JOURNAL REHABILITÁCIA
--
LCRH
ISSN 0375 – 0922 www.journal.rehabilitacia.sk

(SK) Asymetrický vzorec aktivácie svalov u pacientov s cervikálnou dystóniou počas pohybu cervikálnej flexie – pilotná štúdia.

(EN) Asymmetric muscle activation pattern found in patients with cervical dystonia during cervical flexion movement – a pilot study

[1*] Hirofumi SAGESHIMA, [1] Dagmar PAVLŮ, [1] Dominika DVOŘÁČKOVÁ, [1] Martin MUSÁLEK.

[1]Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic

**Corresponding author: sageshima.hirofumi@ftvs.cuni.cz*

SUMMARY/ABSTRACT

Starting point: Cervical dystonia is a common form of focal dystonia, resulting in neck pain and the development of asymmetric neck and head postures. These abnormal postures contribute to muscular impairment, muscle imbalances, and, as a result, alteration in movement patterns. This study aimed to compare the asymmetry of cervical muscle activation pattern during cervical flexion movements between individuals with cervical dystonia and healthy young subjects.
Methods: Eight individuals with cervical dystonia and eight healthy participants participated in this study. We recorded muscle activation from five pairs of cervical muscles (sternocleidomastoid, scalene, trapezius, suprahyoid, and infrahyoid) using surface electromyography. Normalized cross-correlation was used to analyze the symmetry of bilateral muscle activation.
Results: The results showed significant differences in muscle activation symmetry between the cervical dystonia group and healthy subjects. Notably, patients with cervical dystonia exhibited less symmetric activation in the trapezius and sternocleidomastoid muscles compared to healthy controls ($p < 0.01$ and $p < 0.05$, respectively). Additionally, the trapezius muscle on the dystonic side lacked coordination with other cervical muscles, unlike in healthy individuals who displayed better coordination.
Conclusions: These findings underline the challenges faced by individuals with cervical dystonia in achieving symmetric activation and coordination of cervical muscles. Evaluating cervical muscle activation symmetry may be a valuable approach for assessing motor impairments in these patients.

KEYWORDS

Cervical dystonia (spasmodic torticollis), Asymmetric movement pattern, Torticollis, Electromyography.

DOI: 10.61983/lcrh.v62i2.103

1 INTRODUCTION

Cervical dystonia is one of the most prevalent forms of focal dystonia. It is characterized by sustained, involuntary contractions of the neck muscles, usually resulting in abnormal neck and head postures [1,2]. The primary motor symptom of cervical dystonia commonly includes abnormal head and neck postures, persistent of cocontraction of agonist and antagonist muscles, and the occurrence of head tremor. Patients with cervical dystonia also demonstrate impairments in postural control, including changes in vestibular function and body orientation perception, and studies have revealed that asymmetries in the vestibulo-ocular reflex, vestibular hyperreactivity, and difficulties in recognizing postural and visual vertical [1,3,4]. Additionally, pain around neck and shoulder represents a prevalent and distinct characteristic of cervical dystonia, affecting more than 80% of patients [5–7].

Postures of cervical dystonia patients have often been classified in the four basic forms: torticollis, laterocollis, retrocollis, and anterocollis, based on the deviations in transverse, coronal and sagittal planes [8]. The Col-Cap concept differentiates between caput and collis types of abnormal head and neck movements. For example, in torticaput form, the head moves in relation to the neck, while in laterocaput, a lateral flexion induces a malalignment only of the head, preserving cervical spine posture [9]. A study revealed that the most frequent form was torticaput, nearly half of patients, and the second most frequent form was laterocaput, over 16% [10]. These findings emphasize that cervical dystonia patients often exhibit asymmetric neck and head positions, wherein the head may rotate to one side with flexion, extension, or lateral bending.

Abnormal posture and pain around the neck and shoulders significantly impact motor functions, including impairments in voluntary movement, in patients with cervical dystonia [5,11]. Compared to asymptomatic individuals, patients with cervical dystonia show reduced amplitude and velocity during cervical flexion, extension, lateral flexion, and axial rotation movements [12], Additionally, they demonstrate reduced smoothness, particularly during axial rotation of the head, especially toward the nondystonic side [13]. Another study further revealed that isometric maximum strength during neck rotation is less symmetrical between sides in cervical dystonia patients compared to healthy [14]. Concerning cocontraction, cervical dystonia patients often experience delayed muscle relaxation, resulting in prolonged coactivation of agonist and antagonist muscles. This contributes to a significant slowness in voluntary movements [15]. Moreover, a study examined the activation patterns of dystonic muscles and found that individuals with cervical dystonia exhibit increased muscle activity during both resting tasks and submaximal contractions [16]. These findings indicate the difficulty in deactivating dystonic muscles, regardless of the direction of muscle activity, highlighting the complex nature of motor dysfunction in cervical dystonia.

Although several impairments of motor functions experienced by individuals with cervical dystonia were revealed in previous studies, there have been a limited number of studies specifically focusing on symmetricity and coordination in cervical muscle activation across cervical dystonia patients.

2 GROUP AND METHODS

2.1 PARTICIPANTS

Eight patients diagnosed with cervical dystonia, confirmed by neurologists, voluntarily participated in this study, recruited by a neurologist in the Faculty of Physical Education and Sport, Charles University. Among them were five females and three males, with a mean age of 50.25 years (± SD: 12.54). The characteristics of the patients shows in Table 1. The exclusion criteria encompassed antecollis or retrocollis patients, segmental, multifocal, secondary or hereditary forms of dystonia, as well as any previous episodes of spinal disorders. Six out of eight patients diagnosed with cervical dystonia were regularly treated with a botulinum toxin injection and at least three months after the last botulinum toxin injection, and the rest of the cervical dystonia patients were drug naive. On the other hand, the control group, comprising eight healthy university students, voluntarily enrolled in the study. This group consisted of five females and three males, with a mean age of 22.13 years (± SD: 2.48). Inclusion in the control group was the absence of acute or chronic neck pain, no restriction in cervical spine range of motion, and no history of spinal disorders. Approval for this study was obtained from the Charles University FTVS Ethics Committee (EK 079/2020 and EK 092/2021), and each participant provided written informed consent after a comprehensive explanation of the study's objectives and protocol.

Table 1. Characteristics of patients with cervical dystonia.

No.	Age	Sex	Duration (years)	TWSTRS				Tremor	Head yaw
				Severity	Disability	Pain	Total		
1	27	M	4	16	7	0	23	1	10° (R)
2	64	F	12	20	10	9	39	1	20° (L)
3	41	M	3	20	19	7	46	0	15° (L)
4	61	F	3	17	14	14.5	45.5	0	5° (R)
5	49	F	3	10	18	10.5	38.5	0	5° (R)
6	48	F	11	11	13	12	36	0	5° (L)
7	49	F	10	19	13	13.5	45.5	1	40° (R)
8	63	M	3	18	24	16.5	58.5	1	10° (R)

Note: No.: patient number. Sex: F = female, M = male. Tremor: 0 = no visible tremor, 1 = visible tremor during the experiment. Head yaw: R = right, L = left.

2.2 PROCEDURES

Before initiating the measurements, patients in the cervical dystonia group completed the Toronto Western Spasmodic Torticollis Rating Scale (TWSTRS), a widely used questionnaire for assessing the status of patients with cervical dystonia [1]. The head rotation angles were then measured manually using a goniometer by two experienced physiotherapists with the intraclass correlation coefficient (ICC2,1), showing an ICC of 0.93 (95% CI: 0.71-0.98), indicating higher reliability [17].

Subsequently, all participants performed a series of eight consecutive physiological cervical flexion-extension movements, transitioning from a neutral position to maximum cervical flexion, while in a crook lying position on the thoracic spine. Recognizing that EMG signals can be influenced by movement velocity, participants were instructed to complete the flexion-extension cycle within eight seconds (four seconds from neutral to maximum flexion and four seconds returning) with the aid of a metronome set at 60 beats per minute [18,19]. Data collection was conducted by trained physiotherapists under the supervision of a medical doctor specializing in neurosciences.

Surface EMG activity was recorded during the cervical flexion-extension task from the following bilateral muscle groups: suprahyoid (digastric, mylohyoid, and geniohyoid muscles); infrahyoid (omohyoid, sternohyoid, sternothyroid, and thyrohyoid muscles); sternocleidomastoid; scalene; and upper parts of the trapezius muscles. Ag/AgCl surface bipolar electrodes (Noraxon U.S.A. Inc., Scottsdale, AZ) measuring 40 mm x 22 mm with an interelectrode distance of 20 mm were used. The skin was prepared by shaving and cleaning with alcohol before attaching the electrodes at recommended sites.

For the suprahyoid and infrahyoid muscle groups, electrodes were placed midway between the inferior tip of the mandible and the thyroid cartilage [20], and midway between the superior attachment on the body of the hyoid bone and the inferior attachment on the manubrium and clavicle to minimize cross-talk from the sternocleidomastoid muscle [21]. Electrodes for the sternocleidomastoid muscle were placed at one-third of the distance from the sternal notch to the mastoid process, while for the scalene muscles, they were placed along the lateral border of the clavicular portion of the sternocleidomastoid muscle [22]. EMG signals were recorded using a Noraxon TeleMyo 2400 transmitter (Noraxon U.S.A. Inc., Scottsdale, AZ).

2.3 DATA PROCESSING

All of the collected data (raw EMG signals) were processed by MR 3.8.30, a software program for biomechanical analysis (Noraxon U.S.A. Inc., AZ, USA) following the Noraxon manuals [23]. Each cycle of cervical flexion-extension movement was determined manually according to the footage shot during measurements. Movement from the neutral position to maximum flexion was defined as the flexion phase while maximum flexion to the neutral position was defined as the extension phase. The EMG processing was followed by the steps below. First, the bandpass filter was applied at 10-500 Hz [23], and then the contamination of electrocardiography (ECG), which has been found in EMG data from neck muscles [24], was reduced using a cancelation algorithm equipped with Noraxon software. Each signal was rectified and enveloped with a root-mean-square window approach with 100 ms to produce the linear envelope for each measured muscle. Then, each channel was normalized using the mean value recorded in the same channel during the experiment with the participant. After data processing, to allow point-to-point comparison, time normalization was performed to produce ensemble averaging of the EMG signals from six movement cycles. Thus, each phase contains 100 data points; one cycle of cervical flexion test has 200 data points in total.

2.4 DATA ANALYSIS

Normalized cross-correlation was used to compare processed EMG envelopes of cervical muscles in each participant, measuring the similarity in shape of two envelopes. The cross-correlation coefficient R_{xy} is calculated as follows [25]:

$$R_{xy}(\tau) = \frac{\frac{1}{N} \quad \sum_{i=1}^{N}(x_i - \bar{x})\left(y_{i+\tau * f_s} - \bar{y}\right)}{\frac{1}{N}\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2 \ \sum_{i=1}^{N}(y_i - \bar{y})^2}}$$

Here, R_{xy} represents the normalized cross-correlation of two signals, N is the number of data points, τ is the discrete temporal phase shift, and f_s is the frequency at which the original signals are samples [26]. A coefficient of 1 indicates that two signals are in phase, -1 indicates they are out of phase, and approximately 0 indicates dissimilarity in shape and timing [26,27]. Calculations were focused at a phase shift $\tau = 0$ to assess the similarity of muscle activation patterns between bilateral cervical muscles. Figure 1 illustrates sample results of the cross-correlation coefficient from representative individuals in both the cervical dystonia and control groups, highlighting bilateral muscle activation patterns during cervical flexion.

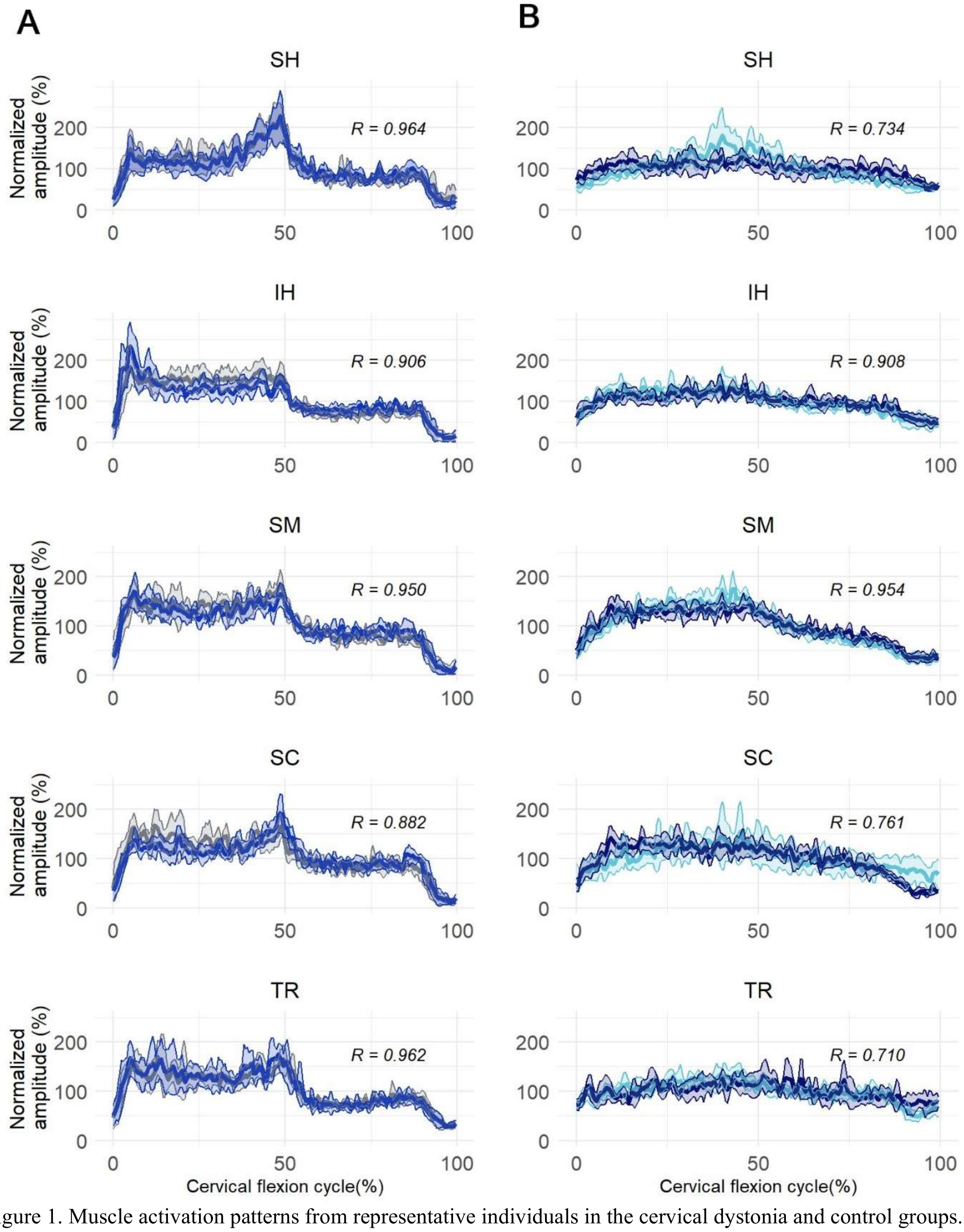

Figure 1. Muscle activation patterns from representative individuals in the cervical dystonia and control groups.
Line plots show the comparison of muscle activation patterns during cervical flexion movement from five bilateral cervical muscles. The cross-correlation coefficient (R) showed cross-correlation coefficients. A: control group, gray: right side, blue: left

side; B: cervical dystonia group, light blue: nondystonic side, navy: nondystonic side. SH: suprahyoid, IH: infrahyoid, SM: sternocleidomastoid, SC: scalene, TR: trapezius muscles.

2.5 STATISTICAL ANALYSIS

All statistical analyses were performed using RStudio (version 2023.06.0 421, R Foundation for Statistical Computing, Vienna, Austria). Due to the non-normal distribution of variables, nonparametric tests were applied. Specifically, the Mann–Whitney U test was used to compare the cervical dystonia and control groups, while Kendall's Tau was applied to evaluate associations between cross-correlation coefficients, age, and disease severity in participants with cervical dystonia. A 95% confidence interval was applied, with $p < 0.05$ indicating statistical significance.

3 STARTING POINT, OBJECTIVE, TASKS

The present study aimed to address this research question by comparing the symmetry of muscle activation in the bilateral neck muscles with a cervical flexion movement requiring bilateral muscle activation between patients with cervical dystonia and healthy young adults. We hypothesized that patients with cervical dystonia would exhibit less symmetric muscle activation compared to controls, particularly in the sternocleidomastoid, scalene, and trapezius muscles, as opposed to the hyoid muscle groups. Additionally, we anticipated that patients with cervical dystonia would show reduced muscle coordination on the dystonic side.

4 RESULTS

Figure 2 shows the mean cross-correlation coefficients for muscle activation in the bilateral cervical muscles during cervical flexion movement in both the cervical dystonia group and the control group. Significantly higher cross-correlation coefficients were found in the sternocleidomastoid ($p < 0.05$) and trapezius muscles ($p < 0.01$), indicating that these two muscles in individuals with the cervical dystonia were less symmetry of bilateral muscle activation compared to the healthy controls (Figure 2).

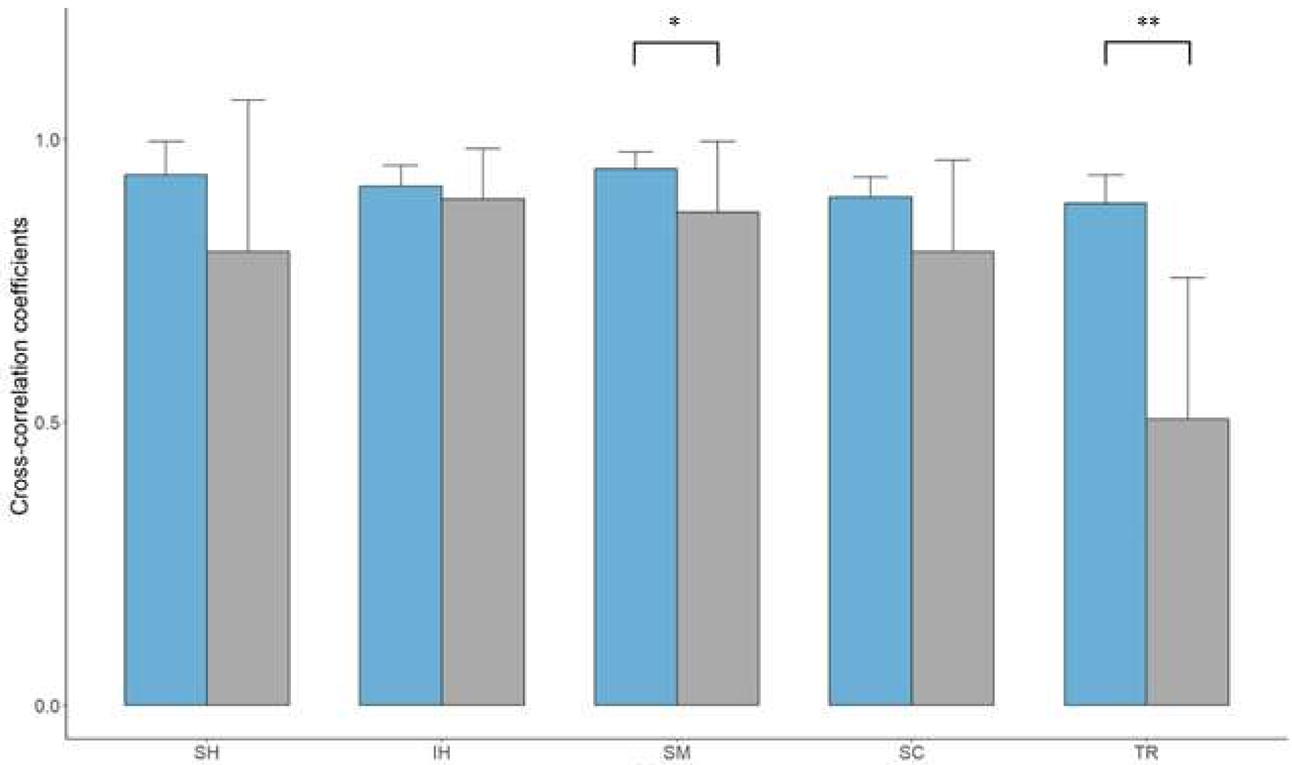

Figure 2. Mean cross-correlation coefficients in the bilateral cervical muscles.
Blue: control group; gray: patients with cervical dystonia. SH: suprahyoid, IH: infrahyoid, SM: sternocleidomastoid, SC: scalene, TR: trapezius muscles. *: $p < 0.05$, **: $p < 0.01$

Across the five bilateral muscle groups, significant differences were observed in both the cervical dystonia patients and healthy control groups ($p < 0.001$). Specifically, the bilateral trapezius and suprahyoid muscles exhibited lower mean cross-correlation coefficients compared to the bilateral sternocleidomastoid muscles in both groups ($p < 0.05$), suggesting greater variability in muscle activation regardless of the presence of cervical dystonia in these tow muscles. Additionally, in the cervical dystonia group, the scalene muscles showed lower mean cross-correlation coefficients than the sternocleidomastoid muscles ($p < 0.05$), whereas this difference was not observed in the control group (Figure 3).

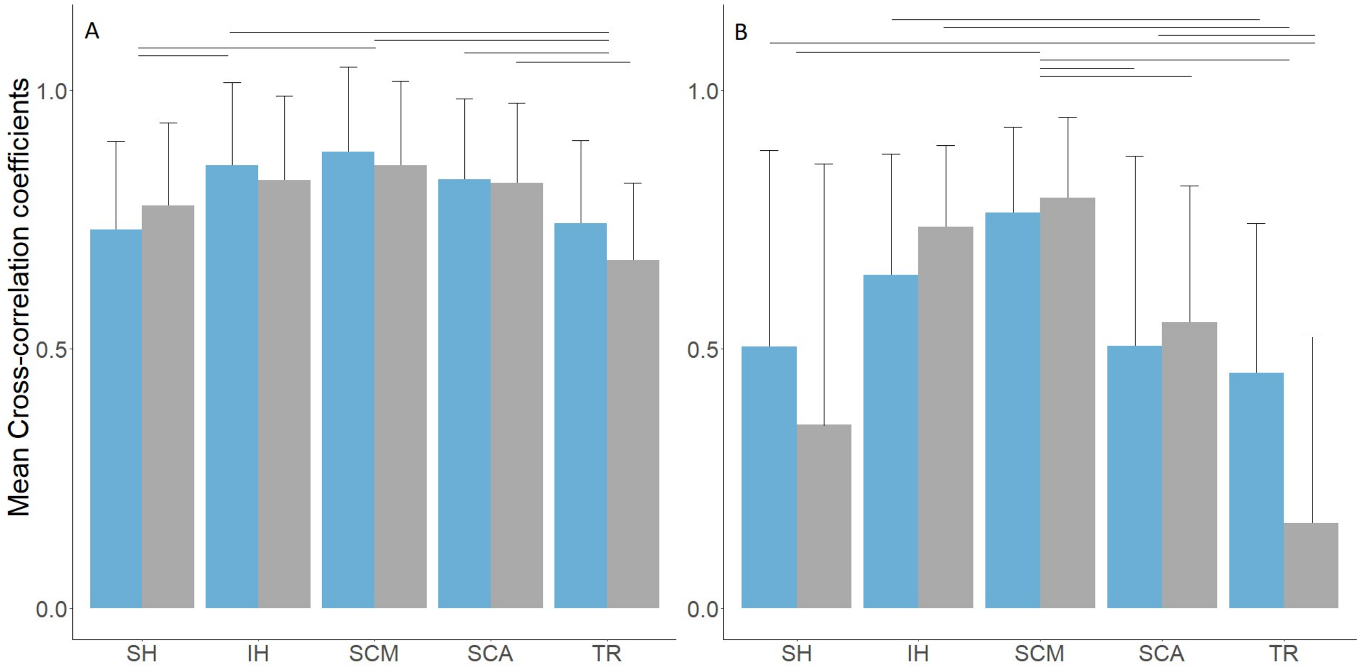

Figure 3. Interindividual variability in the muscle activation pattern for five bilateral muscles during cervical flexion movement. A: control group (blue: right, gray: left), B: cervical dystonia group (blue: nondystonic side, gray: dystonic side). SH: suprahyoid, IH: infrahyoid, SCM: sternocleidomastoid, SCA: scalene, TR: trapezius muscles. R and L in the control group indicate the right and left sides, respectively. Horizontal lines denote significant differences ($p < 0.05$).

Additionally, heatmaps show the mean cross-correlation coefficients for all possible combinations of recorded muscles for each group in Figure 4. Significant differences between the two groups are detailed in Table 2. In the cervical dystonia group, eight out of the nine muscle pairings involving the trapezius on the dystonic side exhibited significantly lower cross-correlation coefficients compared to the control group, suggesting that less muscle coordination between trapezius in dystonic side and other muscles was found in the patients compared to the healthy controls during the neck flexion movement. Similarly, smaller cross-correlation coefficients were observed in bilateral sternocleidomastoid and between the scalene on the dystonic side and the sternocleidomastoid on the nondystonic side in the comparison between the two groups.

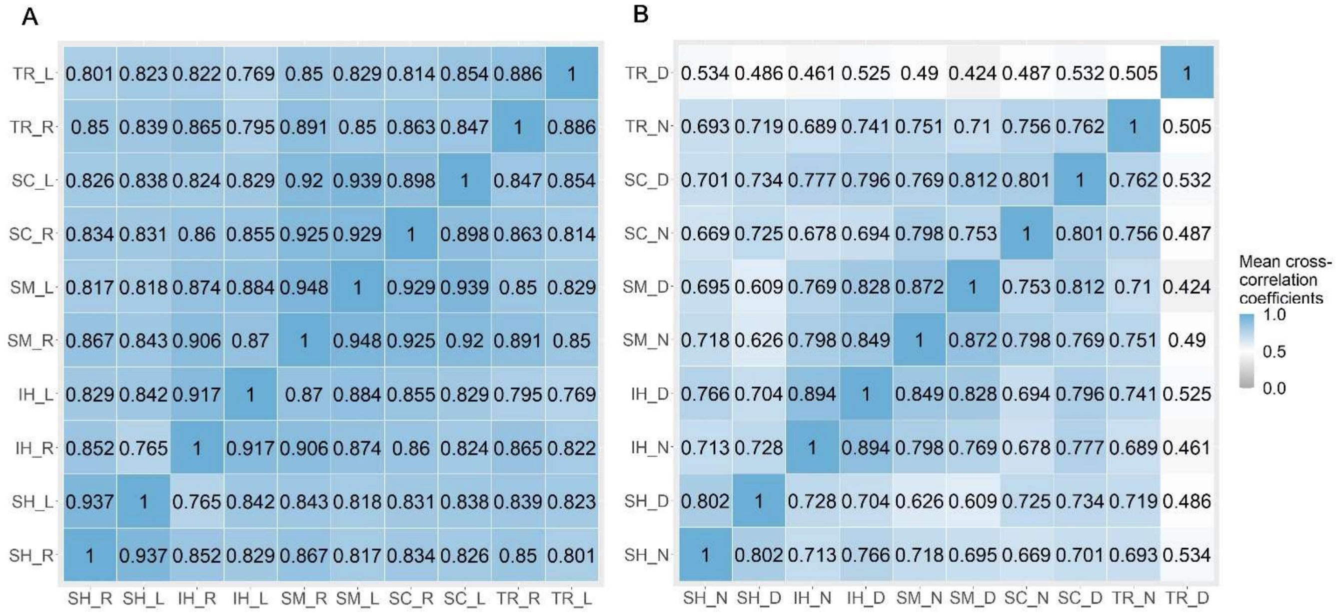

Figure 4. Mean cross-correlation coefficients of all pairs of recorded muscles in both groups.
A: control group, B: cervical dystonia group. SH: suprahyoid, IH: infrahyoid, SM: sternocleidomastoid, SC: scalene, TR: trapezius muscles. R and L in the control group indicate the right and left sides, respectively. N and D in the cervical dystonia group indicate the nondystonic and dystonic sides, respectively.

Table 2. Group differences in the cross-correlation coefficients of muscle pairs.

	Control		Dystonia		*p*-value
	Mean	SD	Mean	SD	
SM_L-SM_R	0.948	0.029	0.872	0.125	< .05
SC_L-SM_R	0.920	0.030	0.769	0.182	< .05
TR_L-SH_R	0.801	0.097	0.534	0.249	< .05
TR_L-SH_L	0.823	0.059	0.486	0.282	< .001
TR_L-IH_R	0.822	0.078	0.461	0.250	< .001
TR_L-SM_R	0.850	0.100	0.490	0.389	< .001
TR_L-SM_L	0.829	0.094	0.424	0.382	< .001
TR_L-SC_R	0.814	0.151	0.487	0.304	< .001
TR_L-SC_L	0.854	0.064	0.532	0.203	< .001
TR_L-TR_R	0.886	0.050	0.505	0.250	< .001

Note: This table only shows pairs that had significant differences between two groups. R and L in the control group indicate the right and left sides, respectively. R and L in the cervical dystonia group indicate the nondystonic and dystonic sides, respectively. SH: suprahyoid, IH: infrahyoid, SM: sternocleidomastoid, SC: scalene, TR: trapezius muscles. SD: standard deviation.

In the patient group, no significant correlations were observed between age and the cross-correlation coefficients across muscles (Kendall's Tau (τ) = 0.07–0.35, $p > 0.05$). However, a significant negative correlation was found between the severity of cervical dystonia, as measured by TWSTRS scores, and the cross-correlation coefficients in the infrahyoid muscle ($\tau = -0.71$, $p < 0.05$). This finding suggests that patients with higher TWSTRS scores exhibit greater asymmetry in infrahyoid muscle activation. In contrast, no significant correlations were observed between disease severity and asymmetric muscle activation in the remaining muscles ($p > 0.05$ for all comparisons).

5 DISCUSSION

The aim of this study was to compare the symmetry of cervical muscle activation during cervical flexion movement between patients with cervical dystonia and the control group. From the outcomes of the present study, the activation of the sternocleidomastoid and trapezius muscles in the cervical dystonia group was significantly less symmetric than that in the control group. Furthermore, the trapezius muscle on the dystonic side in the patients with cervical dystonia had significantly lower mean cross-correlation coefficients with other cervical muscles, while all paired cervical muscles in the control group showed relatively higher mean cross-correlation coefficients.

The sternocleidomastoid muscle, which showed asymmetric activation during cervical flexion movement, is one of the most commonly involved muscles in cervical dystonia along with splenius capitis muscles [10,28]. Persistent unilateral involuntary contraction of this muscle causes the torticollis posture, which tends to ipsilaterally incline the head toward the shoulder and contralaterally rotate the face and chin. With abnormal postures being present in chronic conditions, this could lead to adaptations in muscle length, strength and stiffness, and these adaptations could cause muscle impairments and muscle imbalance [29], kinesthesia deficits [30], and proprioceptive abnormalities in both dystonic and nondystonic segments [31]. Furthermore, treatment with botulinum toxin injection could be a cause of asymmetric muscle strength [14,32,33]. Isometric neck muscle strength temporally weakens after treatment with botulinum toxin injection, although it improves disabilities from cervical dystonia [33]. In addition, a study reported that patients with cervical dystonia exhibit a significant difference in cervical muscle strength between dystonic and non-dystonic sides in cervical rotation [14], which is a movement of the trapezius and splenius muscles on the ipsilateral side, and the sternocleidomastoid muscle on the contralateral side has an isometric moment-generating capacity at a neutral position [34].

Neck pain is also a common complaint from the patients, and seven out of eight patients in this study reported pain in TWSTRS (average 10.4 ± 5.18). Pain itself is also a factor that aggravates muscle imbalance, and it consequently leads to the alteration of movement patterns through compensatory movements and the protective adaptation of pain [29,35]. The compensatory movement patterns led by pain vary from person to person [36], as patients with cervical dystonia showed lower cross-correlation coefficients than the control group, especially in the upper trapezius and suprahyoid muscles. These muscles are not considered as primary power producers of cervical flexion. The upper trapezius muscle is a cervical extensor and an antagonist muscle of the cervical flexion movement, and although suprahyoid muscles are able to produce the flexion moment by contracting with infrahyoid muscles [37], the sternocleidomastoid and scalene muscles have greater moment-generating capacities [34]. Thus, muscles with more variability might represent individual compensatory mechanisms. In support of this thought, muscles with lower variability play a role as primary power producers, while other muscles with higher variability would have the role of fine-tuning systems [38]. Furthermore, patients in this study had different characteristics of age, severity of cervical dystonia and duration of the disease, so these factors may lead to more variations in movement patterns.

Muscles such as suprahyoid and infrahyoid muscles are considered as less affected by focal dystonia, and no participants experienced botulinum toxin injections as a treatment for these muscles in the present study. Nonetheless, the symmetry of muscle activation in these muscles in cervical dystonia patients was also lower than in the control group despite the absence of significant differences. Additionally, in the infrahyoid muscles, higher severity of cervical dystonia patients showed less symmetric muscle activation. Thus, the asymmetric manifestations of cervical dystonia are found in the vicinity of segments through the cross-correlation analysis due to a failure of surround inhibition. Hallet mentioned that when a specific movement is generated, unwanted movements are suppressed, leading to overflow movements in other segments, a phenomenon often shown in patients with focal dystonia [39].

The task all participants performed in this study, that is, cervical flexion movement in the supine position, is a movement to overcome the gravitational force and then the resistance from the dorsal soft tissues to reach a maximal range of motion in the movement [40]. Another previous study reported that the cervical flexor muscles along with supra- and infrahyoid muscles coordinately activate from the beginning of the movement with higher amplitude to overcome opposing external and internal forces against the cervical flexion movement [41]. In addition, as the gravitational force and resistance from the dorsal act as destabilizing factors of the joints, higher coactivation between agonist and antagonist muscles would increase the apparent stiffness of the joints to improve the stability [42]. From the findings in this study, pairs with the trapezius muscle on the dystonic side in the cervical dystonia group, however, showed less similarity of muscle activation patterns, as these pairs were significantly lower in cross-correlation coefficients than those in the control group. The trapezius muscle in the dystonic side persistently activated with a higher amplitude, even when other muscles and the trapezius muscle on the asymptomatic side showed lower activation. In the control group, on the other hand, higher mean cross-correlation coefficients were found in all possible pairs, although only 10 pairs showed significant differences between the two groups.

To the best of our knowledge, the comparison of cervical muscle activation patterns between dystonic and nondystonic sides has not been investigated in patients with cervical dystonia. It is still unknown how the symmetry and activation pattern of cervical muscles change after specific interventions, such as botulinum toxin injections, physiotherapy and transcranial magnetic stimulation. Wren suggested that cross-correlation is a useful tool for evaluating individual changes in patient muscle activation patterns [27]. Thus, in order to improve the utility and reliability of the evaluation with the symmetry of muscle activation patterns, it is necessary to have larger sample size and to conduct interventions in cervical dystonia patients.

The findings from this study suggest that asymmetric muscle activation and abnormal coactivation may contribute to postural abnormalities and compensatory movements in individuals with cervical dystonia. These findings emphasize the importance of individual rehabilitation approaches, considering disease severity, duration, and treatments such as botulinum toxin injections. Lower cross-correlation coefficients in muscle activation in cervical dystonia patients indicate that this analysis may be useful for monitoring treatment outcomes. Future research should explore the effects of interventions such as botulinum toxin injections, physiotherapy, and transcranial magnetic stimulation on cervical muscle activation patterns with a greater sample size.

5.1 LIMITATION

There were several limitations in this study. One is that significant differences existed between the cervical dystonia patients and the healthy control group in terms of age, weight, and body mass index. Even in the patient group, there were different backgrounds including age, disease duration and severity of disease. As aging is associated with a change in fiber types in the sternocleidomastoid muscle [43], a decline in the number of motor units and its functions [44], the age differences between the groups would be a confounding factor to show the significantly asymmetric movement in this study. However, we assumed that the age differences between the groups were not the primary factor influencing movement symmetry in this study, as no significant correlations were observed between the age and the symmetry of muscle activation across the evaluated neck muscles. Muscle activation patterns often change in response to various pathologies, including pain and abnormalities in the vestibular systems [45,46]. In addition, the task all participants performed was a one-axial movement in cervical spine, the abnormal movement patterns are often detected due to pathological changes, including neck muscles imbalance [29,47,48].

In addition, the sample size was relatively small in this study, which may have caused some of the variability within the data. However, this sample size was adequate to detect significant differences in symmetry of muscle activation during cervical flexion movement between the individuals with cervical dystonia and healthy controls. Therefore, with greater sample size, it is speculated that more significant differences could be observed between the two groups.

There was a technical limitation of measuring the muscle activation from splenius capitis, which is one of the most symptomatic muscles in cervical dystonia patients. As splenius capitis situated deep beneath the trapezius and other neck muscles, it is challenging to isolate and measure accurately the activation from this muscle [49,50]. Likewise, the conventional surface electrode we used in this study was unable to evaluate the activity from other deep layer muscles, including levator scapulae, semispinalis, longus colli and longus capitis, which can be primary and secondary causes abnormal head and neck postures [10]. Given that these muscles are involved in cervical dystonia, future research should consider advanced techniques such as fine-wire EMG to better evaluate their contribution to abnormal head and neck postures. In addition, cross-talk is also one of the limitations as is the case with all surface EMG studies. In the cervical region, muscles are a relatively compact and anatomically complex, especially where muscle activation from the hyoid muscles has been recorded. However, surface EMG has been used in studies to record muscle activation during cervical movements. In the present study, the locations of appropriately sized surface electrodes were carefully chosen according to voluntary muscle contraction to minimize potential cross-talk.

6 CONCLUSIONS

In the context of cervical dystonia, a condition often characterized by asymmetric postural configurations involving the head, neck, and shoulders, this study revealed notable disparities in muscle activation patterns during cervical flexion movements. Specifically, significant asymmetry in the activation of the sternocleidomastoid and trapezius muscles was observed among patients with cervical dystonia. Moreover, unlike the coordinated muscle activation typically observed in asymptomatic individuals, those with cervical dystonia displayed impaired coordination, which was particularly evident in the trapezius muscles on the affected side. These findings show the difficulties faced by individuals with cervical dystonia when performing activities requiring symmetrical muscle activation and coordinated movement within the cervical region. We suggest that evaluating the symmetry of cervical muscle activation for the cervical dystonia patients can be a useful approach for assessing motor impairments. It also provides a useful evaluation tool for monitoring changes in motor function and tracking treatment outcomes over time.

REFERENCES

1. Crowner, B. E. Cervical dystonia: Disease profile and clinical management. *Phys. Ther.* **87**, 1511–1526 (2007).
2. Dressler, D., Altenmüller, E., Giess, R., Krauss, J. K. & Adib Saberi, F. The epidemiology of dystonia: the Hannover epidemiology study. *J. Neurol.* **269**, 6483–6493 (2022).
3. Colebatch, J. G., Lazzaro, V. Di, Quartarone, A., Rothwell, J. C. & Gresty, M. Click-evoked vestibulocollic reflexes in torticollis. *Mov. Disord.* **10**, 455–459 (1995).
4. Dauer, W. T., Burke, R. E., Greene, P. & Fahn, S. Current concepts on the clinical features, aetiology and management of idiopathic cervical dystonia. *Brain* **121**, 547–560 (1998).
5. Chan, J., Brin, M. F. & Fahn, S. Idiopathic cervical dystonia: Clinical characteristics. *Mov. Disord.* **6**, 119–126 (1991).
6. Kutvonen, O., Dastidar, P. & Nurmikko, T. Pain in spasmodic torticollis. *Pain* **69**, 279–286 (1997).
7. Williams, L. *et al.* Epidemiological, clinical and genetic aspects of adult onset isolated focal dystonia in Ireland. *Eur. J. Neurol.* **24**, 73–81 (2017).
8. Jankovic, J., Leder, S., Warner, D. & Schwartz, K. Cervical dystonia: Clinical findings and associated movement disorders. *Neurology* **41**, 1088–1091 (1991).
9. Jost, W. H. & Tatu, L. Selection of Muscles for Botulinum Toxin Injections in Cervical Dystonia. *Mov. Disord. Clin. Pract.* **2**, 224–226 (2015).
10. Jost, W. H. *et al.* Frequency of different subtypes of cervical dystonia: a prospective multicenter study according to Col–Cap concept. *J. Neural Transm.* **127**, 45–50 (2020).
11. Molnárová, M. POSTURA- VÝZNAM, DIAGNOSTIKA A PORUCHY. *časopis REHABILITÁCIA* **46**, 195–205 (2009).
12. De Beyl, D. Z. & Salvia, P. Neck movement speed in cervical dystonia. *Mov. Disord.* **24**, 2267–2271 (2009).
13. Caronni, A. *et al.* Smoothness of movement in idiopathic cervical dystonia. *Sci. Rep.* **12**, 1–11 (2022).
14. Häkkinen, A. *et al.* Decreased neck muscle strength is highly associated with pain in cervical dystonia patients treated with botulinum toxin injections. *Arch. Phys. Med. Rehabil.* **85**, 1684–1688 (2004).
15. Buccolieri, A. *et al.* Muscle relaxation is impaired in dystonia: A reaction time study. *Mov. Disord.* **19**, 681–687 (2004).
16. De Bruijn, E. *et al.* Improved identification of dystonic cervical muscles via abnormal muscle activity during isometric contractions. *J. Neurol. Sci.* **354**, 10–16 (2015).
17. Koo, T. K. & Li, M. Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **15**, 155–163 (2016).
18. Siegmund, G. P., Blouin, J. S., Brault, J. R., Hedenstierna, S. & Inglis, J. T. Electromyography of superficial and deep neck muscles during isometric, voluntary, and reflex contractions. *J. Biomech. Eng.* **129**, 66–77 (2007).
19. Vikne, H., Bakke, E. S., Liestøl, K., Sandbæk, G. & Vøllestad, N. The smoothness of unconstrained head movements is velocity-dependent. *Hum. Mov. Sci.* **32**, 540–554 (2013).

20. Falla, D., Jull, G., O'Leary, S. & Dall'Alba, P. Further evaluation of an EMG technique for assessment of the deep cervical flexor muscles. *J. Electromyogr. Kinesiol.* **16**, 621–628 (2006).

21. O'Leary, S., Falla, D., Jull, G. & Vicenzino, B. Muscle specificity in tests of cervical flexor muscle performance. *J. Electromyogr. Kinesiol.* **17**, 35–40 (2007).

22. Falla, D., Dall'Alba, P., Rainoldi, A., Merletti, R. & Jull, G. Location of innervation zones of sternocleidomastoid and scalene muscles - A basis for clinical and research electromyography applications. *Clin. Neurophysiol.* **113**, 57–63 (2002).

23. Konrad, P. The ABC of EMG. *Noraxon* vol. 1 1–61 https://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf (2005).

24. Sommerich, C. M., Joines, S. M. B., Hermans, V. & Moon, S. D. Use of surface electromyography to estimate neck muscle activity. *J. Electromyogr. Kinesiol.* **10**, 377–398 (2000).

25. Nelson-Wong, E., Gregory, D. E., Winter, D. A. & Callaghan, J. P. Gluteus medius muscle activation patterns as a predictor of low back pain during standing. *Clin. Biomech.* **23**, 545–553 (2008).

26. Nelson-Wong, E. A., Howarth, S. A. M., Winter, D. A. & Jack, J. P. Application of autocorrelation and cross-correlation analyses in human movement and rehabilitation research. *J. Orthop. Sports Phys. Ther.* **39**, 287–295 (2009).

27. Wren, T. A. L., Patrick Do, K., Rethlefsen, S. A. & Healy, B. Cross-correlation as a method for comparing dynamic electromyography signals during gait. *J. Biomech.* **39**, 2714–2718 (2006).

28. Jankovic, J. *et al.* Primary results from the Cervical Dystonia Patient Registry for Observation of OnabotulinumtoxinA Efficacy (CD PROBE). *J. Neurol. Sci.* **349**, 84–93 (2015).

29. Page, P., Frank, C. C. & Lardner, R. *Assessment and Treatment of Muscle Imbalance*. (Human Kinetics, 2010). doi:10.5040/9781718211445.

30. Putzki, N. *et al.* Kinethesia is impaired in focal dystonia. *Mov. Disord.* **21**, 754–760 (2006).

31. Pelosin, E., Bove, M., Marinelli, L., Abbruzzese, G. & Ghilardi, M. F. Cervical dystonia affects aimed movements of nondystonic segments. *Mov. Disord.* **24**, 1955–1961 (2009).

32. Prodoehl, J. *et al.* Changes in the relationship between movement velocity and movement distance in primary focal hand dystonia. *J. Mot. Behav.* **40**, 301–314 (2008).

33. Mustalampi, S., Ylinen, J., Korniloff, K., Weir, A. & Häkkinen, A. Reduced Neck Muscle Strength and Altered Muscle Mechanical Properties in Cervical Dystonia Following Botulinum Neurotoxin Injections: A Prospective Study. *J. Mov. Disord.* **9**, 44–49 (2016).

34. Vasavada, A. N., Li, S. & Delp, S. L. Influence of muscle morphometry and moment arms on the moment-generating capacity of human neck muscles. *Spine (Phila. Pa. 1976).* **23**, 412–422 (1998).

35. Ziakova, E., Sladeckova, N., Istonova, M., Luliak, M. & Vrabel, D. Traditional Chinese Medicine in Distance Physiotherapy of non-specific Back Pain during the COVID-19 Pandemic. *Clin. Soc. Work Heal. Interv.* **13**, 64–75 (2022).

36. Gizzi, L., Muceli, S., Petzke, F. & Falla, D. Experimental muscle pain impairs the synergistic modular control of neck muscles. *PLoS One* **10**, (2015).

37. Kapandji, A. I. *The Physiology of the Joints. The vertebral column, pelvic girdle and head*. vol. III (Handspring Publishing Limited, 2019).

38. Hug, F., Drouet, J. M., Champoux, Y., Couturier, A. & Dorel, S. Interindividual variability of electromyographic patterns and pedal force profiles in trained cyclists. *Eur. J. Appl. Physiol.* **104**, 667–678 (2008).

39. Hallett, M. Pathophysiology of writer's cramp. *Hum. Mov. Sci.* **25**, 454–463 (2006).

40. Olson, M., Solomonow, M. & Li, L. Flexion-relaxation response to gravity. *J. Biomech.* **39**, 2545–2554 (2006).

41. Sageshima, H., Pavlů, D., Dvořáčková, D. & Pánek, D. Onset Timing of Hyoid Muscles Activation during Cervical Flexion Is Position-Dependent: An EMG Study. *Life* **12**, (2022).

42. Latash, M. L. Muscle coactivation: Definitions, mechanisms, and functions. *J. Neurophysiol.* **120**, 88–104 (2018).

43. Meznaric, M., Eržen, I., Karen, P. & Cvetko, E. Effect of ageing on the myosin heavy chain composition of the human sternocleidomastoid muscle. *Ann. Anat.* **216**, 95–99 (2018).

44. Hunter, S. K., Pereira, X. H. M. & Keenan, K. G. The aging neuromuscular system and motor performance. *J. Appl. Physiol.* **121**, 982–995 (2016).

45. Van Dieën, J. H., Selen, L. P. J. & Cholewicki, J. Trunk muscle activation in low-back pain patients, an analysis of the literature. *J. Electromyogr. Kinesiol.* **13**, 333–351 (2003).

46. Rinalduzzi, S. *et al.* Balance dysfunction in Parkinson's disease. *Biomed Res. Int.* **2015**, (2015).

47. Hullmanová, M. & Líška, D. VÝSKYT SVALOVÝCH DYSBALANCIÍ U DOSPIEVAJÚCICH HÁDZANÁROK. *časopis REHABILITÁCIA* **61**, 20–37 (2024).

48. Masaryk, V. MUSCULAR DISBALANCE OF THE NECK MUSCLES. *Clin. Soc. Work Heal. Interv.* **1**, 35–45 (2015).

49. McManus, L., De Vito, G. & Lowery, M. M. Analysis and Biophysics of Surface EMG for Physiotherapists and Kinesiologists: Toward a Common Language With Rehabilitation Engineers. *Front. Neurol.* **11**, 1–25 (2020).

50. Benhamou, M. A. M., Revel, M. & Vallee, C. Surface electrodes are not appropriate to record selective myoelectric activity of splenius capitis muscle in humans. *Exp. Brain Res.* **105**, 432–438 (1990).