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Influence of cervical muscle strength and pain severity on functional balance and limits of stability in elderly individuals with chronic nonspecific neck pain: a cross-sectional study

Shaker Hassan S. Alshehri[1], Ravi Shankar Reddy[2*], Mohammad A. ALMohiza[3], Mastour Saeed Alshahrani[2], Batool Abdulelah Alkhamis[2], Hani Hassan Alnakhli[2], Ghada Mohammed Koura[2], Ajay Prashad Gautam[2], Debjani Mukherjee[2], Raee S. Alqhtani[4], Saeed Y. Al Adal[4], Abdullah Mohammed Alyami[4] and Faisal M. Alyazedi[5]

Abstract

Background Chronic nonspecific neck pain (CNSNP) is a common musculoskeletal disorder, particularly in the elderly, leading to reduced cervical muscle strength, impaired functional balance, and decreased postural stability. This study investigated the correlation between cervical muscle strength, functional balance, and limits of stability (LOS) in elderly individuals with CNSNP. Additionally, it assessed the moderating effect of pain severity on the relationship between cervical muscle strength and these balance outcomes.

Methods A prospective study included a total of 186 participants, including 93 with CNSNP and 93 asymptomatic individuals, were recruited. Cervical flexor and extensor muscle strength were assessed using an ergoFET hand-held dynamometer. Functional balance was measured using the Berg Balance Scale (BBS) and Timed Up and Go (TUG) test, while LOS were evaluated using the Iso-Free machine.

Results Individuals with CNSNP exhibited significantly lower cervical flexor strength (32.45 ± 5.67 N vs. 40.75 ± 5.20 N, $p < 0.001$) and extensor strength (28.30 ± 6.05 N vs. 36.90 ± 5.90 N, $p < 0.001$) compared to asymptomatic individuals. Functional balance was also poorer in the CNSNP group, with lower BBS scores (47.85 ± 4.20 vs. 53.65 ± 3.85, $p < 0.001$) and slower TUG times (11.30 ± 2.05 s vs. 8.45 ± 1.80 s, $p < 0.001$). Cervical muscle strength showed moderate to strong positive correlations with LOS ($r = 0.56$ to 0.62, $p < 0.001$) and BBS ($r = 0.48$ to 0.53, $p < 0.001$). Pain severity significantly moderated the relationship between cervical muscle strength and functional balance ($\beta = 0.20$, $p = 0.045$) as well as LOS ($\beta = 0.22$, $p = 0.038$), suggesting that higher pain levels diminish the positive effects of muscle strength on balance.

Conclusion Cervical muscle strength plays a crucial role in maintaining functional balance and postural stability in elderly individuals with CNSNP. Pain severity moderates the relationship between cervical muscle strength and

*Correspondence:
Ravi Shankar Reddy
rshankar@kku.edu.sa

Full list of author information is available at the end of the article

balance outcomes, emphasizing the importance of integrating muscle strengthening and pain management in rehabilitation programs for elderly individuals with CNSNP to optimize postural control and minimize fall risk.

Keywords Neck pain, Chronic pain, Cervical muscle strength, Functional balance, Postural Stability

Introduction

Chronic nonspecific neck pain (CNSNP) is a widespread musculoskeletal condition that impacts a substantial segment of the global population, with a notably higher prevalence among older adults [1]. CNSNP is characterized by persistent pain in the cervical region, typically lasting longer than three months without a specific identifiable pathology such as disc herniation or cervical spine deformities [1]. Persistent pain in CNSNP is thought to result from a combination of peripheral and central sensitization mechanisms [2]. Repeated nociceptive input from the cervical region may lead to changes in the central nervous system, resulting in hyperalgesia, reduced pain thresholds, and heightened pain perception [2]. These processes often contribute to reduced physical function, diminished quality of life, and increased psychosocial burden [2]. Furthermore, chronic pain is associated with alterations in neuromuscular control, proprioception, and coordination, which can exacerbate postural instability and functional impairments in affected individuals [2]. This condition can lead to considerable physical and psychosocial impairments, including decreased range of motion, muscle weakness, and pain-related disability [3]. The persistent nature of CNSNP presents significant challenges in its management, frequently leading to diminished engagement in daily activities, heightened fall risk, and a corresponding reduction in overall quality of life [4]. Due to its multifactorial etiology, the identification and implementation of effective therapeutic interventions targeting the primary contributing factors are essential for optimizing patient outcomes [5].

Cervical muscle strength is pivotal in preserving the functional stability of the cervical spine and its associated musculature [6]. The muscles in the cervical region, especially the flexor and extensor groups, are fundamental in regulating head and neck movement, stabilizing the spine, and maintaining proper posture [7]. In individuals with CNSNP, cervical muscle strength is often compromised due to pain, disuse atrophy, and altered neuromuscular control [8]. This decline in strength is associated with increased muscle fatigue, reduced endurance, and impaired coordination, which can further exacerbate pain and dysfunction [9]. Previous research has shown that individuals with CNSNP exhibit significant deficits in both cervical flexor and extensor strength, which in turn may affect their ability to maintain proper head posture and respond effectively to external perturbations [9]. As a result, improving cervical muscle strength has become a key focus in the rehabilitation of individuals with CNSNP, with evidence suggesting that strengthening exercises targeting these muscles can alleviate pain, enhance postural control, and improve overall function [9].

In addition to cervical muscle strength, postural control, specifically limits of stability (LOS) and functional balance, plays a vital role in maintaining equilibrium and preventing falls in individuals with CNSNP [10]. The LOS represents the maximal distance an individual can shift their center of mass without compromising balance, serving as a crucial measure of postural control [11, 12]. Functional balance refers to the capacity to sustain or restore balance during dynamic tasks, such as ambulation or transitioning from a seated to a standing position [13]. In individuals with CNSNP, functional balance is frequently compromised, attributable to the interplay of diminished muscle strength, altered proprioceptive feedback, and disrupted vestibular function [14]. Research has indicated that individuals with CNSNP exhibit reduced LOS and perform poorly on functional balance tests, such as the Berg Balance Scale (BBS) and Timed Up and Go (TUG) test, compared to asymptomatic individuals [15]. These impairments increase the risk of falls, which can lead to further disability, hospitalization, and a decline in quality of life [16]. Therefore, understanding the interplay between cervical muscle strength and postural control in individuals with CNSNP is crucial for developing targeted interventions aimed at improving balance and preventing falls.

Despite the growing body of literature on CNSNP and its impact on muscle strength and balance, several research gaps remain. While previous studies have established the importance of cervical muscle strength in maintaining balance and postural control, few have explored the moderating effect of pain severity on these relationships [17]. Pain is a central feature of CNSNP and is known to interfere with neuromuscular function, movement patterns, and physical performance [18]. However, the extent to which pain severity influences the relationship between cervical muscle strength and balance outcomes has not been well studied. Additionally, most research to date has focused on younger or middle-aged adults, with limited attention given to the elderly population, who are at a greater risk of falls and injury [18]. Understanding how pain severity moderates the effect of cervical muscle strength on functional balance and LOS in elderly individuals with CNSNP is essential for developing more effective, individualized treatment strategies [19].

This study differentiates itself by focusing on elderly individuals with CNSNP, a population at greater risk of falls and functional impairments but often underrepresented in the literature. It uniquely investigates the moderating effect of pain severity on the relationship between cervical muscle strength, functional balance, and limits of stability, providing new insights into how pain alters postural control. These findings offer valuable guidance for developing targeted interventions that integrate pain management and muscle strengthening for improved functional outcomes in this population. The primary aim of this study was to explore the relationship between cervical muscle strength, functional balance, and LOS in elderly individuals suffering from CNSNP. Specifically, the study sought to determine whether pain severity modulates the relationship between cervical muscle strength and these postural control measures. The hypothesis proposed that greater cervical muscle strength would be positively correlated with improved functional balance and enhanced LOS in individuals with CNSNP.

Materials and methods

Duration, Ethics, setting and design, ethics

This prospective cross-sectional study was conducted between 12/05/2023 and 15/02/2024 at the Physical therapy clinic affiliated with DMRS, KKU, a tertiary care hospital specializing in musculoskeletal disorders. The study was approved by the Institutional Review Board (IRB) of King Khalid University, Saudi Arabia (REC#2023 – 492) on 26/ 04/ 2023. Informed consent was obtained from all participants prior to their inclusion in the study. Participants were provided with a detailed explanation of the study's purpose, procedures, potential risks, and benefits in a language they could understand. Written informed consent forms were then presented, and participants were given the opportunity to ask questions and seek clarification. Only those who voluntarily agreed to participate by signing the consent form were included in the study.

Clinical trial number Not applicable.

Participants

Initial screenings were performed through a comprehensive review of medical records and clinical assessments conducted by a certified orthopedic physician. Following this process, participants were referred from the orthopedic clinic to the physical therapy clinic for further evaluation. The study involved two groups: elderly individuals diagnosed with CNSNP and an age-matched asymptomatic control group. Eligibility criteria for both groups were carefully defined to ensure a focused assessment of cervical muscle strength, functional balance, and LOS.

The CNSNP group included individuals aged 65 years and older who had experienced neck pain for more than six months, with no specific underlying pathology such as disc herniation or cervical spine deformities. Participants in this group were required to have adequate cognitive function to follow instructions and complete the necessary assessments. They also needed to be ambulatory without assistance. Exclusion criteria for this group included a history of cervical spine surgery, neurological disorders (e.g., stroke or Parkinson's disease), vestibular conditions, severe osteoarthritis, or any other musculoskeletal conditions that could affect balance. Individuals with psychiatric conditions or active malignancies were also excluded to prevent confounding variables that could impact the study outcomes. Cervical radiculopathy was excluded to ensure the study focused exclusively on CNSNP. This condition can independently impact muscle strength, balance, and postural control due to nerve involvement, which could introduce confounding variables and obscure the specific effects of CNSNP [20]. The asymptomatic group consisted of elderly individuals aged 65 years and older who had no history of neck pain or musculoskeletal disorders in the previous six months. They were also required to have no history of cervical spine surgery, neurological disorders, or vestibular dysfunction. As with the CNSNP group, participants were expected to have adequate cognitive function and be independently ambulatory. Exclusion criteria for this group mirrored those of the CNSNP group, ensuring that only healthy individuals without significant medical or musculoskeletal conditions affecting balance or strength were included. Participants for both groups were selected using purposive sampling. To ensure participants met the inclusion criteria for adequate cognitive function, cognitive screening was performed using the Mini-Mental State Examination (MMSE). A minimum score of 24 was required for inclusion, indicating sufficient cognitive ability to follow instructions and complete the study assessments.

Variables

Assessment of cervical flexor and extensor muscle isometric strength

Cervical muscle strength for flexion and extension was assessed using the ergoFET hand-held dynamometer (HHD) (Hoggan Scientific, LLC) [21]. Each test was conducted on an adjustable height treatment table (Seers Group) to ensure proper positioning and participant stability. The testing session lasted approximately 15 min [21]. Before testing, the examiner documented each participant's height (in centimeters) and weight (in kilograms). A brief screening assessment was then performed, which included active cervical flexion and extension, followed by the Spurling test to exclude cervical radiculopathy or any other conditions that could potentially affect muscle performance. The cervical flexion and extension strength tests involved three isometric contractions held for 3 s each. The first contraction was submaximal (approximately 50% of maximal effort) to allow participants to become familiar with the movement and the use of the dynamometer. The subsequent two contractions were maximal, and the peak force generated during these two maximal contractions was recorded. A 30-second rest interval was provided between each contraction to avoid muscle fatigue and ensure reliable measurements [22].

For cervical flexion testing, participants were positioned in a supine position on the treatment Table [21]. The dynamometer pad was placed on the forehead, just superior to the eyebrows (Fig. 1A). Participants were instructed to push their foreheads upward against the dynamometer while maintaining their heads and bodies in a stable position on the table. For cervical extension testing, participants were positioned in a prone position. The dynamometer pad was placed on the posterior aspect of the head, slightly superior to the external occipital protuberance (Fig. 1B). Participants were instructed to push the back of their heads against the dynamometer while maintaining stability. This standardized procedure for cervical flexion and extension allowed for consistent placement of the HHD and accurate assessment of cervical muscle strength. The peak force from the two maximal contractions was recorded as the final strength measurement, providing valuable data on the participant's cervical muscle function. The cervical flexor and extensor strength assessments using the ergoFET dynamometer are validated methods with excellent intra-rater reliability (ICC = 0.93–0.98) [21]. These measurements reflect the capacity of cervical muscles to generate force, with lower values indicative of reduced muscle performance [21].

Limits of stability assessment

The assessment of LOS was conducted utilizing the Iso-Free machine by Techno Body [23]. The LOS assessment, conducted using the Iso-Free machine, is a valid measure of postural control with reported test-retest reliability (ICC = 0.87–0.92) in clinical populations [24]. Higher LOS percentages indicate superior postural stability [24]. This evaluation measured participants' capacity to control their center of pressure (COP) across eight distinct directions (Fig. 2): forward (A1), right forward (A2), right (A3), right backward (A4), backward (A5), left backward (A6), left (A7), and left forward (A8) [25]. The overall performance across these directions was quantified as a total percentage, with a maximum attainable score of 100% [25].

Before starting the test, the necessary participant data were entered into the software. Participants were then positioned on the force platform of the Iso-Free machine according to the specific format required by the device. The test began with a demonstration from the therapist, showing the correct movement in one direction to ensure participants understood the procedure. Visual feedback was provided via the machine's screen, where participants could observe their COP as a black dot on the screen. The desired direction of movement was indicated by a yellow box. Participants were instructed to shift their body weight in the direction of the yellow box, attempting to move the black dot (representing their COP) toward the box until it coincided [25]. Once a direction was completed successfully, the machine randomly prompted the participant to move in a new direction. This process was repeated for all eight directions, with the test concluding once movements in all directions were completed. The LOS results were presented as a percentage of an overall score representing the participant's total LOS.

Functional balance assessment

Functional balance was assessed using two validated and reliable tools: the BBS and the TUG test [26]. Both assessments are widely used in clinical and research settings to evaluate balance, mobility, and fall risk, particularly in elderly populations and individuals with musculoskeletal conditions such as CNSNP [26].

The BBS is composed of 14 tasks aimed at assessing a participant's capacity to maintain balance during routine activities, such as sitting, standing, transferring between surfaces, and reaching forward [26]. Each task is evaluated using a 5-point ordinal scale, where a score of 0 signifies the inability to perform the task, and a score of 4 represents the ability to complete the task independently and safely [26]. The cumulative score ranges from 0 to 56, with higher scores indicating superior balance performance, while lower scores suggest balance impairment. Before starting the test, participants were briefed on the objectives and procedures, and the physical therapist demonstrated each task to ensure consistency and minimize variability. Participants were given clear instructions and allowed time to ask questions if needed. Tasks included standing unsupported, sitting to standing, transferring, and more complex tasks such as standing on one leg or with eyes closed. Once participants completed the 14 tasks, their total score was calculated and recorded for further analysis. The Berg Balance Scale (BBS) has demonstrated excellent reliability (ICC = 0.95–0.98) and validity in assessing functional balance in elderly populations and those with musculoskeletal conditions [27]. A higher BBS score indicates better balance performance,

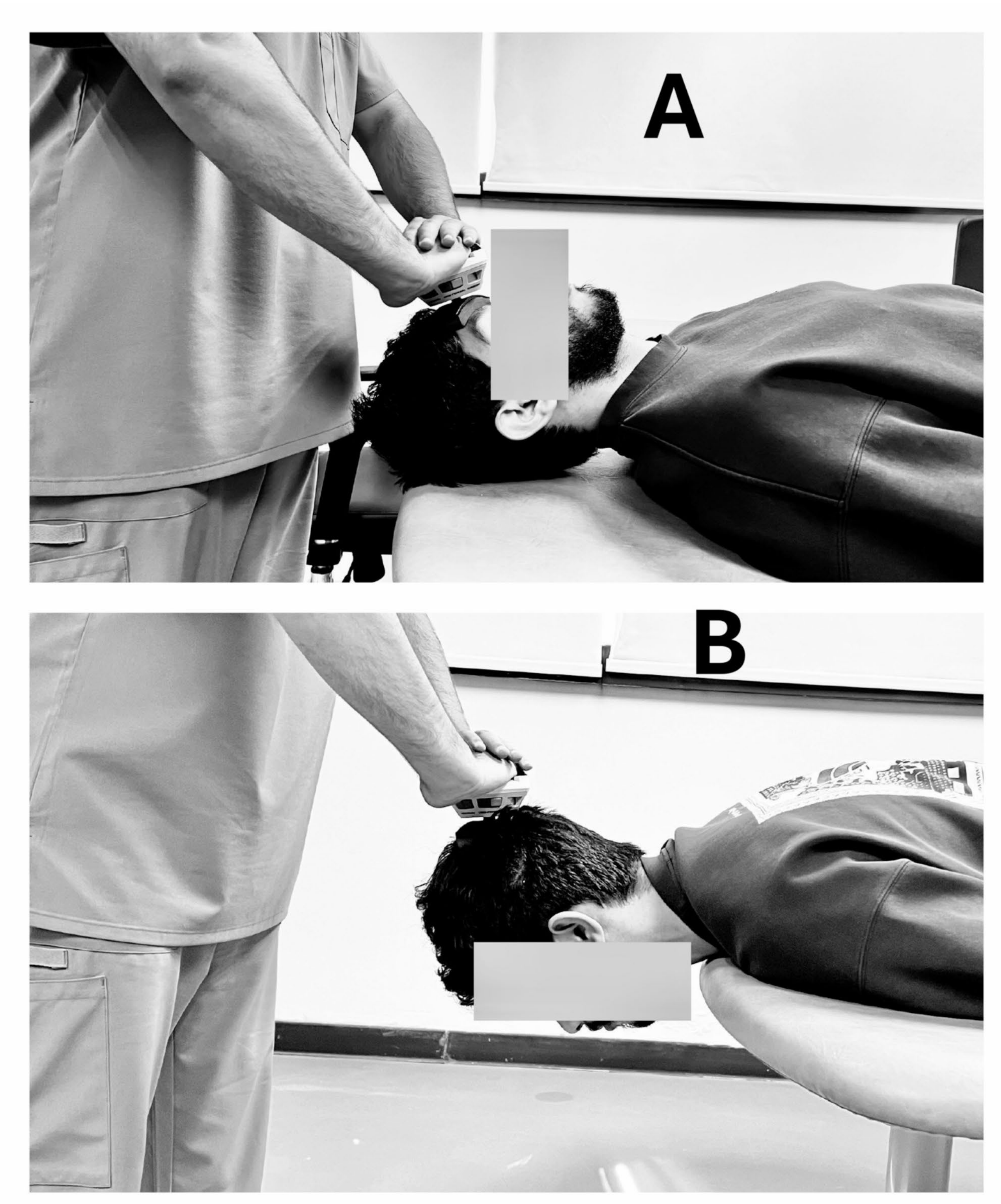
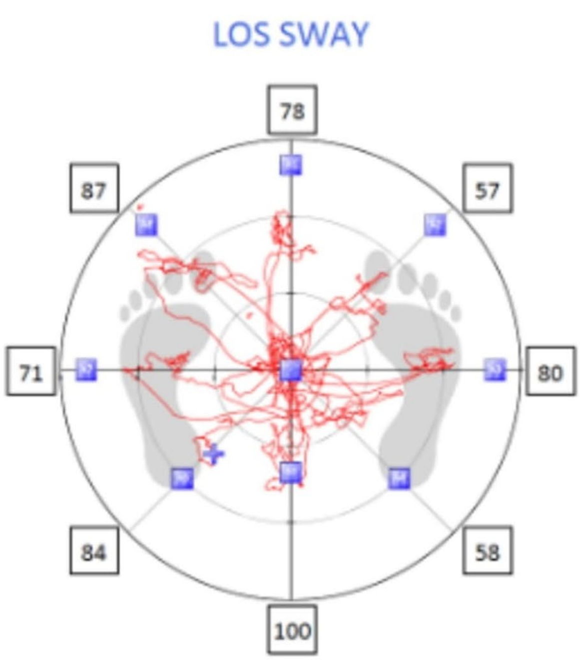


Fig. 1 Measurement of cervical flexor and extensor strength using a hand-held dynamometer



Total objective	76.95 %
A1-Forward	77.71 %
A2-Right-Forward	57.37 %
A3-Right	80.39 %
A4-Right-Backward	58.33 %
A5-Backward	100 %
A6-Left-Backward	83.95 %
A7-Left	71.14 %
A8-Left-Forward	86.73 %

Fig. 2 Assessment of limits of stability (LOS) using the iso-free computerized posturography machine

with scores below 45 suggesting an increased risk of falls [27].

The second tool employed to evaluate functional balance was the TUG test, a straightforward yet highly effective measure of mobility and balance [28]. The TUG test measures the time it takes for a participant to rise from a seated position, walk a distance of 3 m, turn, return to the starting point, and sit back down. Prior to the test, participants received detailed instructions and a demonstration from the therapist. The assessment was conducted in a controlled environment with a clear, unobstructed walking path to ensure safety. Participants were instructed to perform the test at a normal walking pace, and the time to complete the task was recorded using a stopwatch. The TUG test is widely regarded for its reliability and strong correlation with functional mobility and fall risk, particularly in elderly individuals and those with musculoskeletal conditions. Shorter completion times indicate better mobility and balance, whereas longer times suggest impaired balance and an elevated risk of falls [29]. The Timed Up and Go (TUG) test is a reliable tool (ICC = 0.92–0.96) for evaluating mobility and balance, with shorter completion times reflecting better functional ability [30]. A TUG time exceeding 13.5 s is commonly associated with a higher risk of falls [30].

Neck disability index administration

The Neck Disability Index (NDI) was used to assess the level of disability related to neck pain. Participants completed the NDI questionnaire, which consists of 10 sections evaluating pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleeping, and recreation. A higher percentage score indicates greater disability.

Demographic data collection

Demographic data, including age, gender, and body mass index (BMI), were collected through a comprehensive review of medical records and clinical assessments conducted by a certified orthopedic physician. This ensured that relevant baseline characteristics were appropriately recorded.

Sample size estimation

The sample size for this study was calculated using G*Power statistical software to ensure sufficient power for detecting significant differences and relationships between cervical muscle strength, LOS, and functional balance. The calculation was based on an independent t-test for group comparisons, anticipating a moderate effect size (0.5) with a significance level of 0.05 and a power of 0.80. Additionally, Pearson's correlation was used to detect a moderate correlation ($r = 0.3$) between cervical muscle strength and balance measures, and a multiple regression model was employed to examine moderation effects with three predictors. Initially, the estimated sample size was 90 participants, with a 5% buffer added for potential dropouts, bringing the target to 95.

Statistical analysis

The normality of the dataset was assessed using the Shapiro-Wilk test and Q-Q plot inspection, confirming a normal distribution and supporting the use of parametric statistical methods. Descriptive statistics, including means and standard deviations, were calculated for all continuous variables to summarize the dataset. Independent t-tests were conducted to compare cervical muscle strength, functional balance, and LOS between individuals with CNSNP and an asymptomatic control group. Pearson's correlation coefficients were applied to evaluate the strength and direction of the relationships between cervical muscle strength and functional balance outcomes, specifically using the BBS and the TUG test as key measures of postural control. Additionally, multiple linear regression analysis, incorporating interaction terms, was performed to investigate the moderating effect of pain severity on the relationship between cervical muscle strength and balance performance.

Results

The demographic and clinical characteristics of the CNSNP group and the asymptomatic group were compared (Table 1). No significant differences were observed between the two groups in terms of age, gender distribution, and BMI. However, individuals in the CNSNP

Table 1 Demographic and clinical characteristics

Characteristic	Chronic Neck Pain Group ($n = 93$)	Asymptomatic Group ($n = 93$)	*p*-value
Age (years)	72.45 ± 5.60	71.85 ± 5.80	0.452
Gender (Male/Female)	45/48	43/50	0.645
BMI (kg/m^2)	27.56 ± 3.45	26.95 ± 3.60	0.295
Duration of neck pain (years)	4.20 ± 1.30	N/A	N/A
Pain Severity (VAS, 0–10)	6.75 ± 1.50	1.05 ± 0.80	< 0.001
Falls in the past year (number)	1.45 ± 0.70	0.25 ± 0.40	< 0.001
Neck Disability Index (NDI, %)	42.35 ± 10.50	5.10 ± 2.25	< 0.001

VAS: Visual Analog Scale; N: Newtons; NDI: Neck Disability Index; BMI: Body Mass Index; N/A: Not Applicable

Table 2 Comparison of cervical muscle strength, limits of Stability, and functional balance between CNSNP and asymptomatic groups

Variable	CNSNP Group (Mean ± SD)	Asymptomatic Group (Mean ± SD)	t-value	*p*-value	Cohen's d
Cervical Flexor Strength (N)	32.45 ± 5.67	40.75 ± 5.20	-9.23	< 0.001	1.52
Cervical Extensor Strength (N)	28.30 ± 6.05	36.90 ± 5.90	-8.55	< 0.001	1.48
Limits of Stability (degrees)	78.45 ± 11.30	92.90 ± 11.50	-19.45	< 0.001	1.70
Berg Balance Scale (score)	47.85 ± 4.20	53.65 ± 3.85	-8.25	< 0.001	1.44
Timed Up and Go (seconds)	11.30 ± 2.05	8.45 ± 1.80	8.75	< 0.001	1.68

N: Newtons; SD: Standard Deviation; t: t-statistic; p: *p*-value; Cohen's d: Effect size (Cohen's d)

Table 3 Correlation between cervical muscle strength, limits of stability and functional balance in CNSNP Group

Variable	Limits of Stability (*r*, *p*-value)	Berg Balance Scale (*r*, *p*-value)	TUG (*r*, *p*-value)
Cervical Flexor Strength (N)	0.56, < 0.001	0.48, < 0.001	-0.51, < 0.001
Cervical Extensor Strength (N)	0.62, < 0.001	0.53, < 0.001	-0.57, < 0.001

r: Pearson's correlation coefficient; N: Newtons; p: *p*-value

group reported significantly higher pain severity scores, a greater number of falls in the past year, and a markedly higher NDI percentage compared to the asymptomatic group.

The comparison between the CNSNP and asymptomatic groups revealed significant differences across all assessed variables (Table 2). The CNSNP group exhibited significantly lower cervical flexor strength (32.45 ± 5.67 N) compared to the asymptomatic group (40.75 ± 5.20 N), with a t-value of -9.23 and a large effect size (Cohen's d = 1.52). Similarly, cervical extensor strength was lower in the CNSNP group (28.30 ± 6.05 N) compared to the asymptomatic group (36.90 ± 5.90 N), with a t-value of -8.55 and a Cohen's d of 1.48. LOS was also significantly reduced Íin the CNSNP group (78.45 ± 11.30 degrees) versus the asymptomatic group (92.90 ± 11.50 degrees), with a t-value of -19.45 and Cohen's d of 1.70. Functional balance, as measured by the BBS, was poorer in the CNSNP group (47.85 ± 4.20) compared to the asymptomatic group (53.65 ± 3.85), with a t-value of -8.25 and Cohen's d of 1.44. Lastly, the CNSNP group took significantly longer to complete the TUG test (11.30 ± 2.05 s) than the asymptomatic group (8.45 ± 1.80 s), with a t-value of 8.75 and Cohen's d of 1.68. All differences were statistically significant ($p < 0.001$), indicating that CNSNP considerably impairs both muscle strength and balance control.

The analysis revealed significant positive correlations between cervical muscle strength and postural control measures in individuals with CNSNP (Table 3; Fig. 3). Both cervical flexor and extensor strength showed moderate to strong positive correlations with LOS ($r = 0.56$ and $r = 0.62$, respectively) and the BBS ($r = 0.48$ and $r = 0.53$, respectively). In contrast, there were significant negative correlations between cervical muscle strength and the TUG test, indicating that higher cervical strength was associated with faster performance on this test (r = -0.51 for flexors and r = -0.57 for extensors), with all p-values being < 0.001.

The moderation analysis demonstrated that pain severity significantly moderated the relationship between cervical muscle strength and both functional balance and LOS (Table 4). Cervical muscle strength had a positive impact on functional balance and LOS, with β values of 0.45 and 0.50, respectively. Pain severity showed a negative effect, reducing both functional balance and LOS (β = -0.32 and β = -0.35, respectively). The interaction term between muscle strength and pain severity was significant, indicating that the strength of the relationship between cervical muscle strength and both outcomes was influenced by pain severity (β = 0.20 for functional balance and β = 0.22 for LOS), with all p-values below 0.05.

Discussion

The observed significant differences in cervical muscle strength, functional balance, and LOS between the CNSNP and asymptomatic groups can be attributed to the multifactorial impacts of CNSNP on neuromuscular function [31]. CNSNP often leads to a reduction in neuromuscular efficiency, particularly affecting the activation and endurance of both flexor and extensor muscles [31]. This can result in muscle weakness and fatigue, contributing to decreased postural control and balance [1]. The lower cervical muscle strength observed in the CNSNP group is likely a consequence of disuse atrophy, whereby prolonged periods of pain lead to avoidance behaviors and reduced physical activity [32]. The impaired LOS and prolonged TUG performance in this group reflect deficits in dynamic balance, which may stem from altered proprioception and vestibular function commonly associated with chronic musculoskeletal pain conditions [33]. These factors collectively reduce the body's ability to maintain equilibrium, especially when performing functional tasks that require balance and coordination [34].

The current findings align with previous studies that have documented similar deficits in individuals with CNSNP [31, 35]. Johnston et al. [31] reported a significant reduction in cervical flexor and extensor muscle

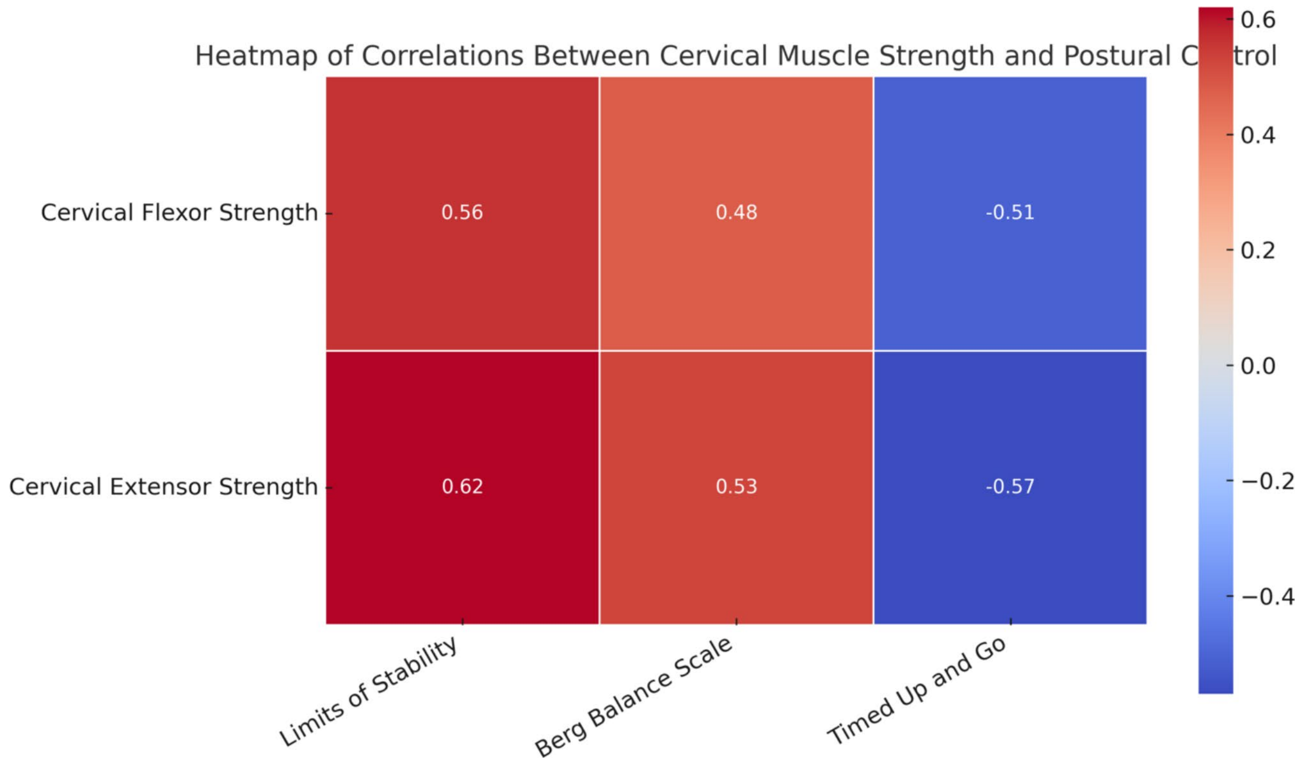


Fig. 3 Heatmap: Correlation between cervical muscle strength limits of stability and functional balance parameters

Table 4 Moderating Effect of Pain Severity on the relationship between cervical muscle strength and functional balance and limits of Stability

Predictor	Functional Balance (Berg Balance Scale)	SE (Functional Balance)	95% CI (Functional Balance)	*p*-value (Functional Balance)	Limits of Stability	SE (Limits of Stability)	95% CI (Limits of Stability)	*p*-value (Limits of Stability)
Cervical Muscle Strength (β1)	0.45	0.12	(0.21, 0.69)	0.003	0.50	0.11	(0.29, 0.71)	0.001
Pain Severity (β2)	-0.32	0.10	(-0.53, -0.11)	0.012	-0.35	0.09	(-0.53, -0.17)	0.010
Muscle Strength × Pain Severity (Interaction term β3)	0.20	0.09	(0.02, 0.38)	0.045	0.22	0.08	(0.04, 0.40)	0.038

β: Regression coefficient; SE: Standard Error; CI: Confidence Interval; p: *p*-value

strength among patients with CNSNP, attributing this to impaired neuromuscular control. Similarly, Goudarzi et al. [35] demonstrated that individuals with neck pain exhibit altered muscle activation patterns and reduced proprioceptive acuity, which negatively impacts balance and postural control [35]. The observed correlation between reduced muscle strength and impaired functional balance is consistent with the work of Song et al. [36], who noted that weakened cervical muscles contribute to instability and an increased risk of falls [36]. Collectively, these studies corroborate the present findings, reinforcing the notion that CNSNP significantly diminishes both muscular strength and balance, thereby impacting daily functional activities.

The significant positive correlations between cervical muscle strength and postural control measures in individuals with CNSNP likely stem from the role that cervical muscles play in maintaining postural stability and balance [16]. Stronger cervical flexor and extensor muscles likely enhance the capacity to control head and neck movements, which in turn contributes to improved balance and stability, as reflected by the positive correlations with the LOS and BBS [10]. Conversely, the negative correlations with the TUG test suggest that stronger cervical muscles enable more efficient movement, leading to faster task completion [37]. These findings are supported by previous research, such as the study by Goudarzi et al. [35], which indicated that stronger cervical muscles enhance proprioception and neuromuscular control, thereby improving postural control [35]. Similarly, Rodrigues et al. [38] demonstrated that increased cervical muscle strength is associated with better balance performance in individuals with neck pain, consistent with the current findings [38]. These studies confirm the critical role of cervical muscle strength in maintaining functional balance and postural control in individuals with CNSNP.

The moderation analysis revealed that pain severity significantly weakens the positive relationship between cervical muscle strength and both functional balance and LOS. The results suggest that while stronger cervical muscles generally improve postural control and balance, the presence of higher pain severity diminishes these benefits [39]. This can be explained by the fact that pain not only disrupts neuromuscular function but also impacts proprioception and movement patterns, thereby interfering with an individual's ability to effectively engage their muscles during functional tasks [40, 41]. These findings align with the work of Lppersiel et al. [42], who demonstrated that higher pain levels are associated with decreased physical performance due to pain-related fear and altered movement strategies [42]. Similarly, Viseux et al. [14] reported that pain can alter muscle coordination, further contributing to decreased balance and stability [14]. The significant interaction effect observed in the current study supports these previous findings, highlighting the dual role of cervical muscle strength and pain severity in determining postural control outcomes in individuals with CNSNP.

Clinical significance

This study underscores the association between cervical muscle strength, functional balance, and limits of stability in elderly individuals with CNSNP. The results highlight the potential importance of addressing cervical muscle weakness and pain severity in this population, which are linked to impaired postural control and an increased fall risk. While these findings suggest that interventions targeting muscle strength and pain management may be beneficial, further interventional studies are needed to confirm their efficacy in improving balance and reducing fall risk in elderly individuals with CNSNP.

Limitations and future recommendations

This study was limited to a specific population of elderly individuals with CNSNP, which may restrict the generalizability of the findings to other age groups or types of neck pain. Additionally, the reliance on self-reported measures, such as pain severity, could have introduced bias or inaccuracies. Another limitation is the potential influence of pain on cervical strength measurements, as pain may inhibit maximal muscle activation despite efforts to standardize procedures and minimize discomfort. While familiarization trials, isometric testing, and adequate rest intervals were employed to reduce this effect, some degree of pain-related inhibition may still have affected the results. Future research should employ prospective designs to explore the causal effects of cervical muscle strengthening on balance and stability over time and examine whether similar patterns are observed in younger populations or those with different musculoskeletal conditions. Furthermore, studies investigating the efficacy of combined interventions focusing on both pain management and muscle strengthening could provide evidence to inform and optimize clinical practice.

Conclusion

This study demonstrated that cervical muscle strength is associated with functional balance and postural stability in elderly individuals with CNSNP, and pain severity moderates these relationships. These findings emphasize the need for further research to explore the effectiveness of interventions targeting cervical muscle strengthening and pain management in this population. Future studies should assess whether such interventions can improve balance and reduce fall risk in elderly individuals with CNSNP.

Abbreviations

CNSNP	Chronic Nonspecific Neck Pain
LOS	Limits of Stability
BBS	Berg Balance Scale
TUG	Timed Up and Go test
VAS	Visual Analog Scale
NDI	Neck Disability Index
COP	Center of Pressure
HHD	Hand-Held Dynamometer

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Author contributions

All authors collaboratively designed and conceptualized the study. SHS, RSR, MAA, MSA, BAA, and APG drafted the 1st version of the manuscript and conducted all analyses. SHS, RSR, MAA, HHA, GMK, and DM led the management of the work and helped draft the manuscript. RSA, AMA, and FMA formulated the statistical techniques. SHS, RSR, MAA, MSA, BAA, and APG contributed to interpreting the results, reviewing the article, and revising it critically. All authors approved the manuscript's submission for publication.

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Data availability

The datasets generated and analyzed during the current study are available in the publicly accessible repository, "Zenodo". The dataset can be accessed through the following DOI: 10.5281/zenodo.13936139. (https://doi.org/10.5281/zenodo.13936139). This repository ensures that the data is openly available and can be used by other researchers under the terms that permit unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Declarations

Ethics approval and consent to participate

The King Khalid University ethics committee, Saudi Arabia, approved the study protocol (REC#2023 – 492), which complies with the Declaration of Helsinki and Good Clinical Practice Guidelines. All patients signed a written informed consent form to be enrolled.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Orthopaedic Surgery, College of Medicine, King Khalid University, Abha 61421, Saudi Arabia
[2]Physical Therapy Program, Department of Medical Rehabilitation Sciences, College of Applied Medical Sciences, King Khalid University, Abha 61423, Saudi Arabia
[3]Department of Health Rehabilitation Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia
[4]Department of Physical Therapy, Faculty of Applied Medical Sciences, Najran University, Najran, Saudi Arabia
[5]Physical Therapy Department, Prince Sultan Military College of Health Sciences, Dhahran, Saudi Arabia

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