Relationship Between Proprioception and Endurance Functionality of the Cervical Flexor Muscles in Chronic Neck Pain and Asymptomatic Participants

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Abstract

Objective: The purpose of this study was to compare the relationship between flexion endurance capacity and joint position error in participants with or without chronic neck pain (CNP).
Methods: Sixty-one CNP and 60 asymptomatic volunteers participated in this cross-sectional, case-control, and correlational analysis study. The measured variables included absolute and constant joint repositioning errors in the sagittal and horizontal directions, clinical flexor endurance test score, pain intensity, and neck disability index.
Results: The groups did not statistically differ in flexion endurance ($P > .05$). The CNP group had a smaller absolute error on the right ($P < .01$) and left ($P = .01$) rotation and an overshooting error pattern in the flexion direction ($P < .05$). But the asymptomatic group did not exhibit any over-/undershooting pattern tendency ($P > .05$). Although flexion endurance was not correlated with any of the joint repositioning error components in either group, pain and disability scores were significantly correlated with left rotation absolute error ($r = -0.34$ and $\rho = -0.37$, respectively).
Conclusion: The clinical cervical flexor endurance test, ignoring the relative contribution of the deep and superficial groups of muscles, may not efficiently characterize CNP patients. (J Manipulative Physiol Ther 2018;41:129-136)
Key Indexing Terms: *Chronic Pain; Spine; Proprioception*

Introduction

Chronic neck pain (CNP) is a common musculoskeletal problem with considerable personal and financial costs.[1] Physical,[2-4] psychological,[5] and sensorimotor[2] impairments have been found to be correlated with CNP in several studies. The multifactorial nature of the disease has made it difficult to identify the main contributing mechanisms and their relative relevance to the consequences of CNP.

Proprioceptive function accuracy has recently gained considerable attention in the description and assessment of CNP.[6-8] Proprioception functioning in a closed loop between peripheral mechanoreceptors (lying within muscles and other connective soft tissues) and the brain plays a crucial role in the maintenance of joint stability in a dynamic situation.[9] This sense (in conjunction with visual and vestibular afferents) provides the central nervous system (CNS) with the necessary information to parameterize the efferent motor commands necessary for postural and motor control.[10,11] Some investigators assume that proprioception deficit might be a factor predisposing to pain and injury via poor motor control.[12] Understanding the proprioceptive function alterations in the presence of CNP thus seems necessary for evaluation and rehabilitation of these patients.[13,14]

Muscles are proprioceptive information sources. The deep cervical muscles, being rich in muscle spindles,[15,16] have been thought to play a relatively more prominent role in sensory motor function of this region.[17] The deep neck flexors are responsible for maintenance of cervical lordosis and intersegmental stability during activities of daily living.[15] Patients with CNP tend to have lower flexor muscle endurance compared with asymptomatic persons.[18-20] There is evidence indicating that fatigue of the cervical and scapular muscles may adversely affect the cervical joint position sense.[21,22] Hence, deep neck flexor muscle dysfunction in terms of increased fatigability may be associated with proprioceptive

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dysfunction and poor postural control in patients with CNP. Endurance training of the deep cervical flexor muscles has been reported to improve joint position sense accuracy in CNP patients.[14,23] This might suggest the 2 functions have a common source, that is, the deep flexor muscles. Although there is evidence for the relevance of both factors to CNP, to our best knowledge no study has yet investigated the association between the force maintenance (endurance) capacity and proprioceptive functioning of the deep cervical flexor muscles in CNP patients. In this study, we addressed the following questions: Is there a relationship between proprioceptive and endurance functioning of the cervical flexor muscles? Is this relationship affected by the presence of CNP?

The objectives of the current study were to (1) investigate the association between cervical proprioceptive functioning, cervical flexor endurance, pain intensity, and disability scores and (2) compare the proprioceptive accuracy and cervical flexor endurance capacity of CNP patients with those of asymptomatic participants.

Methods

Design

This was a cross-sectional, case-control, and correlational analysis study. The participants were recruited into the study after being familiarized with the purpose and content of the study and signing the informed consent form approved by the human ethics committee of the University of Social Welfare and Rehabilitation Sciences (Approval Code: IR.USWR.REC.1394.224). The study was registered with ClinicalTrials.gov (No. NCT02789631).

Participants

Sixty-one participants (41 female) with idiopathic CNP and 60 asymptomatic participants (37 female) from the community voluntarily participated in this study between October 2015 and August 2016. The inclusion criteria for the CNP group were as follows: age 20-55 years, pain experience in the suboccipital to the first thoracic vertebra region for at least 6 months with a frequency no less than once a week. The control group participants had no history of neck pain within the last year. Participants would be excluded from either group if they had any history of trauma or surgery on the spine; congenital deformity or inflammatory diseases; positive Spurling[24] and Dix Hallpike[25] tests for radiculopathy signs and vestibular impairment, respectively; diagnosis of fibromyalgia; or history of neck physical therapy within 6 months prior to our testing. The physical examination and medical history review were performed by an experienced orthopedic physical therapist. The demographic characteristics of both groups are summarized in Table 1.

Table 1. *Demographic Characteristics of Chronic Neck Pain Patients and Asymptomatic Participants*

	Chronic Neck Pain (n = 60)	Asymptomatic (n = 61)	*P* Value
Age, y	33.61 ± 9.5	31.00 ± 9.70	.10
Weight, kg	67.03 ± 16.96	66.75 ± 15.97	.95
Height, cm	167.58 ± 7.84	167.40 ± 9.57	.91
Body mass index (kg/cm^2)	23.85 ± 5.10	23.74 ± 4.41	.84
Past-week VAS (cm)	4.81 ± 2.32		
NDI score	10.57 ± 6.53		

Values are presented as means ± standard deviation.
NDI, neck disability index; *VAS,* visual analogue scale.

Outcome Measures

Clinical Characteristics of the CNP Group. Pain intensity over the last week was measured using a blank 100-mm visual analogue scale (VAS), where 0 corresponded to “no pain at all” and 100 to “the worst imaginable pain.” Neck pain-related disability was assessed with the Persian version of the Neck Disability Index (NDI-P).[26] The NDI covers 10 items of daily living activities and is scored from 0 to 50, with higher scores corresponding to greater disability.

Neck Flexor Endurance Test. The participants would assume the “crook lying” position with the arms alongside the body and were asked to raise their head approximately 2 cm of the plinth while keeping their chins tucked in (craniocervical flexion posture). Losing the chin-tucked posture, having the back head in contact with the plinth for more than 1 second, or reluctance to continue for any reason would lead to test termination. The test duration was measured in seconds with a stopwatch. The examiner visually monitored the cervical posture during the test.[27] The test was performed only once to prevent pain exacerbation in patients.

Joint Position Reproduction Test. The test was performed as described by Revel et al.[28] After being familiarized with the test procedure, the participants were asked to sit upright in a comfortable position on a chair and look straight ahead. A Velcro strap was fixed around the skull, level with the top of the ears. A laser pointer (Class 3A Laser product, Wen Zhou Xinke, China) was fixed on the Velcro strap between the eyebrows aimed at a target 90 cm away. The participants were instructed to remember baseline neutral head position before moving their heads slowly through the maximum comfortable range of motion and to return to the initial position with their eyes kept closed. The point where the laser beam stopped on the target was marked and labeled according to the movement direction and trial number. The test was performed through 4 directions of cervical motion (flexion, extension, right and left rotation, with 3 trials for each) with a 1-minute rest interval between the directions; the order of movements was randomized. After each trial, the examiner moved the participant’s head back to the neutral position. The laser beam projection on the target in the neutral head position was regarded as the reference zone (0, 0 coordinate on the *x*- and *y*-axes). For each of the motion directions and repetitions, deviations from the reference zone on the *x*- and *y*-axes were measured in centimeters. The line projecting from the reference point to the end beam location point was considered the global (*R*) joint position error (JPE). The length of R was calculated using the equation $R = \sqrt{x^2 + y^2}$, where *x* and *y* are the abscissa and ordinate coordinates of the endpoint, respectively. All repositioning errors measured in centimeters were converted into degrees using the equation angle = tan − 1[*R*/90 cm]. To isolate the error component in the primary plane (in which the repositioning movement was to occur), the *Y* and *X* components of the *R* vector were also considered in the flexion/extension and rotation movements, respectively. The mean of the 3 trials' error angles (considering the negative or positive values representing under- and overshooting errors, respectively) would yield the constant error (CE), and the root mean square of errors represented the absolute error (AE); these were used to describe the joint position reproduction (JPR) accuracy.[29,30]

Procedure

Demographic data, including age, sex, height, weight, past medical history, and location and duration of symptoms, were collected. All CNP patients completed the NDI and VAS following familiarization with the test procedure. The endurance test was performed following JPR to avoid fatigue.

Statistical Analysis

Data distribution was verified with the Shapiro-Wilk test. An independent *t*-test and Mann-Whitney *U*-test were used for between-group comparisons of anthropometric data for normally and non-normally distributed data, respectively. Multivariate analysis of variance was used to examine the endurance, CE, and AE score differences between the 2 groups. A 1-sample *t*-test was used to check if the overshoot/undershoot errors were statistically different from zero or not. Pearson and Spearman correlation coefficient tests were also conducted to examine the correlation between the endurance, JPE, NDI, and VAS scores. Correlation coefficients were classified as follows: <0.25 = little or no, 0.25-0.5 = fair, 0.5-0.75 = moderate to good, and >0.75 = good to excellent.[31] To investigate the discriminating capabilities of the variables, those revealing significant between-group differences were analyzed with the receiver operating characteristic (ROC) curve. Statistical analyses were performed using the statistical package SPSS software (Version 21; IBM, Armonk, New York). The level of statistical significance was set at $P < .05$.

Table 2. *Comparison of Absolute Repositioning Error and Flexor Endurance Between the 2 Groups*

Direction	Component	Chronic Neck Pain	Asymptomatic	*P* Value
Flexion (°)	*X*	1.47 ± 0.93	1.77 ± 1.21	.12
	Y	2.34 ± 1.15	2.43 ± 1.15	.64
	R	2.89 ± 1.21	3.16 ± 1.36	.23
Extension (°)	*X*	1.30 ± 0.75	1.74 ± 1.17	.01 [a]
	Y	2.71 ± 1.35	2.80 ± 1.22	.61
	R	3.11 ± 1.31	3.45 ± 1.36	.15
Right rotation (°)	*X*	2.24 ± 1.33	3.29 ± 1.65	<.01 [a]
	Y	1.59 ± 1.07	2.23 ± 1.18	<.01 [a]
	R	2.92 ± 1.40	4.16 ± 1.61	<.01 [a]
Left rotation (°)	*X*	2.44 ± 1.42	2.98 ± 1.57	.05
	Y	1.69 ± 0.96	2.07 ± 1.30	.05
	R	3.11 ± 1.43	3.81 ± 1.65	.01 [a]
Flexor endurance (s)		24.06 ± 14.61	26.63 ± 15.95	.36

Values are presented as means ± standard deviation.
[a] Statistically significant difference.

Results

Sixty-one CNP and 60 asymptomatic participants were involved in the current study. There were no dropouts, but 1 patient and 3 asymptomatic participants were missing data because of reluctance to conduct the flexor endurance test. Although all demographic variables followed a normal pattern of distribution in the control group, they did not exhibit a statistically normal distribution in the CNP group, except for the height and VAS variables. The JPE variable in both groups and flexion endurance in the control group were found to be normally distributed. Mann-Whitney *U*-test results revealed no statistically significant difference between the 2 groups with respect to age, weight, body mass index, and sex distribution. An independent *t*-test also revealed no significant difference between their heights (Table 1).

The Mann-Whitney *U*-test revealed no significant difference in flexor endurance capacity between the 2 groups ($P = .37$). Table 2 compares AEs in CNP patients and asymptomatic participants. Multivariate analysis of variance test results revealed that there were significant differences for the *X* ($P = .01$) component of extension AE; *X* ($P < .01$), *Y* ($P < .01$), and *R* ($P < .01$) components of right rotation AE; and *R* ($P = .01$) component of left rotation AE between the 2 groups.

The 1-sample *t*-test revealed a significant overshoot for flexion repositioning in the *Y* ($P = .01$) and *R* ($P = .02$) components in the CNP group. In the asymptomatic group, there were no significant overshoot/undershoot tendencies for any of the repositioning directions (Table 3).

The findings revealed that in the CNP group, 49%, 50%, 50%, and 44% of the participants had inconsistent overshoot/undershoot patterns of JPR during the 3 trials

Table 3. *One-Sample t-Test Result Evaluating the Under-/Overshooting Error of Participants in Both Groups*

		Chronic Neck Pain		Asymptomatic	
Direction	Component	Mean ± SD	*P* Value	Mean ± SD	*P* Value
Flexion (°)	*Y*	0.63 ± 1.84	.01 [a]	–0.13 ± 1.83	.57
	R	0.64 ± 2.21	.02 [a]	–0.18 ± 2.46	.56
Extension (°)	*Y*	0.43 ± 2.36	.15	–0.20 ± 2.27	.49
	R	0.44 ± 2.57	.18	–0.28 ± 2.73	.43
Right rotation (°)	*X*	–0.05 ± 2.13	.84	–0.45 ± 2.69	.19
	R	–0.04 ± 2.57	.88	–0.30 ± 3.39	.49
Left rotation (°)	*X*	–0.33 ± 2.19	.23	0.41 ± 2.60	.21
	R	–0.27 ± 2.70	.42	0.65 ± 3.27	.12

SD, standard deviation.
[a] Statistically significant difference.

Table 4. *Correlational Analysis of Absolute Errors With Visual Analogue Scale, Neck Disability Index, and Flexor Endurance in the 2 Groups*

		Flexion			Extension			Right Rotation			Left Rotation		
		X	*Y*	*R*	*X*	*Y*	*R*	*X*	*Y*	*R*	*X*	*Y*	*R*
Chronic neck pain													
Visual	r	0.03	0.11	0.08	–0.18	–0.08	–0.13	0.01	0.01	0.02	–0.34 [a]	0.21	–0.20
Analogue Scale	*P*	.79	.40	.56	.19	.54	.32	.89	.89	.88	.01	.13	.14
Neck	ρ	–0.01	–0.05	–0.09	–0.18	–0.06	–0.06	–0.07	0.03	–0.13	–0.37 [a]	–0.04	–0.35 [a]
Disability Index	*P*	.94	.72	.51	.19	.68	.65	.61	.80	.35	.00	.77	.01
Flexor	ρ	–0.25	0.07	–0.03	–0.05	0.17	.17	–0.23	0.16	–0.12	0.11	0.24	0.17
Endurance	*P*	.05	.55	.17	.70	.19	.19	.06	.19	.36	.36	.05	.18
Asymptomatic													
Flexor	r	–0.06	–0.12	–0.09	–0.01	.09	.07	0.00	0.06	0.05	–0.00	0.13	0.07
endurance	*P*	.62	.35	.48	.90	.47	.60	.96	.64	.69	.98	.33	.58

r and *ρ* indicate correlation coefficients for Pearson (for normally distributed data) and Spearman's rank-order (for non-normally distributed data) correlation tests, respectively.
[a] Statistically significant difference.

in flexion, extension, and right and left rotations, respectively. The corresponding values were 60%, 60%, 50%, and 46% for the asymptomatic participants.

In the CNP group, NDI was negatively correlated with *X* (ρ = –0.37, P < .01) and *R* (ρ = –0.35, P = .01) components of left rotation AE. There was a significant negative correlation between pain intensity and the *X* component of the left rotation AE (r = –0.34, P = .01). There was no correlation between JPE and flexor endurance in either group. No significant correlation was found between the studied variables in the asymptomatic group. The details of the correlation test statistics are provided in Tables 4, 5, and 6.

Analysis of the ROC curve revealed that the areas under the curve of the absolute global JPE of the right and left rotations were 0.72 (95% confidence interval [CI]: 0.63-0.79) and 0.62 (95% CI: 0.52-0.70), respectively (Fig 1).

Discussion

This study explored the association between JPE and neck flexor endurance in participants with or without neck pain. The findings have been addressed in subsections of flexor endurance, joint repositioning error, and the correlation between the measured variables.

Neck Flexor Endurance Capacity

Previous studies revealed inconsistent findings after comparison of flexor endurance capacity between participants with and those without neck pain. Some studies have reported neck pain patients with lower scores of flexion endurance.[19,27] In contrast, some others,[32,33] including ours, found no difference in flexor endurance capacity between CNP patients and asymptomatic participants. Some believe that because the pain intensity and neck

Table 5. *Correlational Analysis of Constant (B) Errors With Visual Analogue Scale, Neck Disability Index, and Flexor Endurance in the 2 Groups*

		Flexion		Extension		Right Rotation		Left Rotation	
		Y	*R*	*Y*	*R*	*X*	*R*	*X*	*R*
Chronic neck pain									
Visual Analogue Scale	*r*	0.21	0.21	–0.15	–0.17	0.07	0.03	0.14	0.16
	P	.13	.13	.28	.21	.60	.81	.29	.24
Neck Disability Index	ρ	0.12	0.15	0.10	0.09	0.27	0.28	0.24	0.20
	P	.39	.28	.46	.50	.06	.05	.08	.15
Flexor endurance	ρ	0.03	–0.02	0.17	0.20	–0.11	–0.11	–0.20	–0.21
	P	.77	.86	.17	.12	.40	.36	.12	.09
Asymptomatic									
Flexor endurance	*r*	–0.05	–0.02	0.15	0.16	0.05	0.06	0.14	0.11
	P	.67	.85	.24	.23	.66	.65	.29	.40

r indicates Pearson's correlation coefficient for normally distributed data. ρ indicates correlation coefficients for Spearman's rank-order (for non-normally distributed data) correlation tests.

Table 6. *Cross-Correlation Analysis Between Visual Analogue Scale, Neck Disability Index, and Flexor Endurance in the Chronic Neck Patient Group*

	Visual Analogue Scale	Neck Disability Index	Flexor Endurance
Visual Analogue Scale			
ρ	1.00	0.53 [a]	–0.11
P		0	.41
Neck Disability Index			
ρ	0.53 [a]	1.00	–0.21
P	0		.14

ρ indicates correlation coefficients for Spearman's rank-order (for non-normally distributed data) correlation tests.
[a] Statistically significant difference.

pain-related functional disabilities are associated with flexion endurance, the 2 items should be incorporated into the description of the cervical endurance.[33] Nevertheless, comparison of the scores of these 2 items in studies reporting different flexion endurance and in those claiming no difference in endurance between neck pain and asymptomatic participants does not support the hypothesis. It should be noted that these findings are all based on the clinical cervical endurance test for the flexor group of muscles. The validity of this test in defining the true flexor endurance capacity of the cervical spine may be in question. There is no opportunity to discriminate the deep and superficial flexor muscles of the neck with this test. By comparing the results of the clinical flexor endurance test against electromyographic indices, Jull et al reported no acceptable validity for this clinical test,[34] although it has been proposed that there is a differential involvement in the superficial and deep cervical muscles in the presence of CNP.[35] This may highlight the necessity for application of clinical tests capable of differentiating the deep and superficial groups of cervical flexor muscles while assessing the CNP patients and may have applications in the prescription of exercises to address endurance in these patients.

JPR Accuracy

The JPE can be evaluated from 2 aspects: pattern of repositioning error (over/undershoot) and error magnitude.

Pattern of Repositioning Error. Analysis of the CE scores revealed a significantly-different-from-zero overshoot error in the flexion direction in the CNP group, whereas the CE scores of the asymptomatic group did not statistically differ from the zero value in any of the directions. This finding is in agreement with that of Rix and Bagust,[29] revealing the flexion repositioning overshooting pattern in CNP patients and no significant tendency to over-/undershoot in the control group. Hallgren and Andary,[36] however (by descriptive evaluation), reported that most (>80%) asymptomatic participants undershot while repositioning the head in the sagittal plane. The undershooting pattern error in the antigravity direction has been attributed to an energy expenditure minimization strategy of the CNS by some authors.[37] This energy consumed for bringing the head from the flexed position into neutral does not seem to be a concern in the context of a few degrees of movement. On the other hand, the undershooting pattern observed during the extension reproduction test cannot be explained by this mechanism. Some others have also explained this pattern

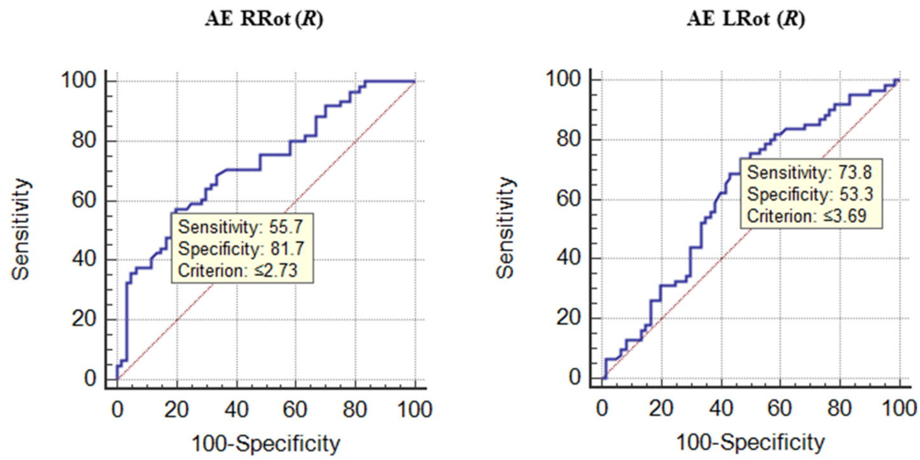

Fig 1. *Receiver operating characteristic curve analysis of the absolute joint position reproduction error of the right (left panel) and left (right panel) rotations, R.*

by the increased variability in the behavior of the motor control system in the presence of neck pain,[38] whereas all the evidence for such an explanation has been the concurrent increased variability and undershooting pattern, which lacks any physiological rationale and does not permit us to conclude a cause-and-effect relationship. Before coming to a physiological explanation of the error pattern seen in our CNP patients, we find it necessary to reconsider the inherent limitations of the CE variable to describe proprioceptive accuracy. To describe the error pattern, CE takes the direction of error vector into consideration, and while averaging the multiple trials of repositioning, there is the chance that the error magnitudes are partly offset by those of the opposite direction. This makes the CE variable inappropriate to describe error magnitude and maybe the only correct usage might be error pattern description. It should also be noted that in most studies, an under-/overshoot pattern has been diagnosed by any deviation of the CE from the zero value regardless of the magnitude of this deviation.[29,36,39] The question is how much deviation (CE magnitude) should be considered an error regardless of its direction. To address this issue, we and a few others[39] have applied a statistical test to differentiate the CE values indicating an error and those smaller than that to be considered any error. Additionally, a more detailed investigation of our data revealed a considerable amount of variability in the error pattern behavior of the participants during the 3 repetitions of the test. More than half of the participants in both groups revealed inconsistent repositioning error patterns. Thus, a new question arises: Is it useful to try to label different groups of participants as demonstrating undershoot/overshoot error pattern even though individualized investigations reveal considerable inconsistency in this behavior? We suggest postponing the discussion on the repositioning error patterns of CNP patients and its relevance to neck pain rehabilitation until further investigations unmask the mechanisms underlying the consistency of the behavior in subgroups of neck pain patients.

Error Magnitude. The AE measures the magnitude of the repositioning error regardless of its direction. Previous studies have reported no difference in AE[29,40] or higher AE[6,41] in patients with neck pain compared with asymptomatic participants. Contrary to what was expected, AE in the CNP group was found to be smaller than that of the asymptomatic group in all directions although the difference reached statistical significance only in the horizontal plane, although the groups were statistically different in the other direction (sagittal plane) based on CE analysis. The differential difference of the 2 aspects of the repositioning error is explained by considerable within-subject and within-group variability of the repositioning behavior. Inconsistent reports on the difference in AE magnitude between neck pain patients and asymptomatic participants and especially the finding that proprioceptive functioning of the patients is more accurate (in studies such as the current 1 with adequate sample size), which is not easy to accept, may make it difficult to accept AE as a valid tool for the assessment of proprioception. The relatively small areas under the curve obtained in the ROC curve analysis of AE, adding only poor to fair discriminating strength to the test, also confirm the aforementioned possibility.

Correlation Among JPE, NDI, and Flexion Endurance

No correlation was found between any of the JPE components and flexion endurance in either group. Deep, local slow-twitch muscles are believed to be responsible for the posture maintenance task manifested as the endurance score. Because the same group of muscles have been proposed to be rich in muscle spindles providing proprioceptive afferent to the CNS, we thought the 2 functions should be correlated, but the hypothesis was rejected. Neither of the 2 variables was found to meaningfully discriminate the 2 groups, so lack of correlation between them may not seem so surprising. The AE in the horizontal direction was found to be negatively correlated with NDI. This finding is also explained by the smaller AE magnitudes in the CNP group. This relationship might indicate that not only did the CNP patients have smaller AEs, but those with higher disability levels had a smaller error range on the repositioning task. Although it is not easy to explain this strange characteristic of the AE behavior of the CNP patients with respect to their repositioning performance at this stage, it might further elucidate that the smaller AEs in our patients were not an accidental finding. Further studies are needed to clarify the relevance of the AE parameter to the proprioceptive acuity specifically and to CNP in general.

Limitations

Endurance was scored based on the inability of the participants to hold the desired position, regardless of what made them lose this position. Specifically, for the CNP group, pain might play a major role in the process, underscoring the tension production capability of the cervical muscles. Absence of a relationship between proprioceptive function in terms of AE and CE variables and endurance scored by the clinical flexion endurance test warrants further investigation into the validity and relevance of these commonly used assessment tools in evaluation of the cervical spine.

Conclusion

Our findings indicate that the clinical cervical flexor endurance test, ignoring the relative contribution of the deep and superficial groups of muscles, may not efficiently characterize CNP patients. This emphasizes the necessity for the differential evaluation and possibly rehabilitation of the endurance capacity of the 2 groups of muscles in CNP patients. The results also warrant further precautions while interpreting the 2 parameters commonly used to evaluate the proprioceptive functioning of the cervical spine.

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Contributorship Information

Concept development (provided idea for the research): A.H.K., A.M.A., M.R.N.
Design (planned the methods to generate the results): A.H.K., L.G.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): A.H.K., A.M.A.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): L.G., A.A.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): A.H.K., A.M.A., L.G.
Literature search (performed the literature search): L.G.
Writing (responsible for writing a substantive part of the manuscript): A.H.K., L.G.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): A.H.K., A.M.A.

Practical Applications

- The clinical cervical flexion endurance test may not sufficiently characterize CNP.
- Joint repositioning performance of the cervical spine in terms of AE and CE does not seem relevant to CNP.
- Although proposed to be provided mainly by slow-twitch muscles, proprioceptive functioning of the cervical spine was not found to be correlated with cervical endurance.

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