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ORIGINAL RESEARCH ARTICLE

Trunk-head coordination in chronic neck pain, reliability, influence of visual feedback, and relationship to patient-reported outcomes

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ABSTRACT

Introduction: Neck pain (NP) is associated with sensorimotor impairments, including altered trunk-head coordination. Limited data exists on the reliability of assessments and the influence of visual feedback in NP. Relationships between trunk-head coordination performance and NP, dizziness, disability, or NP onset (traumatic or idiopathic) remain unclear.
Methods: Repeated-measures study to explore intra- and inter-session reliability of trunk-head coordination assessment in traumatic and idiopathic NP subjects, using a head-mounted accelerometer. Assessments were conducted under visual and visually constrained feedback conditions. The latter was repeated twice on the same day and once within a week. Head movement during the task was analyzed for reliability using Constant Error (CE), Absolute Error (AE), Sum of Absolute Errors (SAE), and Variable Error (VE). Differences between visual feedback conditions and pain onset, and correlations with the Neck Disability Index (NDI) and Dizziness Handicap Inventory (DHI) were examined.
Results: CE, AE, and SAE of 19 NP subjects (age 53 ± 18 years; 13 females; NDI 23 ± 11%; DHI 16 ± 15%) demonstrated moderate (VE) and good (CE, AE, SAE) intra-session reliability. All error types reached moderate inter-session reliability. Visual feedback significantly reduced head movement errors for AE ($0.07 m/s^2$) and SAE ($9.02 m/s^2$). Correlations between error types and self-reported outcomes were weak to fair and not statistically significant. No significant differences emerged between traumatic and idiopathic NP groups.
Conclusion: Accelerometer-based trunk-head coordination showed moderate to good intra-session and moderate inter-session reliability, suggesting performance variability over time in NP subjects. Visual feedback improved trunk-head coordination. Performance was not associated with perceived disability, dizziness, or NP onset.

Keywords: Accelerometer, Neck pain, Reliability, Sensorimotor control, Trunk-head coordination

What's already known about this topic:

- *Trunk-head coordination is a component of sensorimotor control, whose deficits are common in individuals with NP. Reliability of trunk-head coordination tests, visual feedback conditions influence, and correlations with NDI and DHI remain insufficiently explored.*

What does the study add?

- *It establishes preliminary intra- and inter-session reliability of an accelerometer-based trunk-head coordination test in NP. It shows trunk-head coordination differences between two visual feedback conditions and hints at low to moderate correlations between trunk-head coordination and NDI or DHI.*

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Introduction

Neck pain (NP) is common across all ages, shows higher prevalence in women, and affects an estimated 203 million people globally in 2020 (1). Between 50% and 85% of individuals with NP do not achieve complete symptom resolution within 1-5 years (2). Effective NP management requires a multifactorial approach and should include sensorimotor control assessment and training (3,4).

Sensorimotor control ensures postural control and movement coordination, and neck proprioception provides crucial afferent input (5-7). In individuals with NP, sensorimotor control is frequently impaired (5,8-10). These impairments may contribute to NP persistence, dizziness, postural instability, and visual disturbances, though their relationships remain unclear (6).

Multiple tests exist to assess cervical-related sensorimotor control (11). Among them, the Trunk-Head Coordination Test (THCT) primarily assesses the cervical afferent contribution to sensorimotor control (12), while minimizing vestibular stimulation (13). The test evaluates the ability to stabilize the head while rotating the trunk “from below“ (13,14), using a laser mounted on the head to aim at a fixed target (15). These trunk movements are expected to elicit reflex responses in the cervical musculature: the cervicocollic reflex (CCR), driven by proprioceptive input from neck muscles and joints and generating a compensatory motor response in these muscles, and the vestibulocollic reflex (VCR), driven by vestibular input and contributing to head stabilization in space through reflex activation of the same muscles (16,17). NP and/or dizziness can disturb the coordination of reflex responses, which may lead to altered trunk-head control (16,17).

As eye-motor responses are also controlled by vestibulo-ocular (VOR) and cervico-ocular reflexes (COR), visual disturbances can occur too, and even further contribute to the situation by the resulting altered visual afferences (7,17).

Accordingly, information and results from the THCT, together with other clinical signs and symptoms, may give further insights into potential disturbed sensorimotor reflex pathways in subgroups of NP patients, and how to address these sensorimotor deficits.

Performance of the THCT is typically expressed as angular errors, comparing initial and final head positions (13-15).

Previous studies report that individuals with NP demonstrate larger angular errors, reflecting reduced head stability, during the task (13,15), as well as decreased trunk movement amplitude and velocity (14). Although informative, angular errors reveal little about how the head is actively controlled throughout the movement. Acceleration, the second derivative of position over time, offers detailed insight into head stability during trunk movement (5). It captures the dynamics of head behavior, including both the magnitude and the variability of the head movement. Under ideal coordination, head acceleration would be negligible despite trunk rotation. Accordingly, performance can be quantified as accelerometer-based errors, expressed in m/s^2.

The THCT has shown discriminant validity, demonstrating greater impairment in individuals with NP than in controls (15). While inertial sensors have been validated for estimating head–trunk kinematics against criterion standards in related tasks (18,19), a criterion-validity study of a head-mounted IMU specifically applied to the THCT in a neck-pain population has not yet been reported; accordingly, the present study focuses on its reliability. Since the amount of head movement during the task represents the primary outcome, different calculations of head movement during the task can be made to represent error types and to provide complementary insights capturing aspects such as accuracy and variability (20). As no single error type may fully characterize these deficits, relying on multiple error types enables a more comprehensive evaluation and may enhance sensitivity in detecting impairments (12,20).

Furthermore, the influence of different visual feedback conditions on trunk-head coordination has not been investigated yet. Additionally, it remains unclear how pain, dizziness, and pain onset (traumatic or idiopathic) are associated with trunk-head coordination.

Despite the potential clinical applications of the THCT, key aspects such as its reliability, sensitivity to visual feedback, and associations with pain, dizziness, and trauma remain unexplored. People with NP do not constitute a homogeneous group, and it is necessary to differentiate patients into subgroups based on their symptoms (8) and comorbidities (21), in order to identify factors that significantly affect cervical sensorimotor control. This study aims to address these gaps through an accelerometer-based assessment of trunk-head coordination. The specific objectives were:

Objectives

1. Explore the intra- and inter-session reliability of THCT in individuals with NP utilizing different variables of head movement error, expecting at least moderate for both intra- and inter-session reliability.
2. Examine within-subject differences in head movement during THCT between visual feedback (facing a mirror) and visually constrained (facing a wall) conditions, with the a priori expectation of reduced head movement under visual feedback.
3. Explore correlations between the THCT and self-reported measures of pain and disability (Neck Disability Index, NDI), and dizziness (Dizziness Handicap Inventory, DHI).
4. Determine if self-reported pain onset (traumatic or idiopathic) is associated with performance of the THCT.

Methods

A repeated measures design, with two visual feedback conditions, was chosen to explore the reliability of the procedure and investigate the relationship between head movement parameters and individual variables, including the influence of visual feedback. Participants with NP were recruited at a private physiotherapy practice, through flyers, posters, and during daily clinical practice. Interested individuals received a study information sheet, were screened for eligibility, and gave written consent. No upper age limit was applied to reflect a clinical NP population.

The inclusion criteria were:

- NP ≥3 months.
- NDI >10%, expressing at least mild pain and disability.
- ≥45° of cervical spine rotation range of motion in the standing position (needed to achieve the required 45° trunk rotation while keeping the head still).
- Given informed consent as documented by signature.
- ≥18 years old.
- Able to communicate in French (verbal and written).

The exclusion criteria were:

- Known vestibular disorder.
- Known inner ear pathology.
- Known central nervous system pathology.
- Previous spinal surgery.
- Psychiatric disorders.

Participants' sex, age, self-reported onset of their NP (traumatic, idiopathic), and the levels of NP, disability and dizziness handicap were assessed with the French versions of the NDI and DHI, respectively. NDI comprises 10 items scored 0–5 (total 0–50), reported here as a percentage of the maximum score (0–100%), with higher scores indicating greater disability (22). In general, NDI scores below five points are regarded as not disabled, 5-14 points as mildly disabled, 15-24 points as moderately disabled, 25-34 points as severely disabled and above 34 points as completely disabled by NP (23). The DHI comprises 25 items scored Yes = 4, Sometimes = 2, No = 0 points, respectively (total 0-100 points; reported here as % for consistency), with higher scores indicating greater handicap (24). A total score of 30% indicates mild, 31-60% as moderate and ≥61% as severe handicap due to dizziness (25). Both questionnaires have been validated and are reliable (22,24,26-29). Sum scores for both questionnaires were calculated at the end of the data collection process to ensure blinding of the tester.

THCT measurement

An open-source Inertial Measurement Unit (IMU) with a triaxial accelerometer (30) was attached to the participant's head using a hook-and-loop fastener (Fig. 1). An accelerometer, rather than a laser projected to a target, was chosen to measure the head movement during the task as it could provide objective numerical data for several parameters and was suitable for comparing visual and visually constrained feedback conditions within the same individual. The sensor transmitted data via Bluetooth to a smartphone running the Movesense Showcase app. Accelerometer data was exported to a computer for further analysis, focusing on horizontal linear accelerations (left and right) of the head during trunk rotations, measured along the X-axis. Raw accelerometer data were converted into four distinct error types. The unit of measurement for each error was m/s^2 (31):

- Constant Error (CE) represents the mean head acceleration, indicating systematic directional deviations. It identifies whether head movement consistently drifts in one direction but may underestimate overall head movement magnitude, as positive and negative deviations can cancel each other out.
- Absolute Error (AE) quantifies overall head movement by computing the mean of absolute acceleration values (12). Unlike CE, AE ensures that all deviations of head movement contribute to the measure, regardless of direction.
- Sum of Absolute Errors (SAE) accumulates absolute accelerations over the movement, emphasizing sustained deviations over time rather than isolated errors. This measure could detect moderate but prolonged errors, particularly in individuals adopting a slow movement strategy.
- Variable Error (VE), calculated as the standard deviation of acceleration values, reflects head movement variability and provides insight into motor control consistency (20).

Although the error values are expressed in m/s^2, they parallel conventional sway metrics in balance testing: AE and SAE correspond broadly to root mean square sway and path length (total excursion), whereas VE reflects sway variability (32,33). Thus, using acceleration shifts the THCT from a static endpoint measure to a dynamic, time-resolved assessment of head control.

Following Ghislieri et al.'s (34) recommendation of a 100 Hz frequency, data collection was set at 104 Hz.

The procedure was adapted from prior studies on THCT (13,15). Before testing, participants practiced the procedure twice with verbal and manual correction. They were instructed to keep their initial head position while standing facing a wall at a distance of 90 cm. During the practice-trial, the examiner gently held the participant's head to prevent movement while the participant rotated the trunk left and right (13,15).

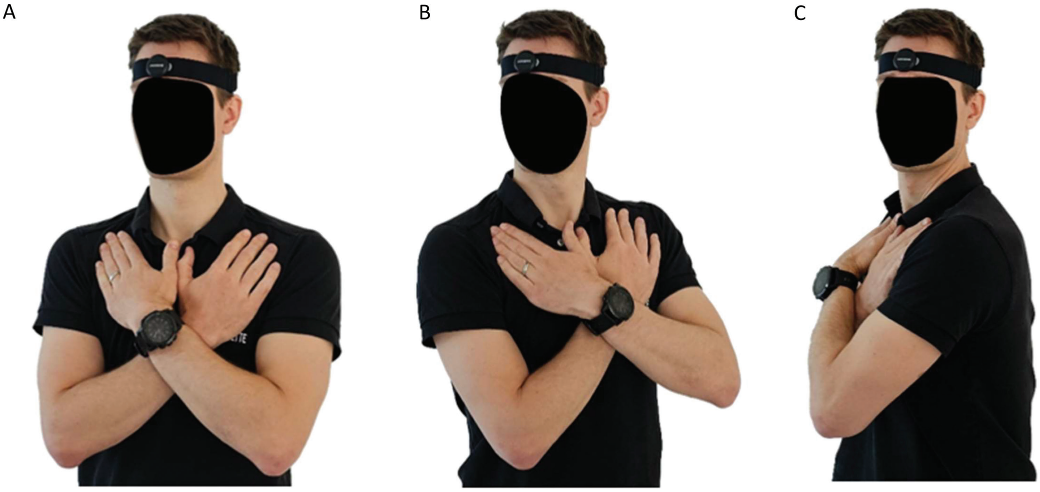

FIGURE 1 - Initial position (A), trunk rotations while keeping the head still (B and C).

Participants were then asked to rotate their trunk at least 45° without reaching the end of their cervical range of motion, once to the left and once to the right, while maintaining head stability without assistance from the examiner.

The test was conducted under two eyes-open conditions: visual feedback (facing a mirror) and visually constrained feedback (facing a wall), with the order randomly assigned. Participants performed one trunk rotation to the left and one to the right in a sub-maximal manner, reaching at least 45° in each direction. Movements were continuous, without pauses, and participants were required to try keeping their head still during the task and return the trunk to neutral between attempts. Throughout the procedure, the examiner provided no additional guidance or correction.

The test was repeated after a two-minute break to explore intra-session reliability under the visually constrained feedback condition. The task was very short and low intensity, and no fatigue was expected, supporting two minutes as an appropriate washout between trials.

The test was repeated again 1-7 days later to assess inter-session reliability for the visually constrained condition, with comparable settings maintained (same evaluator, room, wall, lighting, equipment, and instructions). While the time of day could vary for feasibility, all other controllable factors were standardized.

The evaluator was not blinded to the measurement type or the randomized order of visual feedback conditions. However, the accelerometer captured objective signals, and no numerical readouts or calculations were available during testing, with data quality checks performed offline, so any lack of blinding is unlikely to have influenced the measurements.

Given the exploratory nature of this study, no formal a priori sample size calculation was performed. This analysis was conducted using a two-way random effects, absolute agreement model for a single measurement approach (35). Intraclass correlation coefficients (ICCs) were calculated. ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability (35).

The standard error of the measurement (SEM) was determined using the calculated reliability coefficient and the formula (36):

$$\text{SEM} = \text{standard deviation of measurements}\ \sqrt{(1 - \text{reliability coefficient})}$$

The smallest detectable change (SDC) was calculated with the formula:

$$\text{SDC} = 1.96 \times \text{SEM} \times \sqrt{2}$$

Differences between the two visual feedback conditions for all error types were investigated through Wilcoxon paired tests.

Spearman correlations between error types and NDI or DHI were calculated for correlation analysis for the visually constrained feedback condition (37). Correlation coefficients were interpreted according to Portner (38), who proposes that values ≤0.25 indicate little or no relationship, 0.25-0.50 indicate low to fair, 0.50-0.75 indicate moderate to good, and ≥ 0.75 indicate a strong relationship.

Differences, for all error types for the visually constrained feedback condition, between subjects with traumatic or idiopathic onset of pain were investigated through Wilcoxon non-paired tests. All analyses were conducted using R version 4.2.3 (39).

The research followed ethical guidelines, including the Declaration of Helsinki and Good Clinical Practice principles, as well as local regulations. Ethical clearance was obtained from the relevant regional ethics committee. All participants gave written informed consent before any measures were obtained.

Results

Nineteen NP subjects participated. Demographic and clinical characteristics of participants are summarized in Table 1. The inter-session interval was a median of 4 days (range: 1-7 days). Most participants reported mild pain and disability, mild dizziness, and eight subjects defined their onset of pain as traumatic (Table 1). No dropouts occurred during the study.

TABLE 1 - Patient demographics and clinical characteristics (mean and standard deviation unless specified)

Clinical characteristics	N = 19
Age (years)	52.95 (17.8)
Sex (females: males)	13: 6
Onset (idiopathic: traumatic)	11: 8
Neck Disability Index (%)	23.16 (11.1)
Dizziness Handicap Inventory (%)	15.84 (15.4)

Values are means and standard deviations, unless stated otherwise.

Head accelerations for the four error types are presented in Table 2 and expressed in m/s^2. Higher error values reflect either larger accelerations or greater acceleration variability, denoting poorer head stability and, consequently, impaired trunk-head coordination. Positive values in CE or VE indicate head accelerations to the left, while negative values indicate head accelerations to the right. AE and SAE always present positive values and represent the magnitude of the deviation, irrespective of direction. These accelerations are unrelated to the trunk's motion because head stability was measured continuously throughout the entire movement cycle, first with the shoulders rotating left, then right, and finally returning to the centered position.

Intra- and inter-session reliability

Both intra-session and inter-session reliability analyses were conducted to assess measurement reliability (Table 3). Three error types (CE, AE, SAE) exhibited good intra-session reliability (ICC ≥ 0.75 and Lower CI ≥ 0.5), while VE met moderate reliability. All error types showed a moderate inter-session reliability threshold.

TABLE 2 - Trunk head coordination test (THCT) within (1-2) and between (1 and 3) days, with head movement (errors) during the test with visually constrained feedback

	THCT 1 session one, first measurement (n = 19)	THCT 2 session one, second measurement (n = 19)	THCT 3 session two (n = 19)
Error type	**Median [Q1; Q3] (95% CI)**	**Median [Q1; Q3] (95% CI)**	**Median [Q1; Q3] (95% CI)**
CE	−0.45 [−0.77; −0.21] (−0.73 to −0.26)	−0.33 [−0.77; −0.20] (−0.76 to −0.25)	−0.70 [-0.86; −0.25] (−0.85 to −0.27)
AE	0.59 [0.45; 0.81] (0.50 to 0.79)	0.62 [0.46; 0.79] (0.46 to 0.76)	0.70 [0.39; 0.88] (0.43 to 0.87)
SAE	55.27 [39.99; 74.75] (42.75 to 73.02)	46.78 [36.31; 75.00] (40.50 to 64.52)	57.09 [29.14; 88.84] (30.80 to 79.16)
VE	0.34 [0.22; 0.53] (0.22 to 0.50)	0.50 [0.24; 0.67] (0.24 to 0.64)	0.46 [0.24; 0.63] (0.25 to 0.57)

CE = constant error, AE = absolute error, SAE = sum of absolute errors, VE = variable error, Units of measurement = m/s^2, Q1 = first quartile, Q3 = third quartile, 95% CI = 95% confidence interval. Positive CE or VE values indicate leftward head accelerations; negative values indicate rightward.

TABLE 3 - Intra- and inter-session reliability (ICC) and standard error of the measurement (SEM) for head movement errors of the trunk head coordination test with visually constrained feedback

	Intra-session reliability			Inter-session reliability		
Error type	**ICC (95% CI)**	**SEM**	**SDC**	**ICC (95% CI)**	**SEM**	**SDC**
CE	0.84 (0.63 to 0.93)	0.11	0.3	0.65 (0.3 to 0.85)	0.21	0.58
AE	0.9 (0.76 to 0.96)	0.05	0.14	0.62 (0.24 to 0.84)	0.17	0.47
SAE	0.87 (0.69 to 0.95)	7.72	21.4	0.73 (0.43 to 0.89)	13.99	38.78
VE	0.72 (0.37 to 0.88)	0.09	0.25	0.66 (0.33 to 0.85)	0.1	0.28

CE = constant error, AE = absolute error, SAE = sum of absolute errors, VE = variable error, 95% CI = 95% confidence interval, SEM = standard error of measurement (expressed in m/s^2), SDC = smallest detectable change (expressed in m/s^2).

Visual feedback influences

Table 4 shows the differences between the two visual feedback conditions. While the CE and the VE reveal no significant difference, the AE and the SAE show statistically significant median differences, indicating less error in the movement of the head with visual feedback.

Correlations with NDI, DHI and differences related to the onset of pain

Table 5 shows little to no correlation for CE, AE, and SAE, and a fair correlation for the VE with the NDI. Regarding the DHI, little to no correlation was found with AE, and a fair correlation was observed with CE, SAE, and VE. However, none of these correlations reached statistical significance.

No significant differences related to the onset of pain for any error type were found.

Discussion

The main findings of this explorative study indicate that, for the visually constrained feedback condition of the THCT, good intra-session reliability for three error types (CE, AE, and SAE) and moderate for VE could be demonstrated, while moderate inter-session reliability is observed for all error types. Significantly less head movement was observed for AE and SAE in the visual feedback condition, facing a mirror, than for the visually constrained condition, when facing a wall. No differences regarding the onset of pain (traumatic or idiopathic) or relationships to patient self-reports (NDI, DHI) were found.

Intra- and inter-session reliability

The results demonstrated good reliability for intra-session reliability in CE, AE, and SAE, and moderate reliability for VE and inter-session reliability for all error types. Although inter-session reliability was lower, SAE values approached good reliability.

SDC values for the visually constrained THCT can help to interpret both individual values, like after an intervention in clinical settings, or changes of group values in interventional research settings, to determine clinical meaningfulness (Table 3). As no other study has used acceleration as parameters for the THCT, comparisons are limited.

Between sessions, SDCs increase for all four parameters and approach the magnitude of their respective medians, which markedly constrains individual-level interpretability over time.

Examinations of inter-session reliability for kinematic parameters or sensorimotor tests are scarce. Those that do exist often involve healthy controls rather than individuals with NP and report highly heterogeneous ICC values, ranging from 0.27 to 0.96, depending on the task, plane of movement (40,41).

TABLE 4 - Trunk head coordination test (THCT) head movement (errors) during the test: visual feedback compared to visually constrained feedback

Error type	Visual feedback Median (95% CI)	Visually constrained feedback Median (95% CI)	Median differences (95% CI)	p-value
CE	−0.44 (−0.68 to −0.28)	−0.45 (−0.73 to −0.26)	−0.01 (−0.10 to 0.12)	0.86
AE	0.53 (0.40 to 0.71)	0.59 (0.50 to 0.79)	0.07 (0.02 to 0.12)	0.02
SAE	46.25 (26.37 to 66.21)	55.27 (42.75 to 73.02)	9.02 (3.13 to 10.33)	0.05
VE	0.45 (0.25 to 0.51)	0.34 (0.22 to 0.50)	−0.10 (−0.06 to 0.03)	1

CE = constant error, AE = absolute error, SAE = sum of absolute errors, VE = variable error, Units of measurement = m/s^2, 95% CI= 95% confidence interval. P-value was calculated using a Wilcoxon paired test.

TABLE 5 - Spearman's correlations (r) between head movement error types during the trunk head coordination test (visually constrained feedback condition) to NDI, DHI and differences between traumatic and idiopathic onset of pain

	Spearman's correlation (r) N = 19		Differences related to the onset of pain N = 19			
Error type	**NDI (95% CI)**	**DHI (95% CI)**	**Traumatic median N = 8**	**Idiopathic median N = 11**	**Median difference (95% CI)**	**p-value**
CE	0.14 (−0.41 to 0.58)	0.46 (−0.08 to 0.8)	−0.44	−0.45	0 (−0.46 to 0.62)	0.54
AE	0.11 (−0.41 to 0.64)	−0.24 (−0.67 to 0.39)	0.57	0.79	−0.22 (−0.4 to 0.21)	0.27
SAE	−0.09 (−0.51 to 0.41)	−0.30 (−0.71 to 0.24)	53.65	58.25	−4.6 (−59.55 to 27.03)	0.97
VE	0.46 (−0.07 to 0.82)	0.45 (−0.03 to 0.79)	0.37	0.34	0.02 (−0.28 to 0.3)	0.97

CE = constant error, AE = absolute error, SAE = sum of absolute errors, VE = variable error, Units of measurement = m/s^2, Correlation and 95% CI were calculated using Spearman correlation. P-value was calculated using a Wilcoxon non-paired test.

Nevertheless, our findings are consistent with those reported by Gonçalves et al. (42), who assessed the reliability of the Torsion Test in degrees (rather than acceleration) in individuals with chronic idiopathic NP. In this test, the examiner assists the subject in maintaining the head in a neutral position while rotating the trunk and returning to the initial position, with the error calculated based on trunk repositioning accuracy. Their results, like ours, also showed good intra-session reliability (ICC left rotation = 0.88; right rotation = 0.9) but lower inter-session reliability values (ICC left rotation = 0.58; right rotation = 0.71) (42). They also reported that intra-session SDCs were approximately 50-60% of the group average score, and that between-session SDCs were similar to or greater than the average repositioning errors, suggesting that these measures are more appropriate for group-level comparisons than for fine-grained monitoring of individual change. Further, our findings resonate with observations by Gonçalves et al., who noted that healthy individuals typically reduce their joint repositioning error after repeated practice (i.e., exhibit motor learning), whereas those with NP fail to show such improvement (42). This discrepancy may stem from the effects of pain interfering with neuroplasticity and motor learning mechanisms (43).

Although the Torsion Test and the THCT differ in methodology and measured outcomes, they share similarities in the required task and in minimizing vestibular input. A similar pattern of higher intra-session reliability and lower inter-session reliability appears to emerge, which may stem from greater variability or inconsistency in movement and positioning strategies among NP individuals compared to healthy controls (44,45).

To interpret this variability, it is important to distinguish between outcome variability (the consistency in achieving a result) and coordinative variability (the variability in movement strategies) (46,47). While coordinative variability may serve as an adaptive strategy, outcome variability is often considered detrimental (48,49).

Since this study focused on maintaining head stability, it primarily provides insight into outcome variability.

In the context of NP, outcome variability may be more pronounced, potentially reflecting difficulties in adapting to task demands due to altered sensorimotor control (50).

An impaired ability to reproduce positions and movements over time may contribute to the lower inter-session reliability observed in this study, highlighting the need for further investigation into the mechanisms underlying these fluctuations.

By conducting repeated tests and assessing reliability, clinicians could gain valuable insights into the consistency of sensorimotor control strategies. This approach may serve as an indicator of underlying deficits and help guide interventions for patients with movement-related disorders.

Visual feedback influences

Visual feedback conditions showed significant differences for AE and SAE, indicating improved accuracy when patients could see themselves in the mirror compared to the visually constrained feedback condition, while facing a wall. However, CE and VE were found not to be different for visual conditions. For CEs, the reason might be that errors occurring for one rotation to the right and one to the left have cancelled each other out, regardless of how different the errors were for each condition. The same may apply for the VE, which reflects the average spread of errors occurring in relation to the AE. However, data might also be skewed for the visual feedback condition, with the mean VE closer to the upper confidence interval (Table 4).

Interferences between visual and proprioceptive feedback may have led to more inconsistency in the visual feedback condition, as has been shown for the VE, though differences were small and non-significant (Table 4). Another explanation might be that the VE and the CE are not significantly influenced by the visual feedback condition, because visual feedback may reduce the magnitude of accelerations, as has been shown for AE and SAE (Table 4), but does not improve the consistency of accelerations. This suggests that while testing with visual but constrained feedback, the regulation of acceleration patterns may rely more on proprioceptive and vestibular afferents. Consequently, AE/SAE may be more sensitive parameters for sensorimotor control assessments with visual constraint or conflict, as has also been shown for postural balance tests (51,52), or specific, joint-position error tests after pro-and retraction movements of the head (53). The notion that these error types measure distinct constructs aligns with evidence that various sensorimotor tests capture different skills (54). It underscores the importance of using different measurement conditions and combinations for visual, vestibular and proprioceptive afferents when evaluating sensorimotor function in individuals with NP (6).

Correlations with NDI, DHI and differences related to the onset of pain

Correlation analysis revealed a low to fair correlation between VE and NDI. Similarly, low to fair correlations were found for CE, SAE, and VE with DHI. Correlations did not reach statistical significance, possibly due to the small sample size. However, the low to fair correlations between VE and both NDI and DHI suggest that variability in head movement may be associated with both neck-related disability and dizziness-related impairment. Other correlations were stronger for DHI than for NDI, suggesting that impaired trunk-head coordination might be more closely associated with dizziness-related symptoms than with overall neck disability. Previous studies have found that individuals reporting dizziness have greater impairments in balance and joint position error compared to those not reporting dizziness (52,55). Our findings are consistent with previous work showing limited associations between pain and sensorimotor performance. Dugailly et al. examined head repositioning accuracy in 35 adults with NP and 36 healthy controls aged 30-55 years, and reported that pain intensity and pain duration did not significantly influence head repositioning error (56). In a larger cross-sectional sample of 75 long-standing NP patients and 91 healthy controls, Meisingset et al. likewise found that, across several motor control constructs, only peak movement velocity showed a significant association with kinesiophobia, while proprioception did not differ between groups. Taken together, these data indicate that altered cervical sensorimotor control is not simply proportional to pain intensity or self-reported disability (57).

Mazaheri et al. systematically reviewed joint position sense and static standing balance in whiplash-associated disorder (58). Their meta-analysis highlighted that individuals reporting dizziness showed larger repositioning errors and greater balance disturbances than those without dizziness. These results strengthen the notion that sensorimotor control impairments are notably more pronounced in the presence of dizziness.

No significant difference was observed between subjects with traumatic or idiopathic onset of pain. Franov et al. reported larger impairments in some sensorimotor variables among whiplash subjects compared to healthy controls, which can be regarded as related to trunk-head coordination (5). However, no differences between patient groups have been reported in that review, including studies with mostly larger samples.

The effect size of correlations and the absence of significant differences between the pain onset groups suggest that further research with a larger sample size is necessary to better understand these relationships and their clinical impact.

Limitations

The decision to prioritize the analysis of the X (frontal horizontal) axis in assessing the accelerometer variables may appear somewhat arbitrary. Including analyses of the other axes could have provided a more comprehensive understanding of head movement. Additionally, using acceleration rather than distance or angle as the primary outcome complicates comparisons with previous studies. Further, accelerometer measurements might not be feasible in clinical situations, yet. However, acceleration measures offer the advantage of capturing more detailed aspects of head movement during the test than what would be seen in distance or angular error metrics only. A formal criterion-validity study of the accelerometer-based THCT in NP populations is currently lacking; therefore, our accelerometer outcomes should be interpreted as preliminary and hypothesis-generating.

A higher proportion of women participated. It might relate to the condition's higher prevalence among women, as reported by Hoy et al. (59). However, other recruitment factors may also contribute to this sex imbalance that occurred unintentionally.

To reflect a clinical NP population, the sample included adults across a wide age range, including some participants older than 60 years. This enhances generalizability; however, given the sample size, analyses were not adjusted for age, and age-related effects cannot be ruled out.

In this study, only one repetition was used for each direction. This was done to limit the influence of fatigue when looking at the two visual conditions. Previous studies have used three repetitions (15). Increasing the number of repetitions might improve reliability, and this could be further explored.

It is worth noting that subjects were not blindfolded during the “visually constrained feedback condition,“ and they may have been able to position their head by using the texture of the wall they were staring at. Nevertheless, the visual condition tended to have less error than the visually constrained feedback condition.

The underlying strategies for trunk and neck to achieve the head stability goal, defined as coordinative variability, were not studied in this study. While the focus was on outcome variability (the ability to maintain head stability), analyzing movement strategies could provide further insight into compensatory mechanisms in individuals with NP.

This study should be regarded as exploratory and might be underpowered for some endpoints. In particular, the precision of inter-session ICCs and the correlation analyses with NDI/DHI is limited, as reflected by relatively wide 95% confidence intervals. Mokkink et al. recommend larger samples to ensure adequate precision of reliability estimates (60). These limitations reduce the certainty of the findings and reinforce the exploratory character of the present work. The small sample size reduces statistical power and precision, increasing the risk of type II errors and explains the wide confidence intervals of many parameters. An additional limitation is the relatively low levels of disability in the sample, indicating mild to moderate disability. The same applies to dizziness values by the DHI, which indicate only mild dizziness in the current sample. Accordingly, the current findings might not be generalized to samples with larger NP related disability or dizziness. Prior research has shown that deficits in joint position sense, oculomotor function, and postural control are more pronounced in individuals with higher pain intensity and dizziness (8). Future investigations should consider stratifying participants based on symptom severity to better capture the association with pain intensity and dizziness on sensorimotor control.

Conducting multiple tests and statistical analyses increases the likelihood of obtaining significant findings by chance (type I error). Further, findings are constrained to the specific population studied, limiting generalizability to other groups such as those with acute pain. Future research should explore accelerometer parameters and trunk-head coordination in diverse populations to enhance applicability and validity across various clinical contexts. Lastly, kinesiophobia was not assessed; existing literature demonstrates its significant association with various outcomes, including pain intensity and functional performance (61,62).

Safety

The testing protocol did not increase perceived pain or dizziness intensity. No dropouts or adverse events were reported during data collection, underscoring protocol safety.

Conclusion

This study explored the use of an accelerometer-based approach to assess trunk-head coordination in individuals with NP and examined its reliability, response to visual feedback, and associations with self-reported outcomes. Three of the four error types (CE, AE, and SAE) demonstrated good intra-session reliability but failed to achieve the same for inter-session reliability, indicating higher variability over days. The results suggest that providing visual feedback, while facing a mirror during the test, reduces the amount of movement of the head, so this may have implications for clinical assessment. Patients with higher levels of NP and/or dizziness may have greater deficits, but there were no notable differences in trunk-head coordination observed between individuals with traumatic or idiopathic NP in this small cohort. This suggests that THCT should not be limited to subgroups of patients until this is further explored. Overall, these findings highlight the potential utility of an accelerometer-based assessment for capturing aspects of trunk-head coordination within a single session, while also revealing important variability in performance between testing sessions and across clinical presentations.

Disclosures

Conflict of interest: No conflict of interest is declared.

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All authors have read and approved the final manuscript.

Data Availability Statement: Data available on request. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the lack of means to host them on a repository.

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