation. Behav Res Ther 1996;34:911-8.
34. Greve J, Alonso A, Bordini AC, Camanho GL. Correlation between body mass index and postural balance. Clinics (Sao Paulo) 2007;62:717-20.
35. Balogun JA, Akindele KA, Nihinlola JO, Marzouk DK. Age-related changes in balance performance. Disabil Rehabil 1994;16:58-62.
36. Carbonneau E, Smeesters C. Effects of age and lean direction on the threshold of single-step balance recovery in younger, middle-aged and older adults. Gait Posture 2014;39:365-71.
37. Hageman PA, Leibowitz JM, Blanke D. Age and gender effects on postural control measures. Arch Phys Med Rehabil 1995;76:961-5.
38. Lacroix A, Kressig RW, Muehlbauer T, Gschwind YJ, Pfenninger B, Bruegger O, *et al*. Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: A randomized controlled trial. Gerontology 2016;62:275-88.
39. Uzor S, Baillie L, Skelton DA, Rowe PJ. Falls prevention advice and visual feedback to those at risk of falling: Study protocol for a pilot randomized controlled trial. Trials 2013;14:79.