

Inter- and Intra-Tester Reliability of Postural Stability Tests in Patients With Whiplash-Associated Disorder



Niklas Särkilähti, MHC,^a Airi Oksanen, PhD,^b Eliisa Löyttyniemi, MSc,^c Jenny Mäkelä, BHc,^d Janette Kaukonen, BHc,^d Jani Takatalo, PhD, MD,^{e,f} and Olli Tenovuo, PhD, MD^g

ABSTRACT

Objective: Our study aimed to examine the inter- and intra-tester reliability of postural balance tests in patients with whiplash-associated disorder (WAD).

Methods: Fifteen adults with chronic WAD performed 7 different postural balance tests using a static force platform: in the neutral head position (neutral test), gaze rotated 20° (left and right), head rotated 20° (left and right), and neck torsioned 20° (left and right) positions. Inter- and intra-tester reliability were assessed for both individual tests and the differences between the neutral test and each test variant in sway velocity (mm/s) and velocity moment (mm²/s) parameters. This assessment utilized intra- and interclass correlation, mean differences of 2 measurements (paired t-test or Wilcoxon signed-rank test), the coefficient of within-subject variance, and the 95% percentile.

Results: Overall results showed at least a strong (≥ 0.70) correlation between the 2 testers and the tester's 2 test sessions in the individual tests. Furthermore, the average results did not mainly differ between testers and test sessions, and no wide variability of results was noticeable, indicating that the results can be considered clinically meaningful. However, the correlations of the between-test differences primarily ranged from negligible to moderate, leaving the results clinically insignificant.

Conclusions: The results of this study suggest that individual postural balance tests yield clinically reliable results for patients with WAD. However, caution is warranted when assessing the difference between balance test variations. It is not yet known whether these tests can distinguish between different study groups and whether they are reliable in assessing different sensory systems. (J Manipulative Physiol Ther 2025;48:404-421)

Key Indexing Terms: Neck Pain; Postural Balance, Reproducibility of Results; Whiplash Injuries

INTRODUCTION

Postural balance measurements are commonly used methods in laboratory and clinical settings. Although

postural balance is established by the cooperation of several peripheral senses, such as the visual, vestibular, and somatosensory systems, and the central nervous system,¹⁻³ cervical afferent input appears to play an essential role in maintaining body postural control.

The relationship between altered cervical proprioception and impaired postural control has been demonstrated experimentally using artificial cervical muscle vibration and muscle fatigue methods in asymptomatic individuals.⁴⁻⁷ Furthermore, several studies have shown impaired postural control in individuals with neck pain (NP), especially in those with whiplash-associated disorder (WAD), compared to asymptomatic individuals.⁸⁻¹⁰ However, clinical diagnostic tests for cervical sensorimotor differential diagnosis have yet to be developed for balance testing.

Yu et al.¹¹ introduced an eyes-closed balance test variation, the neck torsion maneuver, to compare balance performance between a neutral head-trunk position and a trunk rotated beneath the neutral head position. Their¹¹ and later Williams et al.'s¹² studies showed that this maneuver decreased postural control compared to the neutral head-trunk position in individuals with chronic NP, but not in asymptomatic individuals or those with unilateral

^a Faculty of Medicine, Department of Clinical Neurosciences, University of Turku, Turku, Finland.

^b Turku University Hospital, Turku, Finland.

^c The Department of Biostatistics, University of Turku and Turku University Hospital, Turku, Finland.

^d Turku University of Applied Sciences, Turku, Finland.

^e Medical Research Center Oulu, University of Oulu, Oulu, Finland.

^f Loisto Terveys, Oulu, Finland.

^g Department of Clinical Neurosciences, Turku Brain Injury Centre and Turku University Hospital, Turku, Finland.

Corresponding author: Niklas Särkilähti, Faculty of Medicine, Department of Clinical Neurosciences, University of Turku, Turku, Finland.
(e-mail: niksar@utu.fi).

Paper submitted October 26, 2024; in revised form October 4, 2025; accepted October 13, 2025.

0161-4754

© 2025 by National University of Health Sciences. This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0/>)

<https://doi.org/10.1016/j.jmpt.2025.10.046>

vestibular loss. Since the eyes are closed and cervical rotation is performed by changing body position (the head remains in place), it has been suggested that the changes in the results of the NP group are related to altered cervical rather than vestibular and visual afferent input.^{11,12}

Other mechanisms should also be considered. In contrast to neck torsion, the neck rotation maneuver (cervical rotation above the neutral trunk position with eyes closed) would not appear to decrease postural control,^{11,12} although cervical afferent input can be assumed to alter in both positions. The different effects of these maneuvers on balance cannot be related to compensation of the vestibular system alone because the neck rotation maneuver does not seem to affect postural control in individuals with unilateral vestibular disorder.¹²

However, changes in head and body position appear to have opposite effects on the spatial weight direction of visual stimuli.^{13,14} Furthermore, animal studies have reported increased activation of the vestibulo-ocular reflex interneurons in the vestibular nuclei during neck torsion movements.¹⁵ Closing the eyes does not appear to resolve this issue, as functional magnetic resonance imaging studies have shown that the eyes-closed condition paradoxically increases brain activity in the visual system compared to the eyes-open condition.^{16,17} These findings challenge the notion that the neck torsion maneuver elicits cervical afferent input alone. Instead, they suggest that the differences in postural control between those with and without NP may be related to the combined effects of different systems, such as altered cervical, visual, and vestibular afferent input.

The literature partially supports this speculation, reporting comparable mean differences in postural balance measurements between individuals with WAD and asymptomatic individuals in both eyes-open and eyes-closed conditions,⁸ along with decreased postural control in individuals with WAD compared to those with acoustic neuroma during eyes-open and visual conflict, but not in eyes-closed comfortable stance.¹⁸ Surprisingly, a similar phenomenon is not reported between individuals with non-specific NP and asymptomatic individuals,¹⁰ further suggesting that these potential combined effects may differ between NP groups.

Only a few studies have evaluated different eye movement task responses to balance control. In healthy individuals, saccadic eye movements seem to increase postural control compared to gaze fixation or random looking.^{19,20} In contrast, the effects of smooth pursuit eye movements appear to vary depending on the target's speed.¹⁹⁻²¹ A space-fixed external visual reference structure seems to have an input component for postural control, independent of whether the eyes are moving.²² On the other hand, individuals with NP may have different balance responses to visual tasks compared to asymptomatic subjects, as neck

muscle activation patterns, with and without neck movement, have been reported to differ between these groups during different eye movement tasks.^{23,24}

Assessing the reliability of balance measurements is necessary to ensure that measurement differences between testers, test sessions, or research groups reflect a real difference or change rather than a random or systematic error in the measurement technique. The reliability of balance measurements using a force platform system has been widely evaluated, showing at least moderate reliability.²⁵⁻²⁷ However, most studies have evaluated the reliability of these measurements in asymptomatic individuals during both normal and narrow stances, with eyes open and closed. In contrast, there have been no reported reliability studies on neck and gaze-related test modifications or on studies involving individuals with NP. Therefore, our study aimed to examine the inter- and intra-tester reliability of static force platform measurements with different gaze tasks and head and body positions in patients with NP due to WAD.

METHODS

Study Design

An inter- and intra-tester reliability study was conducted.

Ethics

The Ethics Committee of the Turku University Hospital (TUH), Finland, reviewed the study protocol, and TUH granted a research permit for this study.

Participants

Auria Clinical Informatics (European Union Digital Innovation Hub) conducted a patient registry search of TUH using the whiplash injury diagnosis codes to recruit participants. Potential participants were sent a Research Information Sheet and a written consent document. After receiving the consent document, the first author (NS) assessed the potential participant's eligibility for the study from the TUH patient register, checked by another author (OT).

Participants were included in the study if their symptoms started after the accident and continued since then but for at least 3 months; symptoms had limited functioning, activity, and participation levels (causing sick leave or the need for repeated/long-term treatments); their age was 18 to 65; and their written and spoken Finnish language was proficient.

Participants were excluded from the study if they had not had a magnetic resonance imaging of the cervical spine;

had a spinal or nervous pathology explaining the symptoms (eg, myelopathy, fracture, radiculopathy); had a congenital structural abnormality of the cervical spine or craniocervical junction (eg, Chiari malformation); were on medication that may cause dizziness or balance problems; or had a traumatic brain injury diagnosed by abnormal imaging findings in the cerebellum or brainstem area, or classified as moderate-severe based on level of consciousness.

The sample size for comparing 2 coefficients of the inter-tester agreement was calculated using G*Power software by selecting the significance level as 0.05 and power as 0.8. The required sample size was 13 subjects, but it was set to 15 subjects, considering a possible dropout rate of 10%.

Measurements

All subjects completed the electronic questionnaire before the test session to collect their demographics, health status, quality of life, and information on physical activity level through single-item questions.^{28,29} The questionnaire also inquired about symptoms and impairments (using a 5-point Likert scale, from none to total) that might relate to balance performance.³⁰ The questionnaire was sent using the Research Electronic Data Capture (REDCap, Vanderbilt University) software.

Testing Equipment

Postural balance measurements were performed in the motion laboratory at TUH with a computer-based force platform system (Good Balance). The testing environment, including lighting, temperature, noise, and time (between 12:00 and 16:00), was standardized.

Balance was evaluated with 7 different tests: (1) The body and neck were in a neutral position with a gaze forward (neutral test); (2) The body and neck were in a neutral position with the gaze turned 20° to the right and left (the gaze right/left rotation test); (3) The body was in a neutral position, gaze forward, and the head was turned 20° to the right and left (neck right/left rotation test); (4) The head was in a neutral position, gaze forward, and the body turned 20° to the right and left (neck right/left torsion test).

All tests were performed with the eyes open because the mean difference in postural balance measurements between individuals with WAD and asymptomatic individuals does not appear to differ between eyes-open and eyes-closed conditions.⁸ Furthermore, the test position was adjusted from the commonly used 45° neck torsion/rotation position in cervical sensorimotor testing to 20° in each direction, as individuals with WAD cervical rotational mobility and gaze-fixed cervical active movement can fall below 45° and 30°, respectively.^{31,32} A smartphone (Apple iPhone X

A1901) and the 3D range of motion (ROM) application were used to assess cervical mobility. The suitability of the phone and application used in the study to measure the mobility of the cervical spine has been verified.³³

The standing position was validated at 1/3 trochanter width to be comparable between subjects. The distance between the trochanters was measured with a flexible measuring tape. The same method has been used, e.g., when testing lumbar movement control.³⁴

Two final-year physiotherapy students (JM and JK) trained by the 2 authors (NS and AO) independently performed 7 balance tests, and one of the testers on 2 occasions. Two testers were used because the tests involved measuring and guiding the test position (e.g., leg and neck test positions) and evaluating the approved test performance. Testers were blinded to all study and subject information, each other's measurements, and one tester's previous measurements. A detailed explanation of the equipment and tests used is presented in [Appendix 1 in the supplementary file](#).

Procedure

Before starting the balance measurements, the testers measured the subjects' cervical active mobility and hip width to determine the standing position. A subject was excluded from the study if the cervical rotation was below 20° in either direction.

Before each balance test, the subjects were given clear and consistent test instructions. However, the testers were allowed, if necessary, to modify the words used in the instructions and demonstrate the test to minimize possible misinterpretations related to the test instructions.²⁵

The neutral test was performed first. The order of the other tests and the side performed first were randomized. Each test was performed without shoes once for 15 seconds, with a 1-minute break in between. If any symptoms were increased during the test, the next test was performed only after the symptoms were relieved. Test practice was not allowed. These interventions aimed to control factors such as muscle fatigue, symptom changes, and learning effects that may affect balance performance.^{5,6,8,10} If the test was not performed according to the instructions, for example, when the head or trunk position was changed, the test was repeated.

After the first tester completed the test session, there was a 5-minute break before the second tester's test session. The first tester performed a second balance assessment 2 to 4 weeks later. The changes in subjects' symptoms between test sessions were assessed using the Global Rating of Change (GROC) scale ranging from -7 (a very great deal worse) to +7 (a very great deal better).³⁵ Subjects with a GROC score of more than ±3 were excluded from the data analysis because they were

considered to have shown clinically meaningful improvement or worsening of symptoms.³⁵ The GROC scale has been found to moderately correlate with disability change scores in patients with NP.³⁶

Statistical Analysis

In each postural balance test, 3 outcome parameters were calculated from the movement of the center of pressure (CoP): 1) anterior-posterior (AP) sway velocity (mm/s), 2) mediolateral (ML) sway velocity (mm/s), and 3) velocity moment (mm²/s).^{25,37}

A 3-layered approach was used to assess reliability. First, the group means of the 2 measurements – both between the 2 testers and between the tester's 2 test sessions – were analyzed to test their agreement (ie, whether scores systematically changed between the 2 measurements). The normality of the data distribution was assessed visually from the graphs (histogram and Q-Q plot) and using the Shapiro-Wilk test. The normally and non-normally distributed data were analyzed with a paired t-test and a Wilcoxon signed-rank test, respectively, with a significant level set at .05 (2-tailed).

Next, the correlation coefficient was used to describe the strength of the association between the 2 measurements. The intraclass correlation coefficient (ICC_{1,k} – 1-way random effects, absolute agreement, multiple raters/measurements) with a 95% CI and Pearson's correlation coefficient (PCC) were used if the data was normally distributed, and Spearman's correlation coefficient (SCC) otherwise. The following classifications were used to interpret correlation coefficients: ≥ 0.90 = very strong correlation; 0.70 to 0.89 = strong correlation; 0.40 to 0.69 = moderate correlation; 0.10 to 0.39 = weak correlation; 0.00 to 0.10 = negligible correlation.³⁸

Finally, the coefficient of within-subject variance (CWV) and 95% percentile were used to describe the variability between the 2 measurements.

Since different test variants, such as the neck torsion maneuver, are used to evaluate the effects of different sensory systems on postural control, the reliability of the change between the neutral test and each variant was also assessed. To achieve this, the differences in CoP parameters between the neutral test and each test variant were calculated (eg, the first tester's first test session: the ML sway velocity of the gaze right rotation test minus the ML sway velocity of the neutral test). The analyses between the 2 testers and between the tester's 2 test sessions were then continued as previously described. Neut-GazeR/L, Neut-RotR/L, and Neut-TorR/L were used to present the differences between the neutral test and the gaze right/left rotation, neck right/left rotation, and neck right/left torsion tests, respectively.

Outside the reliability analysis, the demographic features and severity of symptoms and impairments experienced by the patients were calculated to describe the study population. The severity of symptoms and impairments was reported as the mean and SD and with the frequency of patients who rated items 2-4 on a 5-point scale.

EL performed the randomization and all statistical analyses with SAS software, Version 9.4 of the SAS System for Windows (SAS Institute Inc.). All data are presented to allow comparisons between the results within this publication and between this and other publications.

RESULTS

A total of 15 subjects participated in the study. One subject withdrew from the study before the start of the tests due to an ankle fracture, and 1 subject did not want to participate in the retests, so the sample size was 14 in the inter-tester study and 13 in the intra-tester study. The tests were performed between February 10 and March 21, 2022.

Description of the Subjects

All subjects were women, with nearly half having retired due to WAD. The most severe symptoms reported by the patients were headache, followed by neck pain and dizziness. The mean active cervical rotation to the left and right was 49.8° (SD 14.6) and 50.2° (SD 12.3), respectively. Each subject achieved at least 20° of cervical rotation mobility in both directions, and no clinically meaningful change was observed in their symptoms (range ± 2) on the GROC scale between the 2 test sessions; therefore, the results from all subjects were included in the reliability analysis. Detailed demographic data of the subjects are presented in [Table 1](#).

Inter-Tester Reliability

For individual tests, the ML sway velocity parameter in the Gaze Left Rotation (GLR), Neck Left Torsion (NLT), Neck Right Rotation (NRR), and Neck Left Rotation (NLR) tests; the AP sway velocity parameter in the NLT, NRR, and NLR tests; and the velocity moment parameter in all tests failed to meet the normality assumption and were analyzed using the Wilcoxon signed-rank test and SCC. When considering the data distribution, all tests achieved at least a strong correlation (ICC, PCC, or SCC ≥ 0.70) between the testers. However, in the NLT test, the correlation of the ML sway velocity parameter remained moderate (SCC 0.67). In addition, in the GLR test, the average results of the ML sway velocity parameter differed statistically significantly between testers, and there was a wide range in the 95% percentiles, which might weaken

Table 1. Detailed Demographic Data of the Subjects.

Patient Demographic		Results
Female	n (%)	15 (100)
Age, years	Mean (SD)	47.4 (11.2)
Height, cm	Mean (SD)	164.9 (6.1)
Weight, kg	Mean (SD)	78.1 (15.2)
Body mass index	Mean (SD)	28.8 (5.5)
<i>Education</i>		
- Primary school	n (%)	0 (0)
- Upper secondary education	n (%)	10 (67)
- Higher education	n (%)	5 (33)
<i>Work situation</i>		
- In full-time job / In part-time work	n (%)	5 (33)
- On sick leave / On partial sick leave	n (%)	1 (7)
- Unemployed	n (%)	1 (7)
- Retired / Part-time pension due to incapacity	n (%)	7 (47)
- On maternity or parental leave	n (%)	1 (7)
<i>Perceived health</i>		
- Very good / Good	n (%)	4 (27)
- Average	n (%)	7 (47)
- Fairly poor / Poor	n (%)	4 (27)
<i>Quality of life</i>		
- Very bad / Bad	n (%)	1 (7)
- Neither good nor bad	n (%)	6 (40)
- Good / Very good	n (%)	8 (53)
<i>Amount of leisure time exercise</i>		
- Low	n (%)	3 (20)
- Average	n (%)	11 (73)
- Large	n (%)	1 (7)

(continued)

Table 1. (Continued)

Patient Demographic		Results
<i>Severity of symptoms and impairments*</i>		
- Headache	Mean (SD) / n (%)	2.5 (0.7) / 14 (93)
- Neck pain	Mean (SD) / n (%)	2.4 (0.6) / 14 (93)
- Dizziness	Mean (SD) / n (%)	2.0 (1.1) / 10 (67)
- Numbness in the upper extremity	Mean (SD) / n (%)	1.9 (1.1) / 9 (60)
- Maintaining balance	Mean (SD) / n (%)	1.9 (1.3) / 9 (60)
- Upper back pain	Mean (SD) / n (%)	1.9 (1.4) / 9 (60)
- Pain in the upper extremity	Mean (SD) / n (%)	1.5 (1.1) / 9 (60)
- Low back pain	Mean (SD) / n (%)	1.4 (1.2) / 7 (47)
- Pain in the lower extremity	Mean (SD) / n (%)	1.3 (1.4) / 5 (33)
Cervical rotation to the left	Mean [°] (SD) / Range [°]	49.8 (14.6) / 20 -69.4
Cervical rotation to the right	Mean [°] (SD) / Range [°]	50.2 (12.3) / 23.6 -64.6

* The severity of symptoms and impairments was assessed using a 5-point Likert scale (from 0 = none to 4 = total) and the frequency of patients who rated the items on a scale of 2–4. % = proportion of subjects; cm = centimeter; ° = degrees; kg = kilogram; n = number of subjects.

the correlation coefficient. Despite these, the overall results can be considered clinically meaningful.

For the differences between neutral and each variant, all parameters in the Neut-GazeL, Neutral-TorR, and Neut-TorL; the ML sway velocity parameter in the Neut-RotR; the AP sway velocity parameter in the Neut-GazeL; and the velocity moment parameter in the Neut-GazeR, Neutral-RotR, and Neut-RotL did not meet the normality assumption and were analyzed using the Wilcoxon signed-rank test and SCC. Only the Neut-TorR and Neut-RotL achieved at least a strong correlation (ICC, PCC, or SCC ≥ 0.72) between testers, except for the velocity moment parameter of the Neut-RotL, which exhibited a weak correlation (SCC 0.26). Since the average results did not statistically differ between testers, and the ranges in the 95% percentiles were narrow, the results can be considered clinically meaningful. Otherwise, the correlation of differences between the neutral test and each variant varied from negligible to moderate for each parameter. The detailed values for inter-tester reliability are shown in Tables 2-3.

Intra-Tester Reliability

For individual tests, the ML sway velocity parameter in all tests except the Neutral test; the AP sway velocity parameter in the GLR and NRR tests; and the velocity moment parameter in all tests except the Gaze Right Rotation test failed to meet the normality assumption and were analyzed using the Wilcoxon signed-rank test and SCC. The correlation between the first and second test sessions was at least strong (ICC, PCC, or SCC >0.70) for all tests, except for the AP sway velocity parameter of the Neutral test, which was moderate (ICC 0.68). However, in the GLR test, the average results for 2 out of 3 parameters statistically significantly differed between the test sessions, and there was a wide range in the 95% percentiles, which might weaken the correlation coefficients. The same phenomenon was noticeable in the velocity moment parameter of the NLR test. The overall results can be considered clinically meaningful except for the GLR test.

For the differences between neutral and each variant, all parameters in the Neut-GazeR, Neut-GazeL, and Neut-TorR; the ML sway velocity in the Neut-TorL and Neut-RotR; the AP sway velocity in the Neut-RotR; and the velocity moment in the Neut-TorL, Neut-TorR, and Neut-TorL did not meet the normality assumption and were analyzed using the Wilcoxon signed-rank test and SCC. The correlation was moderate at best (SCC \leq 0.69) between the first and second test sessions, and therefore, the overall results cannot be considered clinically meaningful. Detailed values for the intra-tester reliability are shown in Tables 4-5.

DISCUSSION

The study examined the inter- and intra-tester reliability of force platform measurements in patients with WAD. The overall results showed that postural balance testing with different test variations strongly correlated between the testers and the tester's 2 test sessions. Furthermore, the average results did not mainly differ between testers and test sessions, and no wide variability of results was noticeable, indicating that the results can be considered clinically meaningful. However, the reliability of the difference between the neutral test and each test variant remained mainly below the acceptable level. Therefore, force plate measurements as single tests can be considered reliable for assessing balance performance in patients with WAD.

Systematic reviews and meta-analyses have shown that individuals with NP have impaired postural control compared to asymptomatic individuals.⁸⁻¹⁰ However, there is heterogeneity in the study designs and large differences in the results of the studies included in the reviews.^{9,10} One possible reason for the variability of the results may be related to the reliability of the tests used in the studies.

Previous studies have mainly reported moderate to strong reliability of balance measurements using a force

plate system, but differences between tests and parameters have been large.^{25-27,39-41} However, most reliability studies have been conducted with asymptomatic individuals, except for a few pain disorders such as neck, low back, and lower extremity pain.³⁹⁻⁴⁴ In individuals with NP, the ICC has varied from weak to strong depending on the test and parameter,^{39,40} but these studies used either 3 successive trials⁴⁰ or the Wii measurement device.³⁹ Furthermore, to our knowledge, no studies have been conducted on the reliability of the difference in CoP parameters between 2 different balance tests.

Several factors have been reported to affect the reliability of balance measurements, such as instructions, foot position, visual condition, test duration, and number of repetitions.²⁵ However, changes in the subject's symptoms and performance can also affect the reliability of the tests. Therefore, the study focused on standardizing the test implementation between the subjects while minimizing changes in subjects' performance during and between test sessions.

First, the testers were instructed to ensure that the subjects understood the test instructions before starting each test. Although the test instructions were first given in a precisely defined manner, the testers were allowed to modify the words used in the instructions, supplement the instructions, and demonstrate the test if the subject felt the test implementation was unclear.

Second, commonly used testing positions, such as feet-together, narrow or comfortable stances, were modified because they cannot be considered comparable between subjects. For example, in a feet-together stance, the degree of hip adduction depends on the anatomical width of the subject's pelvis. However, since muscle activity in the narrow stance seems to be greater compared to the wide stance,⁴⁵ the standing position was validated at 1/3 trochanter width.

Third, the recommended long test times (\geq 60 sec) and the use of several repetitions (\geq 3)²⁵ were not followed. The purpose of using short test times, extended breaks if necessary, only 1 repetition, and the GROC scale was to control factors that may affect balance performance, such as the subject's tiredness,^{46,47} muscle fatigue^{5,6,48,49} or changes in symptoms (pain ratings, sensitization, and dizziness).^{8,40,50} In addition, learning can affect balance performance. However, performing the tests with eyes open and on a stable surface⁵¹ and with a short duration and 1 repetition without training has probably kept the learning effect to a minimum.

Statistics

Most previous studies have applied various ICC models to represent the reliability of the balance measurements. However, the ICC assumes a normal data distribution and stable between-subject variance, and its magnitude depends on the number of subjects and raters.⁵²⁻⁵⁴ On the other hand, the PCC and SCC measure only correlations for

Table 2. Detailed Values for the Inter-Tester Reliability of Each Test.

Test	Parameter	Tester 1, Mean (SD)	Tester 2, Mean (SD)	Distribution	t-test, p-value	WSR, p-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neutral	ML sway velocity (mm/s)	8.02 (7.96)	6.93 (7.40)	Normal	.25	.21	0.89 (0.73, 0.96)	0.91	0.84	0.32	-4.9	9.1
	AP sway velocity (mm/s)	11.56 (7.95)	12.74 (11.26)	Normal	.44	.74	0.83 (0.61, 0.94)	0.89	0.67	0.32	-15.3	6.3
	Velocity moment (mm ² /s)	67.52 (115.62)	87.24 (186.30)	Non-normal	.35	.86	0.87 (0.68, 0.95)	0.98	0.88	0.70	-255.6	57.4
Gaze right rotation	ML sway velocity (mm/s)	6.26 (5.86)	5.98 (3.94)	Normal	.67	.87	0.88 (0.70, 0.96)	0.95	0.89	0.28	-3.1	7.3
	AP sway velocity (mm/s)	10.79 (8.16)	12.03 (8.30)	Normal	.08	.08	0.95 (0.86, 0.98)	0.96	0.75	0.16	-6.8	3.3
	Velocity moment (mm ² /s)	61.89 (136.63)	49.50 (78.07)	Non-normal	.47	.46	0.84 (0.62, 0.94)	0.98	0.84	0.78	-19.6	226.9
Gaze left rotation	ML sway velocity (mm/s)	15.57 (27.94)	9.76 (14.82)	Non-normal	.14	.03*	0.78 (0.51, 0.92)	0.98	0.79	0.81	-1.3	50.4
	AP sway velocity (mm/s)	15.19 (17.13)	15.26 (16.59)	Normal	.96	.91	0.96 (0.90, 0.99)	0.96	0.89	0.20	-10.3	10.2
	Velocity moment (mm ² /s)	239.58 (578.11)	147.00 (328.12)	Non-normal	.24	.14	0.80 (0.56, 0.93)	0.96	0.88	1.04	-12.5	1044.4
Neck right torsion	ML sway velocity (mm/s)	11.59 (11.24)	10.11 (9.50)	Normal	.07	.11	0.95 (0.88, 0.98)	0.98	0.89	0.20	-3.3	7.4
	AP sway velocity (mm/s)	13.87 (12.32)	13.36 (11.84)	Normal	.44	.25	0.98 (0.94, 0.99)	0.98	0.94	0.12	-4.3	4.8
	Velocity moment (mm ² /s)	107.52 (205.64)	137.13 (295.64)	Non-normal	.27	.86	0.92 (0.80, 0.97)	0.99	0.95	0.57	-341.0	49.8

(continued)

Table 2. (Continued)

Test	Parameter	Tester 1, Mean (SD)	Tester 2, Mean (SD)	Distribution	t-test, p-value	WSR, p-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neck left torsion	ML sway velocity (mm/s)	8.24 (5.89)	10.87 (10.96)	Non-normal	.27	.71	0.50 (0.17, 0.83)	0.64	0.67	0.63	-29.2	3.1
	AP sway velocity (mm/s)	12.26 (8.30)	15.89 (19.28)	Non-normal	.27	.76	0.66 (0.35, 0.88)	0.95	0.93	0.59	-38.3	5.4
	Velocity moment (mm ² /s)	73.64 (173.35)	135.71 (271.55)	Non-normal	.32	.86	0.49 (0.16, 0.83)	0.57	0.86	1.51	-827.0	51.3
Neck right rotation	ML sway velocity (mm/s)	7.91 (11.14)	9.71 (14.65)	Non-normal	.24	.25	0.90 (0.75, 0.96)	0.94	0.80	0.45	-20.4	1.9
	AP sway velocity (mm/s)	27.29 (53.14)	14.30 (13.28)	Non-normal	.27	.35	0.87 (0.69, 0.95)	0.92	0.76	0.30	-13.1	5.8
	Velocity moment (mm ² /s)	105.66 (219.64)	174.11 (397.25)	Non-normal	.18	.63	0.82 (0.59, 0.94)	1.00	0.84	0.94	-546.8	20.8
Neck left rotation	ML sway velocity (mm/s)	11.14 (17.86)	10.69 (18.07)	Non-normal	.71	.21	0.97 (0.92, 0.99)	0.97	0.87	0.28	-12.7	7.6
	AP sway velocity (mm/s)	14.01 (14.59)	16.71 (19.62)	Non-normal	.15	.27	0.92 (0.78, 0.97)	0.97	0.73	0.32	-13.8	7.5
	Velocity moment (mm ² /s)	338.30 (988.90)	210.16 (492.67)	Non-normal	.44	.33	0.69 (0.38, 0.89)	0.88	0.86	1.53	-454.8	2172.1

AP, anteroposterior; CWV, coefficient of within-subject variation; ICC, intraclass correlation coefficient; ML, mediolateral; PCC, Pearson's correlation coefficient; SCC, Spearman Correlation Coefficient; WSRT, Wilcoxon signed rank test.

Variables according to data distribution are in bold. * = Statistically significant difference (<.05).

Table 3. Detailed Values for the Inter-Tester Reliability of the Differences Between the Neutral and Test Variations.

Test	Parameter	Tester 1, Mean difference (SD)	Tester 2, Mean difference (SD)	Distribution	t-test, P-value	WSR, P-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neutral-Gaze Right Rotation	ML sway velocity (mm/s)	-1.76 (3.28)	-0.95 (4.72)	Normal	.41	.33	0.61 (0.28, 0.86)	0.67	0.43	-1.82	-6.5	7.5
	AP sway velocity (mm/s)	-0.77 (4.30)	-0.71 (4.09)	Non-normal	.96	.66	0.38 (0.08, 0.80)	0.38	0.47	-4.30	-5.4	9.2
	Velocity moment (mm ² /s)	-5.63 (103.53)	-37.74 (136.34)	Non-normal	.32	.90	0.51 (0.18, 0.83)	0.56	0.20	-3.79	-72.8	334.4
Neutral-Gaze Left Rotation	ML sway velocity (mm/s)	7.55 (20.72)	2.84 (8.49)	Non-normal	.19	.55	0.64 (0.32, 0.87)	0.97	0.26	1.78	-6.6	41.3
	AP sway velocity (mm/s)	3.64 (11.42)	2.51 (6.39)	Non-normal	1.0	.49	0.79 (0.53, 0.92)	0.93	0.61	1.35	-5.2	18.2
	Velocity moment (mm ² /s)	172.06 (485.12)	59.76 (160.31)	Non-normal	.22	.76	0.55 (0.22, 0.84)	1.00	0.64	2.03	-36.8	1151.9
Neutral-Neck Right Torsion	ML sway velocity (mm/s)	3.57 (4.87)	3.19 (3.46)	Non-normal	.73	.77	0.51 (0.18, 0.83)	0.55	0.84	0.84	-6.0	12.3
	AP sway velocity (mm/s)	2.31 (7.44)	0.62 (2.46)	Non-normal	.35	.67	0.85 (0.70, 0.93)	0.53	0.78	1.48	-5.5	20.1
	Velocity moment (mm ² /s)	40.00 (100.33)	49.89 (113.85)	Non-normal	.25	.50	0.95 (0.88, 0.98)	0.97	0.88	0.49	-85.4	39.7
Neutral-Neck Left Torsion	ML sway velocity (mm/s)	0.21 (4.00)	3.94 (4.86)	Non-normal	.09	.33	0.00 (., .)	-0.50	-0.25	2.25	-24.3	2.8
	AP sway velocity (mm/s)	0.70 (4.27)	3.15 (10.05)	Non-normal	.35	.84	0.99 (0.98, 0.99)	0.36	0.17	0.32	-30.3	6.8
	Velocity moment (mm ² /s)	6.11 (149.30)	48.46 (94.43)	Non-normal	.35	.81	0.10 (0.00, 0.97)	0.15	0.37	4.25	-571.4	158.8

(continued)

Table 3. (Continued)

Test	Parameter	Tester 1, Mean difference (SD)	Tester 2, Mean difference (SD)	Distribution	t-test, P-value	WSR, P-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neutral-Neck Right Rotation	ML sway velocity (mm/s)	-0.11 (5.95)	2.78 (7.80)	Non-normal	.20	.17	0.28 (0.03, 0.81)	0.35	-0.06	4.37	-29.5	2.1
	AP sway velocity (mm/s)	1.01 (4.15)	1.56 (2.89)	Normal	.63	.60	0.33 (0.06, 0.80)	0.36	0.32	2.21	-7.2	7.3
	Velocity moment (mm ² /s)	38.14 (117.73)	86.87 (236.33)	Non-normal	.16	.07	0.75 (0.48, 0.91)	0.99	0.68	1.44	-439.3	23.7
Neutral-Neck Left Rotation	ML sway velocity (mm/s)	3.11 (10.92)	3.76 (11.70)	Normal	.49	.51	0.95 (0.87, 0.98)	0.96	0.40	0.69	-7.8	5.7
	AP sway velocity (mm/s)	2.45 (9.08)	3.96 (9.01)	Normal	.41	.58	0.72 (0.43, 0.90)	0.73	0.09	1.44	-16.3	8.3
	Velocity moment (mm ² /s)	270.78 (922.19)	122.91 (335.53)	Non-normal	.39	.72	0.59 (0.26, 0.85)	0.94	0.26	2.20	-199.2	2279.6

AP, anteroposterior; CWV, coefficient of within-subject variation; ICC, intraclass correlation coefficient; ML, mediolateral; PCC, Pearson's correlation coefficient; SCC, Spearman Correlation Coefficient; WSRT, Wilcoxon signed rank test.

Variables according to data distribution are in bold.

Table 4. Detailed Values for the Intra-Tester Reliability of Each Test.

Test	Parameter	Session 1, Mean (SD)	Session 2, Mean (SD)	Distribution	t-test, P-value	WSR, P-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neutral	ML sway velocity (mm/s)	8.02 (7.96)	7.04 (5.14)	Normal	.25	.35	0.81 (0.57, 0.93)	0.93	0.82	0.38	-2.2	12.7
	AP sway velocity (mm/s)	11.56 (7.95)	15.00 (13.33)	Normal	.20	.27	0.68 (0.36, 0.89)	0.81	0.65	0.46	-27.1	5.9
	Velocity moment (mm ² /s)	67.52 (115.62)	61.94 (110.17)	Non-normal	.31	.74	0.95 (0.86, 0.98)	0.96	0.75	0.39	-24.3	111.9
Gaze right rotation	ML sway velocity (mm/s)	6.26 (5.86)	6.29 (5.48)	Non-normal	.80	.30	0.95 (0.87, 0.98)	0.96	0.78	0.19	-4.5	2.3
	AP sway velocity (mm/s)	10.79 (8.16)	13.45 (10.42)	Normal	.09	.08	0.85 (0.63, 0.95)	0.90	0.84	0.30	-14.8	2.5
	Velocity moment (mm ² /s)	61.89 (136.63)	76.60 (155.48)	Normal	.18	.54	0.98 (0.94, 0.99)	0.99	0.84	0.30	-86.2	22.8
Gaze left rotation	ML sway velocity (mm/s)	15.57 (27.94)	7.09 (9.11)	Non-normal	.16	<.01*	0.43 (0.12, 0.81)	0.89	0.79	1.36	-1.0	75.4
	AP sway velocity (mm/s)	15.19 (17.13)	12.43 (11.64)	Non-normal	.25	.07	0.75 (0.46, 0.91)	0.85	0.84	0.52	-4.5	35.6
	Velocity moment (mm ² /s)	239.58 (578.11)	75.02 (153.67)	Non-normal	.18	.01*	0.39 (0.09, 0.81)	0.97	0.79	2.07	-3.3	1525.9
Neck right torsion	ML sway velocity (mm/s)	11.59 (11.24)	7.86 (4.44)	Non-normal	.09	.64	0.49 (0.16, 0.83)	0.88	0.81	0.63	-3.4	26.2
	AP sway velocity (mm/s)	13.87 (12.32)	11.98 (9.71)	Normal	.10	.52	0.88 (0.70, 0.96)	0.94	0.72	0.29	-3.4	14.4
	Velocity moment (mm ² /s)	107.52 (205.64)	55.48 (80.12)	Non-normal	.15	.62	0.57 (0.23, 0.85)	0.96	0.87	1.25	-33.1	414.6
Neck left torsion	ML sway velocity (mm/s)	8.24 (5.89)	9.23 (9.85)	Non-normal	.64	.55	0.67 (0.35, 0.88)	0.77	0.89	0.51	-21.6	4.1
	AP sway velocity (mm/s)	12.26 (8.30)	11.72 (10.49)	Normal	.52	.19	0.89 (0.73, 0.96)	0.92	0.95	0.25	-10.7	6.8
	Velocity moment (mm ² /s)	73.64 (173.35)	100.32 (197.88)	Non-normal	.62	.15	0.63 (0.30, 0.87)	0.65	0.90	1.27	-525.0	178.7
Neck right rotation	ML sway velocity (mm/s)	7.91 (11.14)	5.77 (5.53)	Non-normal	.33	.81	0.50 (0.17, 0.83)	0.69	0.97	0.89	-1.2	31.3
	AP sway velocity (mm/s)	12.56 (9.80)	12.06 (10.63)	Non-normal	.32	.06	0.96 (0.89, 0.99)	0.97	0.97	0.16	-6.9	5.6
	Velocity moment (mm ² /s)	105.66 (219.64)	58.45 (115.95)	Non-normal	.19	.22	0.68 (0.37, 0.89)	0.90	0.96	1.18	-6.7	441.6

(continued)

Table 4. (Continued)

Test	Parameter	Session 1, Mean (SD)	Session 2, Mean (SD)	Distribution	t-test, P-value	WSR, P-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neck left rotation	ML sway velocity (mm/s)	11.14 (17.86)	9.67 (13.96)	Non-normal	.49	.85	0.78 (0.52, 0.92)	0.83	0.72	0.70	-13.2	33.6
	AP sway velocity (mm/s)	14.01 (14.59)	12.59 (10.91)	Normal	.28	.31	0.87 (0.68, 0.95)	0.93	0.70	0.34	-7.1	18.2
	Velocity moment (mm ² /s)	338.30 (988.90)	140.44 (305.71)	Non-normal	.32	.03*	0.43 (0.12, 0.81)	0.87	0.78	2.27	-14.7	2791.0

AP, anteroposterior; CWV, coefficient of within-subject variation; ICC, intraclass correlation coefficient; ML, mediolateral; PCC, Pearson's correlation coefficient; SCC, Spearman Correlation Coefficient; WSR = Wilcoxon signed rank test. Variables according to data distribution are in bold. * = Statistically significant difference (<.05).

normally and non-normally distributed data, respectively.⁵³ The pitfalls of different analysis methods can be one reason for varying results in previous studies, and therefore, the study aimed to describe the data comprehensively.

A large part of the data in this study were non-normally distributed. Therefore, it was unsurprising that the ICC and SCC results for individual parameters differed greatly. For example, in the NLT test, the correlation between testers was moderate using ICC and from moderate to very strong, depending on the parameter using SCC. Otherwise, the correlation coefficients were similar between statistical tests, showing at least a strong correlation for individual tests.

Furthermore, the average results were not mainly statistically different, and the 95% percentile intervals were narrow between the 2 measurements, suggesting that the results can be considered clinically meaningful. However, the results showed a significant level of difference and variability between the testers in the ML sway velocity parameter of the GLR test, and between the tester's 2 test sessions in the ML sway velocity parameter of the GLR test and velocity moment parameter of the GLR and NLR tests. This suggests that these results cannot be considered clinically reliable despite the strong correlation of parameters. In any of the tests, there were no indications of factors that would weaken the correlation coefficients in the AP sway velocity parameter.

Although the effect of, e.g., fatigue or learning on the results cannot be excluded entirely, the most likely reason for the significant level of differences and variability is related to the subjects' sudden and unintentional sways on the force platform. Especially in short test durations, such as in this study, the average sway velocities seem to be at their highest.⁵⁵ Furthermore, pre-defined neck and gaze positions and limitations in their movements during the test can change the subject's characteristic corrective responses and cause unintentional uncontrolled movements somewhere else in the body, such as in individuals with vestibular or lower-leg proprioceptive loss during quiet standing.⁵⁶ In any case, performing several repetitions in clinical work is justified to reduce the importance of these sudden and unintentional sways on the results.

Cervical Sensorimotor Control

Measurements of balance performance in patients with NP can be considered non-specific for assessing cervical sensorimotor control. However, Yu et al.¹¹ introduced the eyes-closed neck torsion maneuver to assess the effects of the neck on balance by comparing balance performance between neutral head-trunk and 45° neck torsion positions. Since postural control appears to be decreased in the neck torsion position compared to the neutral position in individuals with chronic NP (most with WAD) but not in asymptomatic individuals or those with unilateral vestibular loss,^{11,12} the neck

Table 5. Detailed Values for the Intra-Tester Reliability of the Differences Between the Neutral and Test Variations.

Test	Parameter	Session 1, Mean Difference (SD)	Session 2, Mean Difference (SD)	Distribution	t-test, P-value	WSR, P-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neutral-Gaze Right Rotation	ML sway velocity (mm/s)	-1.76 (3.28)	-0.75 (3.02)	Non-normal	.29	.67	0.22 (0.01, 0.85)	0.27	0.03	-2.17	-10.4	2.7
	AP sway velocity (mm/s)	-0.77 (4.30)	-1.55 (5.23)	Non-normal	.63	1.0	0.33 (0.06, 0.80)	0.36	0.28	-3.29	-5.9	12.3
	Velocity moment (mm ² /s)	-5.63 (103.53)	14.66 (127.49)	Non-normal	.14	.41	0.89 (0.73, 0.96)	0.93	0.63	8.79	-143.5	25.7
Neutral-Gaze Left Rotation	ML sway velocity (mm/s)	7.55 (20.72)	0.05 (4.70)	Non-normal	.16	.03*	0.26 (0.03, 0.82)	0.83	0.69	3.28	-1.4	62.7
	AP sway velocity (mm/s)	3.64 (11.42)	-2.57 (3.63)	Non-normal	.08	.06	0.00 (., .)	0.05	-0.13	13.65	-4.7	40.0
	Velocity moment (mm ² /s)	172.06 (485.12)	13.08 (83.87)	Non-normal	.18	.15	0.22 (0.01, 0.84)	0.92	0.48	3.26	-18.6	1414.0
Neutral-Neck Right Torsion	ML sway velocity (mm/s)	3.57 (4.87)	0.82 (2.74)	Non-normal	.15	.19	0.00 (., .)	-0.40	-0.004	1.81	-2.9	23.0
	AP sway velocity (mm/s)	2.31 (7.44)	-3.02 (4.35)	Non-normal	.08	.05	0.00 (., .)	-0.42	-0.24	-25.4	-8.3	32.4
	Velocity moment (mm ² /s)	40.00 (100.33)	-6.46 (64.63)	Non-normal	.20	.35	0.00 (., .)	-0.11	0.17	4.83	-56.5	427.0
Neutral-Neck Left Torsion	ML sway velocity (mm/s)	0.21 (4.00)	2.19 (4.99)	Non-normal	.36	.59	0.00 (., .)	-0.63	0.04	3.81	-24.8	3.7
	AP sway velocity (mm/s)	0.70 (4.27)	-3.28 (6.17)	Normal	.03*	.02	0.27 (0.03, 0.82)	0.48	0.40	-3.93	-4.9	16.4
	Velocity moment (mm ² /s)	6.11 (149.30)	38.38 (109.13)	Non-normal	.44	.62	0.38 (0.08, 0.80)	0.44	0.56	4.69	-512.6	66.8

(continued)

Table 5. (Continued)

Test	Parameter	Session 1, Mean Difference (SD)	Session 2, Mean Difference (SD)	Distribution	t-test, P-value	WSR, P-value	ICC (CI95%)	PCC	SCC	CWV	2.5 percentile	97.5 percentile
Neutral-Neck Right Rotation	ML sway velocity (mm/s)	-0.11 (5.95)	-1.27 (3.52)	Non-normal	.66	.96	0.00 (., .)	-0.68	-0.43	-7.14	-12.7	28.1
	AP sway velocity (mm/s)	1.01 (4.15)	-2.94 (6.05)	Normal	.17	.19	0.00 (., .)	-0.29	-0.07	-5.97	-6.3	29.3
	Velocity moment (mm ² /s)	38.14 (117.73)	-3.48 (107.04)	Non-normal	.27	.65	0.31 (0.05, 0.80)	0.38	0.02	4.98	-33.2	454.0
Neutral-Neck Left Rotation	ML sway velocity (mm/s)	3.11 (10.92)	2.63 (9.22)	Normal	.74	.74	0.67 (0.35, 0.88)	0.70	0.28	1.98	-16.4	20.9
	AP sway velocity (mm/s)	2.45 (9.08)	-2.41 (5.41)	Non-normal	.14	.19	0.00 (., .)	-0.11	0.12	68.90	-7.7	32.8
	Velocity moment (mm ² /s)	270.78 (922.19)	78.50 (229.27)	Non-normal	.24	.32	0.39 (0.09, 0.81)	0.95	0.60	2.96	-24.2	2679.1

AP, anteroposterior; CWV, coefficient of within-subject variation; ICC, intraclass correlation coefficient; ML, mediolateral; PCC, Pearson's correlation coefficient; SCC, Spearman Correlation Coefficient; WSRT, Wilcoxon signed rank test.

Variables according to data distribution are in bold. * = Statistically significant difference (<.05).

torsion maneuver has been suggested to identify cervical afferent causes of disturbed postural stability.

However, the existing literature seems to lack evidence supporting a specific position as optimal for assessing cervical sensorimotor control. For example, unlike the 45° torsion position, the 45° cervical rotation position has been reported to increase postural control in individuals with WAD, unilateral vestibular loss, and asymptomatic individuals,^{11,12} while the maximal rotation position has been reported to decrease postural control in asymptomatic individuals.⁵⁷ Furthermore, asymmetric rotational mobility of the upper cervical spine has been shown to decrease postural control compared to symmetrical rotational mobility in individuals with NP.⁵⁸ These findings suggest that neck position related to the subject's cervical mobility or symptoms (e.g., pain or stiffness) may affect balance performance. The literature on oculomotor control also supports this hypothesis, demonstrating medium-level agreement in eye movements during the Smooth Pursuit Neck Torsion test at 2 neck torsion angles (30° and 45°) in individuals with NP, but a higher level of agreement in asymptomatic individuals.⁵⁹

The literature also does not seem to support conducting the postural balance tests only with eyes closed. According to a systematic review and meta-analysis, the mean difference in postural control between individuals with WAD and asymptomatic individuals does not appear to vary when comparing eyes-open and eyes-closed conditions.⁸ Conversely, closing the eyes may highlight the role of other sensorimotor subsystems, such as the vestibular system or central mechanisms, in balance control. For example, individuals with WAD have been found to have decreased postural control in a neutral head-trunk position with their eyes open, compared to those with acoustic neuroma; however, closing their eyes and adopting a narrow stance reverses this outcome.¹⁸ Furthermore, closing the eyes seems to cause more significant impairments in postural control for individuals with WAD and mild brain injury compared to those with WAD alone, although this difference was not observed in the eyes-open condition.⁶⁰ Considering that changing body position has been shown to alter the spatial weight of visual stimuli^{13,14} and that closing the eyes increases activity in the visual system of the brain compared to the eyes-open condition,^{16,17} the differences in postural control between individuals with and without WAD may be related to the combined effects of different sensorimotor subsystems. On the other hand, these potential combined effects may differ between NP groups, as the difference in postural control between individuals with chronic non-specific NP and asymptomatic individuals has been reported in the eyes-closed condition, but not in the eyes-open condition.¹⁰

While the literature supports the use of eyes-open balance tests for individuals with WAD, only a limited number of studies have assessed the eyes-open neck torsion

maneuver across different study groups. The study by de Zoete et al.⁶¹ found no significant difference in the sway area parameter between individuals with non-specific NP and asymptomatic individuals in neutral head-trunk and neck-torsion positions with eyes open (or closed). In contrast, Majcen Rosker et al.⁶² demonstrated a difference in the mean frequency parameter in the neck-torsion position, but not in the neutral head-trunk position, among individuals with non-specific NP, WAD, and mild traumatic brain injury compared to asymptomatic individuals. However, neither study assessed the difference between the neutral head-trunk and neck-torsion positions.

Limitations

Although the individual tests were shown to be reliable in this study, the reliability of assessing the difference between the neutral test and each variant generally fell below an acceptable level. These findings suggest that balance tests with different variants should mainly be used as individual tests to assess postural control. However, the results should be interpreted with caution, as the neck torsion and rotation maneuvers used in previous studies on postural control in individuals with NP were modified. Despite this, the test protocol could help avoid potential subject selection bias related to cervical rotational mobility, especially since individuals with WAD may not meet the 45°³¹ inclusion criterion commonly used in previous studies, a trend also observed in the present study. Given that cervical mobility in each direction ranged between subjects from 20° to 69.4°, some subjects performed the tests at or near their maximum cervical position, while others were far from it, potentially affecting the results. Therefore, in the future, it could be appropriate to select the test position of the neck according to the subject's cervical mobility rather than setting it to a specific predetermined rotation or torsion angle.

CONCLUSION

Many balance threats occur in daily activities and controlling them requires the cooperation of different sensorimotor systems. This study showed acceptable inter- and intra-tester reliability in postural balance tests with various neck and gaze positions in patients with WAD. However, the reliability of the difference between the neutral test and each test variant remained low. These findings suggest that while individual postural balance tests yield clinically reliable results, caution is warranted when assessing the difference between balance test variations. It is not yet known whether these tests can distinguish between different study

groups and whether they are reliable in assessing different sensory systems.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.jmpt.2025.10.046](https://doi.org/10.1016/j.jmpt.2025.10.046).

FUNDING SOURCES AND CONFLICTS OF INTEREST

The Finnish Association of Physiotherapists provided partial support. The authors declare no conflicts of interest.

CONTRIBUTORSHIP INFORMATION

Concept development (provided idea for the research): N.S., O.T.

Design (planned the methods to generate the results): N.S., O.T.

Supervision (oversight, organization and implementation): O.T., J.T.

Data collection/processing (experiments, organization, or reporting data): N.S., A.O., J.M., J.K.

Analysis/interpretation (analysis, evaluation, presentation of results): E.L., N.S.

Literature search (performed the literature search): N.S., A.O.

Writing (responsible for writing a substantive part of the manuscript): N.S., A.O.

Critical review (revised manuscript for intellectual content): O.T., J.T.

Practical Applications

- We examined the reliability of postural balance tests in patients with whiplash-associated disorder (WAD) using a static force platform.
- We found acceptable intra- and intra-tester reliability of the postural balance tests with different test variants.
- These balance tests were considered reliable tools for assessing postural control in patients with WAD.

REFERENCES

1. Røijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation Part 1: Basic science and principles of assessment and clinical interventions. *Manual Ther*. 2015;20:368-377. <https://doi.org/10.1016/j.math.2015.01.009>.
2. Franklin D, Wolpert D. Computational mechanisms of sensorimotor control. *Neuron*. 2011;72:425-442. <https://doi.org/10.1016/j.neuron.2011.10.006>.
3. Riemann BL, Lephart SM. The sensorimotor system, part I: The physiologic basis of functional joint stability. *J Athl Train*. 2002;37:71-79.
4. Koskimies K, Sutinen P, Aalto H, et al. Postural stability, neck proprioception and tension neck. *Acta Otolaryngol*. 1997;117:95-97. <https://doi.org/10.3109/00016489709124093>. Suppl 529.
5. Schieppati M, Nardone A, Schmid M. Neck muscle fatigue affects postural control in man. *Neuroscience*. 2003;121:277-285. [https://doi.org/10.1016/S0306-4522\(03\)00439-1](https://doi.org/10.1016/S0306-4522(03)00439-1).
6. Vuillerme N, Pinsault N, Vaillant J. Postural control during quiet standing following cervical muscular fatigue: effects of changes in sensory inputs. *Neurosci Lett*. 2005;378:135-139. <https://doi.org/10.1016/j.neulet.2004.12.024>.
7. Xie H, Song H, Schmidt C, Chang W-P, Chien J. The effect of mechanical vibration-based stimulation on dynamic balance control and gait characteristics in healthy young and older adults: a systematic review of cross-sectional study. *Gait Posture*. 2023;102:18-38. <https://doi.org/10.1016/j.gaitpost.2023.02.013>.
8. Mazaheri M, Abichandani D, Kingma I, Treleaven J, Falla D. A meta-analysis and systematic review of changes in joint position sense and static standing balance in patients with whiplash-associated disorder. *PLOS ONE*. 2021;8. <https://doi.org/10.1371/journal.pone.0249659>.
9. Ruhe A, Fejer R, Walker B. Altered postural sway in patients suffering from non-specific neck pain and whiplash associated disorder - A systematic review of the literature. *Chiropract Manual Ther*. 2011;19(13). <https://doi.org/10.1186/2045-709X-19-13>.
10. Särkilähti N, Hirvonen M, Lavapuro J, et al. Sensorimotor tests in patients with neck pain and its associated disorders: a systematic review and meta-analysis. *Sci Rep*. 2024;14:12764. <https://doi.org/10.1038/s41598-024-63545-3>.
11. Yu L-J, Stokell R, Treleaven J. The effect of neck torsion on postural stability in subjects with persistent whiplash. *Manual Ther*. 2011;16:339-343. <https://doi.org/10.1016/j.math.2010.12.006>.
12. Williams K, Tarmizi A, Treleaven J. Use of neck torsion as a specific test of neck related postural instability. *Musculoskelet Sci Pract*. 2017;29:115-119. <https://doi.org/10.1016/j.msksp.2017.03.012>.
13. Castro Abarca P, Hussain S, Mohamed O, et al. Visuospatial orientation: differential effects of head and body positions. *Neurosci Lett*. 2022;775. <https://doi.org/10.1016/j.neulet.2022.136548>.
14. McCarthy J, Castro P, Cottier R, et al. Multisensory contribution in visuospatial orientation: an interaction between neck and trunk proprioception. *Exp Brain Res*. 2021;239:2501-2508. <https://doi.org/10.1007/s00221-021-06146-0>.
15. Gdowski G, McCrea R. Neck proprioceptive inputs to primate vestibular nucleus neurons. *Exp Brain Res*. 2000;135:511-526. <https://doi.org/10.1007/s002210000542>.
16. Xu P, Huang R, Wang J, et al. Different topological organization of human brain functional networks with eyes open versus eyes closed. *NeuroImage*. 2014;90:246-255. <https://doi.org/10.1016/j.neuroimage.2013.12.060>.
17. Marx E, Stephan T, Nolte A, et al. Eye closure in darkness animates sensory systems. *NeuroImage*. 2003;19:924-934. [https://doi.org/10.1016/S1053-8119\(03\)00150-2](https://doi.org/10.1016/S1053-8119(03)00150-2).
18. Treleaven J, LowChoy N, Darnell R, Panizza B, Brown-Rothwell D, Jull G. Comparison of sensorimotor disturbance

- between subjects with persistent whiplash-associated disorder and subjects with vestibular pathology associated with acoustic neuroma. *Arch Phys Med Rehab.* 2008;89:522-530. <https://doi.org/10.1016/j.apmr.2007.11.002>.
19. Laffleur D, Lajoie Y. The impact of eye movement on postural control depends on the type of oculomotor behavior and the visual task. *Gait Posture.* 2023;100:65-69. <https://doi.org/10.1016/j.gaitpost.2022.12.002>.
 20. Rodrigues S, Polastri P, Carvalhoa J, et al. Saccadic and smooth pursuit eye movements attenuate postural sway similarly. *Neurosci Lett.* 2015;584:292-295. <https://doi.org/10.1016/j.neulet.2014.10.045>.
 21. Kim S-Y, Moon Y-Y, Cho H. Smooth-pursuit eye movements without head movement disrupt the static body balance. *J Phys Ther Sci.* 2016;28:1335-1338. <https://doi.org/10.1589/jpts.28.1335>.
 22. Laurens J, Awai L, Bockisch CJ, et al. Visual contribution to postural stability: Interaction between target fixation or tracking and static or dynamic large-field stimulus. *Gait Posture.* 2010;31:37-41. <https://doi.org/10.1016/j.gaitpost.2009.08.241>.
 23. Bexander C, Hodges P. Cervico-ocular coordination during neck rotation is distorted in people with whiplash-associated disorders. *Exp Brain Res.* 2012;217:67-77. <https://doi.org/10.1007/s00221-011-2973-8>.
 24. Bexander C, Hodges P. Cervical rotator muscle activity with eye movement at different speeds is distorted in whiplash. *PM R.* 2019;11:944-953. <https://doi.org/10.1002/pmrj.12059>.
 25. Ruhe A, Fejer R, Walker B. The test–retest reliability of centre of pressure measures in bipedal static task conditions – a systematic review of the literature. *Gait Posture.* 2010;32:436-445. <https://doi.org/10.1016/j.gaitpost.2010.09.012>.
 26. Baldini A, Nota A, Assi V, Ballanti F, Cozza P. Intersession reliability of a posturo-stabilometric test, using a force platform. *J Electromyograph Kinesiol.* 2013;23:1474-1479. <https://doi.org/10.1016/j.jelekin.2013.08.003>.
 27. Ponce-Gonzales J, Sanchis-Moysi J, Gonzales-Henriquez J, Arteaga-Ortiz R, Calbet J, Dorado C. A reliable unipedal stance test for the assessment of balance using a force platform. *J Sports Med Phys Fitness.* 2014;54:108-117.
 28. Jylhä M, Guralnik J, Ferrucci L, Jokela J, Heikkinen E. Is self-rated health comparable across cultures and genders? *J Gerontol.* 1998. <https://doi.org/10.1093/geronb/53B.3.S144>. 53B:SI44-SI52.
 29. Weiss T, Slater C, Green L, Kennedy V, Albright D, Wun C-C. The validity of single-item, self-assessment questions as measures of adult physical activity. *J Clin Epidemiol.* 1990;43:1123-1129. [https://doi.org/10.1016/0895-4356\(90\)90013-F](https://doi.org/10.1016/0895-4356(90)90013-F).
 30. Särkilähti N, Leino S, Takatalo J, Löyttyniemi E, Tenovu O. The symptom profile of people with whiplash-associated disorder – a mixed-method systematic review. *J Bodywork Movement Ther.* 2024;40:706-725. <https://doi.org/10.1016/j.jbmt.2024.05.018>.
 31. Stenneberg M, Rood M, de Bie R, Schmitt M, Cattrysse E, Scholten-Peeters G. To what degree does active cervical range of motion differ between patients with neck pain, patients with whiplash, and those without neck pain? A systematic review and meta-analysis. *Arch Phys Med Rehab.* 2017;98:1407-1434. <https://doi.org/10.1016/j.apmr.2016.10.003>.
 32. Treleaven J, Jull G, Grip H. Head eye co-ordination and gaze stability in subjects with persistent whiplash associated disorders. *Manual Ther.* 2011;16:252-257. <https://doi.org/10.1016/j.math.2010.11.002>.
 33. Stenneberg M, Busstra H, Eskes M, et al. Concurrent validity and interrater reliability of a new smartphone application to assess 3D active cervical range of motion in patients with neck pain. *Musculoskelet Sci Pract.* 2018;34:59-65. <https://doi.org/10.1016/j.msksp.2017.12.006>.
 34. Luomajoki H, Kool J, de Bruin E, Airaksinen O. Reliability of movement control tests in the lumbar spine. *BMC Musculoskelet Disord.* 2007;8:90. <https://doi.org/10.1186/1471-2474-8-90>.
 35. Jaeschke R, Singer J, Guyatt G. Measurement of health status. ascertaining the minimal clinically important difference. *Control Clin Trials.* 1989;10:407-441. [https://doi.org/10.1016/0197-2456\(89\)90005-6](https://doi.org/10.1016/0197-2456(89)90005-6).
 36. Bobos P, MacDermid J, Nazari G, Furtado R. Psychometric properties of the global rating of change scales in patients with neck disorders: a systematic review with meta-analysis and meta-regression. *BMJ Open.* 2019;9. <https://doi.org/10.1136/bmjopen-2019-033909>.
 37. Era P, Sainio P, Koskinen S, Haavisto P, Vaara M, Aromaa A. Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology.* 2006;52:204-213. <https://doi.org/10.1159/000093652>.
 38. Schober P, Boer C, Schwarte L. Correlation coefficients: appropriate use and interpretation. *Anesth Analg.* 2018;126:1763-1768. <https://doi.org/10.1213/ANE.0000000000002864>.
 39. Jorgensen R, Ris I, Falla D, Juul-Kristensen B. Reliability, construct and discriminative validity of clinical testing in subjects with and without chronic neck pain. *BMC Musculoskelet Disord.* 2014;15:408. <https://doi.org/10.1186/1471-2474-15-408>.
 40. Ruhe A, Fejer R, Walker B. On the relationship between pain intensity and postural sway in patients with non-specific neck pain. *J Back Musculoskelet Rehab.* 2013;26:401-409. <https://doi.org/10.3233/BMR-130399>.
 41. Takacs J, Carpenter M, Garland S, Hunt M. Test re-test reliability of centre of pressure measures during standing balance in individuals with knee osteoarthritis. *Gait Posture.* 2014;40:270-273. <https://doi.org/10.1016/j.gaitpost.2014.03.016>.
 42. Harringe M, Halvorsen K, Renström P, Werner S. Postural control measured as the center of pressure excursion in young female gymnasts with low back pain or lower extremity injury. *Gait Posture.* 2008;28:38-45. <https://doi.org/10.1016/j.gaitpost.2007.09.011>.
 43. Mientjes M, Frank J. Balance in chronic low back pain patients compared to healthy people under various conditions in upright standing. *Clin Biomech.* 1999;14:710-716. [https://doi.org/10.1016/s0268-0033\(99\)00025-x](https://doi.org/10.1016/s0268-0033(99)00025-x).
 44. Salavati M, Hadian M, Mazaheri M, et al. Test–retest reliability of center of pressure measures of postural stability during quiet standing in a group with musculoskeletal disorders consisting of low back pain, anterior cruciate ligament injury and functional ankle instability. *Gait Posture.* 2009;29:460-464. <https://doi.org/10.1016/j.gaitpost.2008.11.016>.
 45. Henry S, Fung J, Horak F. Effect of stance width on multidirectional postural responses. *J Neurophysiol.* 2001;85:559-570. <https://doi.org/10.1152/jn.2001.85.2.559>.
 46. Liu Y, Higuchi S, Motohashi Y. Changes in postural sway during a period of sustained wakefulness in male adults. *Occup Med (Lond).* 2001;51:490-495. <https://doi.org/10.1093/occmed/51.8.490>.
 47. Nardone A, Tarantola J, Giordano A, Schieppati M. Fatigue effects on body balance. *Electroencephalogr Clin*

- Neurophysiol.* 1997;105:309-320. [https://doi.org/10.1016/S0924-980X\(97\)00040-4](https://doi.org/10.1016/S0924-980X(97)00040-4).
48. Gribble P, Hertel J. Effect of hip and ankle muscle fatigue on unipedal postural control. *J Electromyograph Kinesiol.* 2004;14:641-646. <https://doi.org/10.1016/j.jelekin.2004.05.001>.
 49. Corbeil P, Blouin J-S, Begin F, Nougier V, Teasdale N. Perturbation of the postural control system induced by muscular fatigue. *Gait & Posture.* 2003;18:92-100. [https://doi.org/10.1016/S0966-6362\(02\)00198-4](https://doi.org/10.1016/S0966-6362(02)00198-4).
 50. De Paul R, Coppieters I, Palmans T, Danneels L, Meeus M, Cagnie B. Motor impairment in patients with chronic neck pain: does the traumatic event play a significant role? A case-control study. *Spine J.* 2018;18:1406-1416. <https://doi.org/10.1016/j.spinee.2018.01.009>.
 51. Nordahl S, Aasen T, Dyrkorn B, Eidsvik S, Molvaer O. Static stabilometry and repeated testing in a normal population. *Aviat, Space Environ Med.* 2000;71:889-893.
 52. Lee K, Lee J, Chung C, et al. Pitfalls and important issues in testing reliability using intraclass correlation coefficients in orthopaedic research. *Clin Orthop Surg.* 2012;4:149-155. <https://doi.org/10.4055/cios.2012.4.2.149>.
 53. Koo T, Li M. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropract Med.* 2016;15:155-163. <https://doi.org/10.1016/j.jcm.2016.02.012>.
 54. Bobak C, Barr P, O'Malley J. Estimation of an inter-rater intra-class correlation coefficient that overcomes common assumption violations in the assessment of health measurement scales. *BMC Med Res Methodol.* 2018;18:93. <https://doi.org/10.1186/s12874-018-0550-6>.
 55. Le Clair K, Riach C. Postural stability measures: what to measure and for how long. *Clin Biomech.* 1996;11:176-178. [https://doi.org/10.1016/0268-0033\(95\)00027-5](https://doi.org/10.1016/0268-0033(95)00027-5).
 56. Horlings C, Küng U, Honegger F, et al. Vestibular and proprioceptive influences on trunk movements during quiet standing. *Neuroscience.* 2009;161:904-914. <https://doi.org/10.1016/j.neuroscience.2009.04.005>.
 57. Hansson E, Beckman A, Håkansson A. Effect of vision, proprioception, and the position of the vestibular organ on postural sway. *Acta Oto-Laryngologica.* 2010;130:1358-1363. <https://doi.org/10.3109/00016489.2010.498024>.
 58. Quek J, Pua Y-H, Bryant A, Clark R. The influence of cervical spine flexion-rotation range-of-motion asymmetry on postural stability in older adults. *SPINE.* 2013;38:1648-1655. <https://doi.org/10.1097/BRS.0b013e31829f23a0>.
 59. Majcen Rosker Z, Vodicar M, Kristjansson E. Oculomotor performance in patients with neck pain: does it matter which angle of neck torsion is used in smooth pursuit eye movement test and is the agreement between angles dependent on target movement amplitude and velocity? *Musculoskelet Sci Pract.* 2022;59. <https://doi.org/10.1016/j.msksp.2022.102535>.
 60. Finding O, Schuster C, Sellner J, Ettlin T, Allum J. Trunk sway in patients with and without, mild traumatic brain injury after whiplash injury. *Gait Posture.* 2011;34:473-478. <https://doi.org/10.1016/j.gaitpost.2011.06.021>.
 61. De Zoete R, Osmotherly P, Rivett D, Snodgrass S. No Differences between individuals with chronic idiopathic neck pain and asymptomatic individuals on 7 cervical sensorimotor control tests: a cross-sectional study. *J Orthop Sports Phys Ther.* 2020;50:33-43. <https://doi.org/10.2519/jospt.2020.8846>.
 62. Majcen Rosker Z, Kristjansson E, Vodicar M. How well can we detect cervical driven sensorimotor dysfunction in concussion patients? An observational study comparing patients with idiopathic neck pain, whiplash associated disorders and concussion. *Gait Posture.* 2023;101:21-27. <https://doi.org/10.1016/j.gaitpost.2023.01.011>.