EXPERIMENTAL APPROACH FOR MEASUREMENT OF ISOMETRIC STRENGTH AND ENDURANCE/FATIGUE OF THE HEAD AND NECK MUSCLES

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ABSTRACT
Introduction: Muscle imbalance within the cervical region represents a significant risk factor for the development of postural disorders and other somatic dysfunctions, with far-reaching consequences that can affect the position and function of interconnected segments throughout the postural chain. Even subtle discrepancies in the strength and endurance of postural muscles can have a profound impact over time. On the other hand, many body somatic dysfunctions and organ disorders can contribute to muscle imbalances in the cervical region through segmental reflex pathways, further complicating the interplay between musculoskeletal health and systemic conditions. The aim of the present study was to develop an experimental model and to create a prototype for the quantitative estimation of isometric strength, endurance, and fatigue of head and neck muscles. Methodology: The experimental process consisted of three phases: designing a prototype dynamometric device using biomechanical principles and sensor technology, developing a standardized measurement methodology, and conducting preliminary measurements with a group of students. Results: A specialized setup and procedure were developed to measure the isometric strength, endurance, and fatigue of the head and neck muscles. A pilot study with 12 students measured maximal isometric muscle strength (Fmax [N]) and found that the extension-to-flexion ratio was 1.6 for men (75.68 N flexion, 124.36 N extension) and 1.65 for women (33.17 N flexion, 54.76 N extension). The results showed that male participants had roughly twice the muscle strength of female participants in both movements. Measurements also indicated that, for the variables assessed, endurance and fatigue were higher in women compared to men. Conclusions: A novel experimental approach for assessing isometric neck muscle strength, endurance, and fatigue has been developed, accompanied by the construction of a specialized experimental bench for quantifying cervical muscle functionality. The device was successfully validated, and its potential applications include longitudinal monitoring of rehabilitation outcomes and the enhancement of athletic training programs. Nevertheless, further large-scale validation and methodological refinements are required to establish its reliability and clinical translation.

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INTRODUCTION

The cervical region represents one of the most critical musculoskeletal junctions in the human body (Devir et al., 2008). It functions as a highly intricate system housing essential neurological, vascular, and respiratory structures, as well as the cervical vertebrae and spinal cord (Zhang et al., 2011). Any injury, disease, or dysfunction in this area can disrupt these vital connections (American Osteopathic Association, 2010). Neck pain and dysfunction are highly prevalent, affecting up to 67% of individuals at some point in their lives, and neck disorders rank among the four most common work-related musculoskeletal conditions (Petit et al., 2014). Proper sagittal alignment of the head and neck, including the ability to maintain a horizontal gaze, is essential for everyday activities (Patwardhan et al., 2015). With the widespread use of smartphones and computers, the incidence of forward head posture (FHP) has steadily increased (Szczygieł et al., 2020). Beyond susceptibility to minor pain, the neck is also frequently injured in accidents and sports, particularly in contact sports (Leggett et al., 1991).

Cervical muscles and their relationship to neck disorders.

The cervical spine is the most mobile and least

stable segment of the human spine, and neck disorders (ND) may arise from dysfunction within any of its complex structural systems (Petit et al., 2014). The neck contains over 25 muscle pairs with multi-joint insertions and complex lines of action (Fice et al., 2018). These muscles are arranged in four layers (Schomacher & Falla, 2013) and display varying proportions of fast- and slow-twitch fibers. Cervical muscles are not only important for head movement and posture but also play a key role in preventing neck disorders and injuries (Devir & Prushansky, 2008). Deficits in muscle performance have been observed in individuals with cervical pathology (Ghamkhar & Kahlaee, 2019; Tudini, Myers, & Bohannon, 2019).

The deepest cervical and cranio-cervical muscles are particularly important for segmental support due to their relatively small moment arms, attachments to adjacent vertebrae, and high proportion (approximately 70%) of slow-twitch fibers (Schomacher & Falla, 2013). While superficial muscles primarily assist in voluntary movements, deep muscles support posture and cervical lordosis (Wang et al., 2025). Weakness of the deep cervical muscles can therefore contribute to abnormal head and cervical spine alignment, including FHP and cervical kyphosis. Unlike the lumbar and thoracic regions, the cervical multifidus originates directly from the zygapophyseal joint capsules, which may explain its role in neck pain and injury (Schomacher & Falla, 2013).

Altered activation of the deep cervical flexors is a feature of several neck pain disorders, including whiplash-associated pain, idiopathic neck pain, work-related neck pain, and headache (Falla et al., 2012). Tamai et al. (2019) reported a correlation between paraspinal muscle volume, cervical balance parameters, and disk degeneration using kMRI in a neutral, weight-bearing position. Increasing FHP has been associated with shortening of the cervical flexors and occipital extensors, and lengthening of the cervical extensors and occipital flexors, corresponding to C2–C7 flexion and C0–C2 extension (Patwardhan et al., 2018). Jull et al. (2002) further suggest that poor activation and endurance of deep postural muscles may contribute to headaches (Cibulka, 2006). Neck muscle fatigue is known to disrupt postural control mechanisms by producing abnormal sensory input to the central nervous system, resulting in a persistent sense of instability (Schieppati et al., 2003).

Individuals with chronic idiopathic neck pain often demonstrate increased volume of superficial neck flexors (Snodgrass et al., 2019), while showing impaired activity of the deep flexors, compensated by increased activation of the sternocleidomastoid (SCM) and anterior scalenes (AS) (Blomgren et al., 2018; Falla et al., 2004).

Cervical muscles in sport and rehabilitation.

Reduced cervical muscle size and girth, combined with deficits in strength, endurance, and postural balance, increase the risk of sports-related injuries. Athletes should only return to play once they are asymptomatic and have regained adequate range of motion (ROM), strength, and functional capacity (Todd, 2024). Achieving and maintaining balanced cervical strength is also considered a key preventive strategy to reduce head acceleration and mitigate the risks associated with repetitive heading in soccer (Dezman et al., 2013).

Imaging and electromyography provide valuable diagnostic insights, but they cannot directly assess muscle strength, endurance, or fatigue—parameters essential for evaluating muscle function. Cervical strength can be assessed using isometric or dynamic methods (Devir & Prushansky, 2008). Among these, isometric testing is the most widely used, including manual assessment, handheld dynamometry (HHD), fixed-frame dynamometry (FFD), and isokinetic dynamometry in static mode (Devir & Prushansky, 2008).

Accurate clinical assessment of chronic or recurrent neck pain requires reliable reference data for cervical muscle strength, endurance, and fatigue. Such benchmarks are crucial for meaningful comparison and effective evaluation. Moreover, understanding normative reference values is essential for designing effective rehabilitation programs (Jordan et al., 1999; Peolsson et al., 2001). In both clinical and sports settings, assessing cervical muscle function—including the balance between flexors and extensors—is vital for preventing neck injuries and guiding rehabilitation strategies.

Aim and Objectives

The primary aim of this study was to design and implement an experimental model, along with a prototype device, for the quantitative assessment of isometric strength, endurance, and fatigue of the head and neck muscles. Currently, no such device exists in the fields of kinesitherapy or sports science in Bulgaria. The introduction of this equipment will provide valuable quantitative data to improve the evaluation of rehabilitation programs and advance research in sports science by enabling accurate measurement of these critical muscle groups.

METHODOLOGY

The experimental process was conducted in three distinct phases. The first phase focused on designing a prototype dynamometric device capable of objectively measuring the strength, endurance, and fatigue of the head and neck muscles (see Figures 1 and 3). Prior to constructing the device, a comprehensive review of existing literature and available instruments was performed to ensure both originality and effectiveness. Based on our findings, we determined that the optimal testing position for participants was seated.

In a previous, unpublished study involving 90 second-year undergraduate students (40 men and 50 women), we observed that the upper trapezius muscle (UTM) exhibited the lowest resting muscle tone in the supine position, followed by the prone and side-lying positions, while the highest tone values were recorded in the seated position. Muscle tone was assessed indirectly through the measurement of oscillation frequency using the MyotonPro device. The seated position not only maximizes muscle activation but also enables a comprehensive assessment of cervical strength across all planes and ranges of motion.

To ensure precise measurements, a torque axis was constructed to fine-tune the vertical positioning of the sensors, while horizontal alignment was achieved by adjusting the chair.

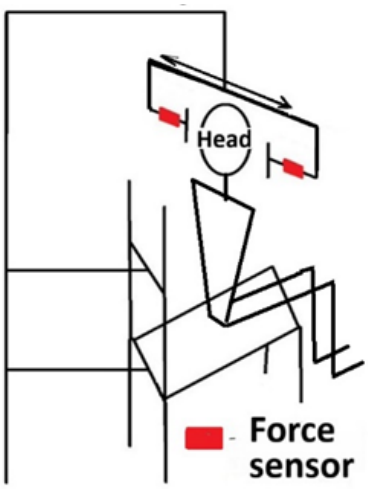

Figure 1. *Mechanical diagram of the proposed dynamometric device for the quantitative estimation of isometric strength, endurance, and fatigue of head and neck muscles.*

Figure 2. *The Chronojump force sensor installed on the vertical lever of the implemented setup.*

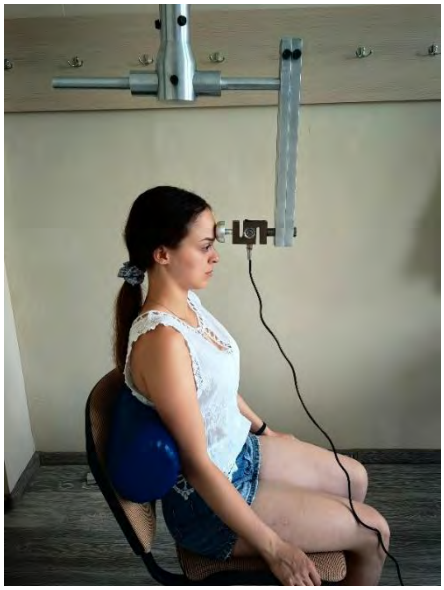

Figure 3. *Implemented installation of the prototype for the quantitative estimation of isometric strength, endurance, and fatigue of head and neck muscles.*

The second phase involved the development of a standardized measurement methodology, with an emphasis on defining both the spatial and temporal parameters necessary for conducting the assessments.

The third phase consisted of a pilot study carried out on a group of students, followed by an initial statistical analysis using SPSS software. A total of 12 healthy students (5 men and 7 women; mean age: 20 years), all free from neck disorders, whiplash injuries, or recurrent headaches, participated in the study. During the assessment, participants sat comfortably with their heads upright and arms relaxed at their sides, while maintaining an erect back position throughout the procedure.

The participants were instructed to press against a plate, using their forehead for flexion and their occiput for extension, applying maximum effort for as long as possible. The trial was terminated either when the force output dropped on the recorded curve or when participants experienced discomfort or subjective symptoms such as pain, numbness, vertigo, or visual disturbances. Shoulder alignment was maintained throughout.

No warm-up exercises were included, as the aim was to assess the muscles in their natural daily state. However, each participant performed 3–4 practice repetitions of neck flexion and extension to familiarize themselves with the required movements. Additional body fixation or stabilization was deemed unnecessary, since the isometric nature of the task ensured that belts would not prevent accessory muscle involvement; on the contrary, such supports might stabilize the chest and shoulder girdle, facilitating unwanted activation of these muscles. To improve comfort and promote an upright sitting posture, a massage roller was placed between the participant's back and the chair backrest.

Quantitative measurements were obtained using the Chronojump force sensor (see Figure 2) in combination with Chronojump software. Statistical analyses were conducted using SPSS Statistics version 19. Descriptive statistics, including skewness and kurtosis, were applied to assess the distribution of the recorded values.

RESULTS

In the pilot study, four variables related to isometric muscle strength, endurance, and fatigue were assessed separately for male and female students. These variables included: maximum strength (Fmax) in Newtons [N]; mean strength during the last 10 seconds before fatigue (MeanFBF/10s) in Newtons [N]; the percentage ratio of MeanFBF/10s to Fmax (%FBF/Fmax); and endurance time in seconds [s]. The results are provided in Tables 1-4.

Table 1. *Results for neck flexor muscles from the descriptive statistics for the measured variables in male volunteers.*

Males
Neck Flexion

Variable	*n*	Xmin	Xmax	R	*Mean*	*SD*	V	Z skewness	Z kurtosis
Fmax, N	5	62.20	110.20	48.00	75.68	19.61	384.40	2.26	2.19
MeanFBF/10s, N	5	21.80	75.30	53.50	46.68	21.96	482.36	0.18	-0.81
%FBF/Fmax	5	30.28	88.52	58.24	61.51	24.31	590.97	-0.41	-1.00
Endurance Time, s	5	29.00	192.00	163.00	99.00	59.54	3544.50	0.96	0.94

Note: n – number of participants; R – range; SD – standard deviation; V - variance

Table 2. *Results for neck extensor muscles from the descriptive statistic for the measured variables in males' volunteers.*

Males
Neck Extension

Variable	*n*	Xmin	Xmax	R	*Mean*	*SD*	V	Z skewness	Z kurtosis
Fmax, N	5	97.30	161.90	64.60	124.36	27.70	767.17	0.38	-0.74
MeanFBF/10s, N	5	48.10	121.80	73.70	99.02	31.60	998.75	-1.54	0.57
%FBF/Fmax	5	49.43	93.79	44.36	78.90	18.14	329.07	-1.56	0.76
Endurance Time, s	5	57.00	210.00	153.00	113.00	59.17	3501.50	1.54	1.07

Note: n – number of participants; R – range; SD – standard deviation; V - variance

Table 3. *Results for neck flexor muscles from the descriptive statistics for the measured variables in female volunteers.*

Females
Neck Flexion

Variable	*n*	Xmin	Xmax	R	*Mean*	*SD*	V	Z skewness	Z kurtosis
Fmax, N	7	17.00	46.50	29.50	33.17	11.34	128.66	-0.37	-1.05
MeanFBF/10s, N	7	12.70	33.80	21.10	23.90	7.89	62.24	-0.06	-0.78
%FBF/Fmax	7	58.28	95.96	37.68	73.76	15.06	226.89	0.70	-0.84
Endurance Time, s	7	65.00	97.00	32.00	82.43	13.38	178.95	-0.10	-1.40

Note: n – number of participants; R – range; SD – standard deviation; V - variance

Table 4. *Results for neck extensor muscles from the descriptive statistics for the measured variables in female volunteers.*

Females
Neck Extension

Variable	*n*	Xmin	Xmax	R	*Mean*	*SD*	V	Z skewness	Z kurtosis
Fmax, N	7	21.70	72.90	51.20	54.76	21.60	466.55	-1.36	-0.56
MeanFBF/10s, N	7	18.50	63.50	45.00	45.81	19.49	379.93	-1.00	-0.86
%FBF/Fmax	7	71.50	94.77	23.27	83.07	9.01	81.16	-.011	-1.24
Endurance Time, s	7	59.00	178.00	119.00	127.29	39.69	1575.57	-0.85	0.16

Note: n – number of participants; R – range; SD – standard deviation; V - variance

All measurement variables demonstrated lower values for flexion compared to extension. For both movements, Fmax and MeanFBF/10s were higher in males (flexion: Fmax – 75.68 ± 8.77 N; MeanFBF/10s – 46.68 ± 9.82 N; extension: Fmax – 124.36 ± 12.39 N; MeanFBF/10s – 99.02 ± 14.13 N) than in females (flexion: Fmax – 33.17 ± 4.29 N; MeanFBF/10s – 23.90 ± 2.98 N; extension: Fmax – 54.76 ± 8.16 N; MeanFBF/10s – 45.81 ± 7.37 N). However, apart from flexion endurance time, both %FBF/Fmax and Endurance Time were generally higher in females (flexion: %FBF/Fmax – 73.76 ± 5.69; Endurance Time – 82.43 ± 5.06 s; extension: %FBF/Fmax – 83.07 ± 3.41; Endurance Time – 127.29 ± 15 s) than in males (flexion: %FBF/Fmax – 61.51 ± 10.87; Endurance Time – 99.00 ± 26.63 s; extension: %FBF/Fmax – 78.90 ± 8.11; Endurance Time – 113.00 ± 26.46 s) (Figure 4).

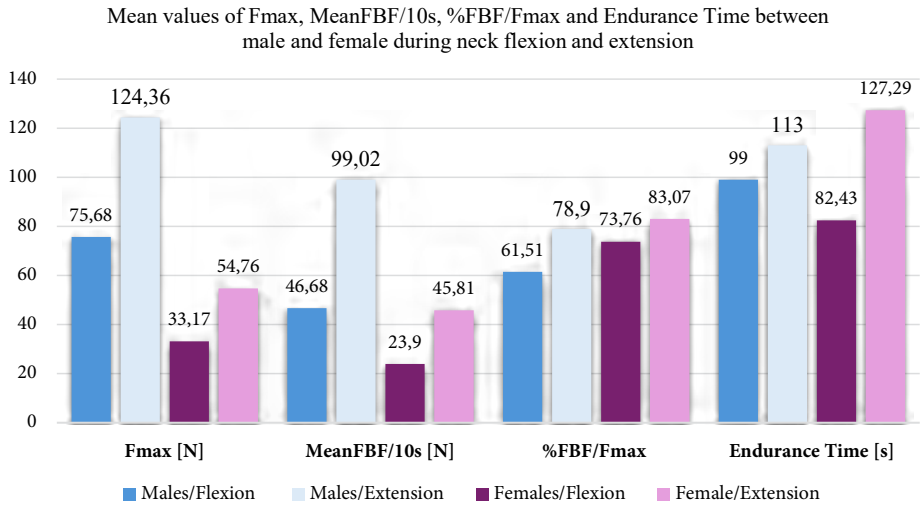

Figure 4. *Mean values of Fmax, MeanFBF/10s, %FBF/Fmax, and Endurance Time between male (blue columns) and female (pink columns) students during neck flexion (darker columns) and extension (lighter columns).*

The ratio of maximal isometric muscle strength between extension and flexion was 1.6 for men and 1.65 for women. A comparison between men and women revealed a difference of approximately 2 for

both flexion and extension.

We identified three distinct patterns in the graphs. They reflect the course of development of muscular strength generated by the respective neck muscle groups. It turned out that this is a strictly individual characteristic of each participant in the study. The first pattern featured an immediate peak at Fmax at the start, followed by a steady decline in the curve, which stabilized before the participant reached their limit. This was observed in 6 participants during flexion and 3 during extension (Figure 5). The second pattern showed a continuous rise in strength values, with Fmax achieved only at the end, just before the participant stopped; this occurred in 4 participants for flexion and 5 for extension (Figure 6). The third pattern involved strength values increasing initially, reaching Fmax somewhere in the middle of the graph, and then declining as the participant approached their limit (arch-like); this was seen in 2 participants for flexion and 4 for extension (Figure 7).

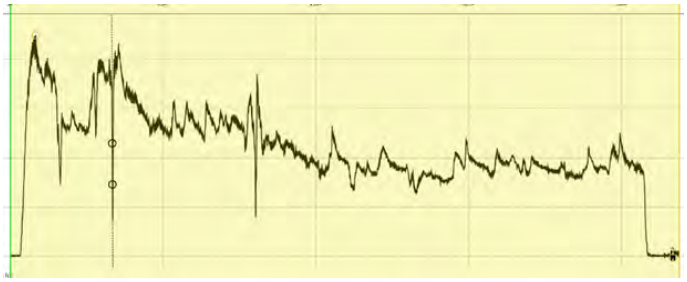

Figure 5. *Graph illustrating a pattern of neck muscle strength development over time with initial peak of Fmax followed by continuous decrease of the strength.*

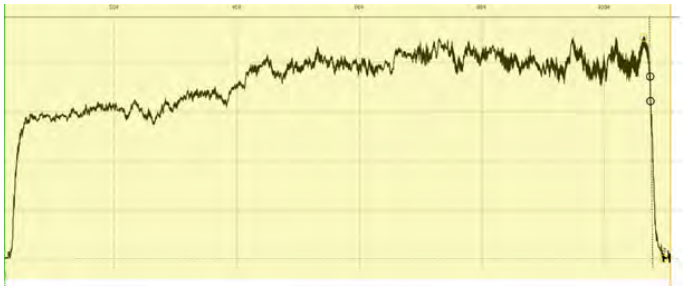

Figure 6. *Graph illustrating a pattern of neck muscle strength development over time, with continuous increase in strength and peak of Fmax at the end of the measurement.*

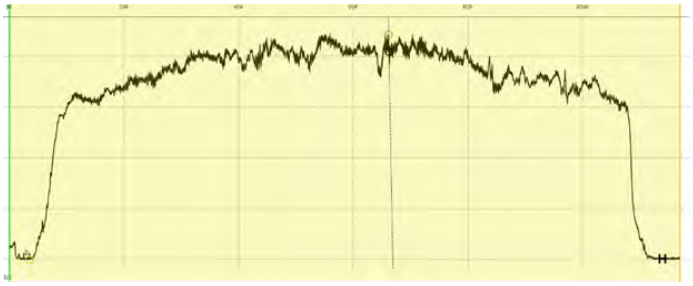

Figure 7. *Graph illustrating a pattern of neck muscle strength development over time with an arch-like curve and a peak of Fmax at the center.*

DISCUSSION

Numerous methods have been employed to evaluate neck strength, including manual muscle testing, handheld dynamometry, strain-gauge dynamometry, isometric and isokinetic testing, as well as specialized devices such as the multi-cervical unit (Abichandani et al., 2023). The wide range of approaches highlights the lack of consensus and the absence of a gold standard for assessing cervical strength (Abichandani et al., 2023). Given that the primary function of the cervical musculature is to maintain postural balance, isometric testing appears to be an appropriate method for evaluating neck strength (Ylinen et al., 1999).

In our previous unpublished study, we found that resting trapezius muscle tone was lowest in the supine position, followed by the prone and side-lying positions, with the highest values observed in the

sitting position. Whether these findings apply to other cervical muscles and whether muscle strength and endurance differ across positions remains uncertain. Peolsson et al. (2001) reported that extension strength in the seated position was approximately twice the values previously described for the prone position. However, this observation was based on data synthesized from multiple studies rather than a direct comparison. Overall, the seated posture appears to provide the most comprehensive means of evaluating neck strength, as it allows for assessment across all movement planes and ranges of motion.

Muscle Strength. Our findings are consistent with prior research on maximal force (Fmax), demonstrating that cervical extension strength is roughly twice that of flexion strength. Moreover, men consistently exhibit values 1.6–2 times higher than women for both extension and flexion (Cagnie et al., 2007; Jordan et al., 1999; Peolsson et al., 2001; Rezasoltani et al., 2003).

In one study of 33 healthy adults aged 18–35 years without a history of neck disorders, mean Fmax values ranged from 88.2 to 99.0 N for flexion, whereas extension strength was substantially greater, ranging from 188.2 to 200.3 N (Ylinen et al., 1999). Rezasoltani et al. (2003) reported even higher values in 35 healthy participants (18 males, 19–30 years; 17 females, 20–28 years). For extension, men achieved 296.8 ± 63.4 N compared to 164.1 ± 40.1 N in women, while in flexion the results were 142.4 ± 43.1 N and 79.9 ± 21.5 N, respectively. Similarly, Jordan et al. (1999) examined 100 active, healthy individuals (with equal numbers of men and women, stratified by decade from 20 to 60 years). For the 20–30 year subgroup, maximal isometric strength at 30° neck extension and flexion was 133 ± 36 N in men and 114 ± 33 N in women for extension, and 91 ± 31 N and 70 ± 16 N for flexion. (Note: the original values were reported in kilograms and have been converted here to approximate Newtons.)

Endurance and Fatigue. Our review of the literature revealed no studies directly comparable to ours regarding isometric endurance and fatigue of cervical muscles assessed in the seated position. However, three research groups have investigated the endurance of the upper cervical flexors in the supine position, each employing slightly different protocols. In these studies, endurance was defined either as the time required for muscle force to decline to 50% of the initial maximum voluntary contraction (MVC) (Barber, 1994; Watson & Trott, 1993), or as the time from assuming the test position until the chin began to protrude forward (Grimmer, 1994), following Trott's (1988) procedure.

Watson and Trott (1993) examined 30 asymptomatic women aged 25–40 years and reported a mean endurance time of 84.9 ± 22.6 seconds. Barber (1994) investigated 54 moderately active, asymptomatic women in three age groups (20–25, 40–45, and 60–65 years), with mean endurance times of 65, 59, and 41 seconds, respectively. Grimmer (1994) used a stopwatch to find considerably shorter average endurance times: 14.5 ± 4.3 seconds in 38 women and 18.2 ± 3.3 seconds in 55 men.

Limitations. The limitations of this research are in three directions. The first is related to the absence of data on the test-retest reliability of the measurements. However, the levels of standard deviations in the data obtained indicate that the proposed experimental protocol with a prototype gives good results in repeated measurements. The second important limitation is the target group and its size. It consists of only healthy young students. Considering that older participants may deliver more interesting observations and conclusions. The last limitation concerns the method used to immobilize the torso during force measurement. There is room for improvement in this area, and this will be one of our first future tasks.

CONCLUSION

A novel experimental approach for assessing isometric neck muscle strength, endurance, and fatigue has been developed, accompanied by the construction of a specialized experimental bench for quantifying cervical muscle functionality. The device was successfully validated in a pilot study involving twelve patients. Its potential applications include longitudinal monitoring of rehabilitation outcomes and enhancing athletic training programs. Nevertheless, further large-scale validation and methodological refinements are required to establish its reliability and clinical translation. The data generated hold considerable therapeutic and clinical significance and may facilitate the development of mathematical models characterizing cervical muscle imbalances.

Future research will focus on several directions. First, the study cohort will be expanded to include a broader range of ages, sexes, and pathological conditions. Furthermore, the experimental protocol will be optimized to ensure higher accuracy in data acquisition and greater efficiency in result processing.

The authors anticipate that, following the necessary improvements, the proposed prototype for neck

force measurement will demonstrate strong diagnostic potential for detecting cervical muscle dysfunction, with broad applications in evidence-based kinesitherapy and sports performance optimization.

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